OPTIMISING THE RELATIONSHIP BETWEEN PASSIVE SOLAR DESIGN OF NEW HOUSING AND THE ECONOMICS OF CONSTRUCTION AND LAND VALUE

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A thesis submitted in partial fulfilment of the
Requirements of
The Robert Gordon University
for the Degree of Doctor of Philosophy

September 2004

CONTAINS PULLOUTS

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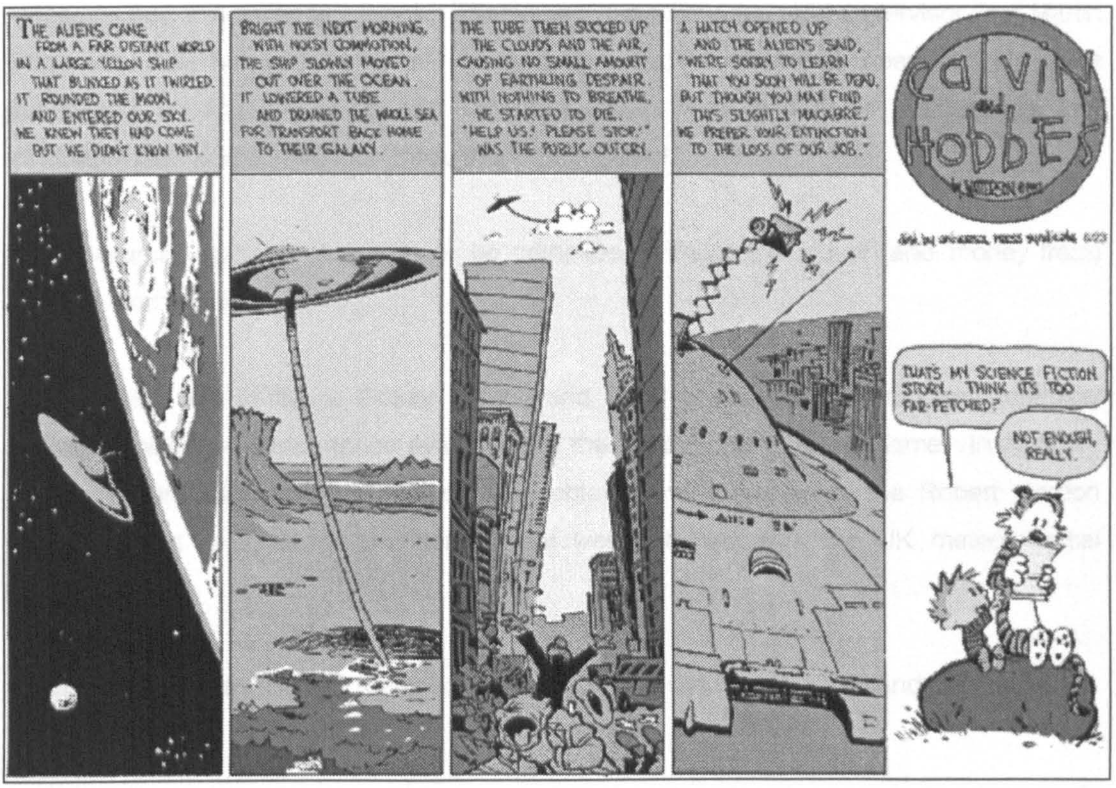


ACKNOWLEDGEMENTS

In the past three years there have been a number of people whom have aided in my research, and it is to those I thank. Thanks are due to my research supervisor Prof Martin Edge who has helped whenever I have asked, and when it was needed. My other supervisors Dr Richard Laing and Dr Peter Martin have also given their special and invaluable help and contribution throughout the research.

This research would, of course, not be completed without the aid of (and money from) EPSRC, and BIAT.

I would also like to thank Gokay Deveci and Peter Martin for their aid and technical assistance with the performance evaluation of the 'Zero Heating' family home. In addition, the equipment used for this analysis was obtained with the aid of the Robert Gordon University and the external monitoring data was obtained from the UK meteorological website.

And of course, I would like to thank my parents and my sister for their aid and patience.

ABSTRACT

The focus of mass housing developments built by speculative developers in the UK has broadly been on maximising density whilst retaining a predominantly detached housing form. This economically led strategy, aimed at maximising sale values, can conflict with the aim of radically reducing environmental impacts. For example by creating very closely spaced, deep, narrow frontage houses, which may not optimise solar design.

Whilst a variety of products have been developed to enable design professionals to model and assess the environmental performance (especially in energy use terms) of individual buildings, there are currently no tools for modelling the performance of whole developments, based on variables such as site layout, density, orientation, topography, etc. Using passive solar design as an exemplar for sustainable development offers the opportunity to improve the environmental, spatial and aesthetic performance of speculative developments.

This thesis describes the development of a tool for planners and developers to optimise the passive solar characteristics of housing developments through an environmental site assessment, encouraging the use of basic environmental techniques early in the design process. In this thesis the characteristics of passive solar design are ascertained and a tool is developed that can show, quantitatively and visually, the savings that passive solar design can achieve compared to more 'standard' modern speculative developments.

This thesis is one small step in the development of a tool to encourage sustainable design through the entire design process from an early stage. It has used passive solar design of mass, speculative housing in the north east of Scotland as a starting point for a tool which, it is hoped, can in future encompass wider aspects of the complex field of sustainable design.

Abbreviations

PSD	Passive Solar Design
WLC	Whole Life Costs
LCC or **LCCA**	Life Cycle Costing or Life Cycle Cost Analysis
DETR	Department of Environment, Transport and Regions
BRE	Building Research Establishment
DTI	Department of Trade and Industry
GIS	Geographical Information Systems
ESA	Environmental Site Assessment
BBC	British Broadcasting Corporation

1 Introduction

1.1 INTRODUCTION TO THE RESEARCH

A large part of the market for speculative mass housing in the UK is for detached houses, built to building regulations minimum standards at as high a density as possible. Despite concern about fuel crises, climate change and other aspects of the environmental agenda moving into the policy mainstream over the past three decades, housing delivering advanced energy conservation and other environmental benefits has generally not been adopted by this mass market. There are a variety of reasons for this slow response to changing needs in housing and this research takes a step towards overcoming part of this problem.

The complexity of the issues surrounding sustainable housing is well documented (Cox, et al, 2002). This research has therefore concentrated on some elements of sustainable design which are relatively quantifiable in empirical research. The research uses passive solar design as an exemplar of more sustainable types of housing development. Passive solar design in itself is complex and its definition and the approach taken to it by the project are introduced in chapter four. Passive solar design (PSD), it is argued, is affordable, reduces dependence on fossil fuels and can provide healthier homes. It does not, however, fit easily into the type of high density developments preferred by house-builders anxious to maximise the returns from their investment in land. This is primarily due to PSD's need for solar access and is especially the case at high latitudes such as in the UK and the north of Scotland in particular. It is the issue of density, therefore, that this research covers, with the potential conflicts between the priorities of private developers and those of environmental design the focus of exploration. The research concentrates on the early planning stages of developments, their overall layouts and the 'footprint' of houses of detached housing types. The specific constraints on this research are more fully discussed in the methodology (Chapter Five, 5.4).

The exploration of this conflict in this project has led to a suggested framework strategy for a computer-based design tool to enable the planners of developments to establish the benefits of various passive solar options and compare them, in terms of economics and energy performance, with more conventional designs. The tool establishes the value of various options given some simple input data. It is suggested that the tool, once fully developed and potentially commercially available, could be used in conjunction with, for example, fast-track planning consent for developments, which exhibit good environmental credentials.

The strategy has been developed after investigation of sites in the North East of Scotland. The research has investigated simple housing forms and created and assessed databases of alternative designs, following study of a number of passive solar solutions.

1.2 PASSIVE SOLAR DESIGN AS AN EXEMPLAR FOR SUSTAINABLE DESIGN

Solar Design is not a new concept (Behling 2000). Most settlements have for millennia considered the effects of the sun, and solar power will always affect the aesthetic, social and economic patterns of individual homes, villages, towns and cities. This has changed during recent centuries due to technological advances, but the use of solar power, and the effect it has on building, can be profound.

Passive solar design (PSD) is a broad term for designing buildings, which are orientated towards the equator to benefit from solar heat gains. PSD requires that a building face approximately south in the Northern Hemisphere and it is a holistic design method for reducing the need for non-renewable fuel (FEMP, 2000; Niemeyer, 2000; Borer & Harris, 1998; Kachadorian, 1997; Yannas, 1994; Balcomb, 1992). In the northern hemisphere, the greatest quantity of solar energy is received on a South face, assuming it is not shaded by some obstruction, with roof glazing collecting more solar radiation compared to a greater area of vertical glazing.

Ensuring that the orientation of glazing faces due south is not critical as solar gains from windows facing 25 degrees off due south are only slightly lower than the maximum solar gain possible (Borer & Harris, 1998; BRECSU, 1997; BRECSU, 1995; Yannas, 1994; EREC, 1994; Littlefair, 1991). The higher the latitude, the more pronounced the overshadowing becomes (BRESCU, 1997). This carries consequences for the building form and grouping within a development, in addition to orientation. In real terms a site, which complements a passive solar design perfectly is not likely to occur. In addition, it is unlikely that a solar heated home at high latitudes will make a heating system redundant, although it will reduce the energy dependency from non-renewable sources while promoting more reliance on renewable energies (DTI, 2000; EC, 2000; Shaw & Halt, 1999; DTI, 1999).

Figure 1.2.1 illustrates some of the considerations required when passive solar designs are grouped together. From this figure, it is clear that the density of a site will be controlled by the angle of the sun and the height of the obstruction, as this dictates the distance between dwellings. BRECSU, 1997 and BRECSU, 1995 further highlight these considerations and add that in Aberdeen the spacing distance for full, year round access is 40m. Compared to the average 21m spacing using current methods of development, and density between these two alternatives becomes a critical issue. The research investigates and compares the two methods of development on sites in the North East of Scotland, to determine the extent of this problem.

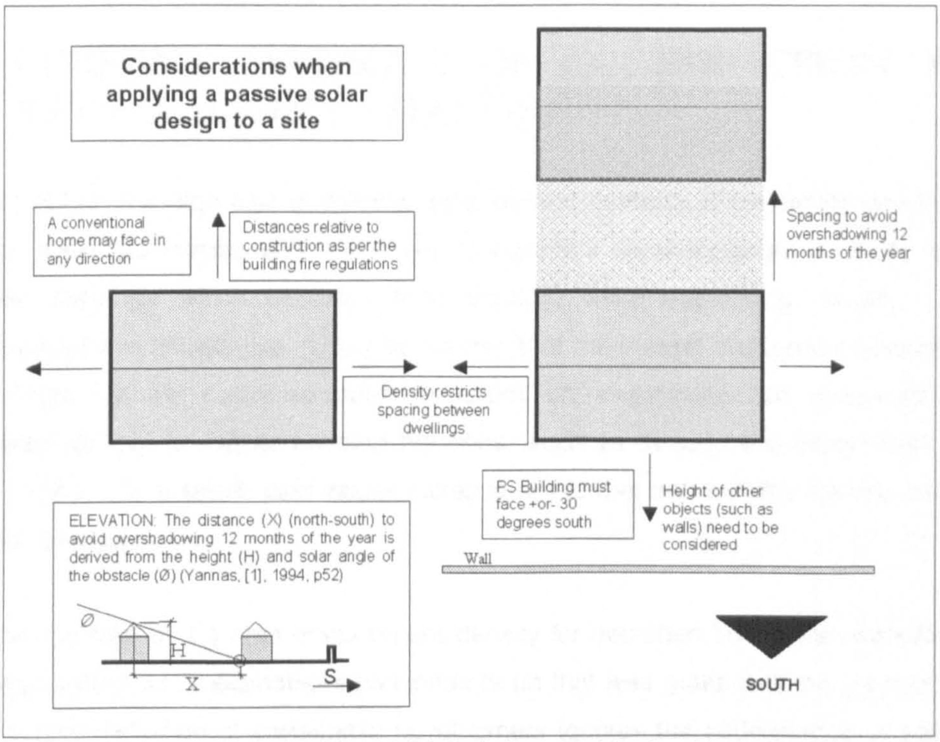


Figure 1.2.1: Preliminary considerations in grouping Passive Solar Designs

Beyond the issue of solar gain, passive solar design encompasses concepts such as thermal mass, air-tightness, super-insulation, green building construction, waste reduction, renewable material, fuel and embodied energy, with few other design approaches making full use of all these features. Where all these strategies are used in an appropriately designed home the greatest savings in terms of heating and CO_2 emissions are possible. Such designs are described by the research as "optimised passive solar design". Careful definition of passive solar design is required. Marsh, et al, (2000) describes a passive solar design as a design which has been intentionally orientated south and an optimised passive solar design as a holistic approach incorporating, for example, various issues of orientation, thermal efficiency and mass. This research will adopt the definition by Marsh, et al, (2000), explore it further and study optimised passive solar design within housing layouts. One example of an optimised passive solar home in the North East Scotland has been shown to reduce heating costs by up to 70% (Deveci, et al, 2000) and reduce CO_2 emissions by similar proportions, thus benefiting both occupier and environment.

Negative characteristics of low-energy designs, such as the perception of high capital costs, need to be overcome before they can be applied to mass housing, but investigation into already built developments provides evidence that passive solar projects provide better benefits to the home buyer and the environment than current construction and layouts (Yannas, [1] & [2], 1994). This research uses passive solar design as part of a more sustainable development. Various passive solar alternatives will be created to determine the cost benefit when compared to current methods of development.

1.3 CURRENT METHODS OF CONSTRUCTION AND THE RATIONALE FOR CHANGE

Primarily due to the high cost of building land, current methods of residential development focus on grouping homes with minimised foot-prints - semi-detached or, more usually, detached dwellings which minimise road frontage while maximising density - within predetermined site boundaries. It may be inferred that the current methods of development, whilst driven by the desire to optimise return on investment, are compounded by government calling for higher housing densities, such as through the Urban Task Force (DETR, 1996). As a result, land values increase still further and building density becomes critical for developers.

Whilst on the face of it a high development density for detached homes can be seen as a basic requirement for 'sustainable' developments (in that less green-field land is built upon) such a narrow definition of sustainable development ignores the performance, in particular the energy performance, of the building as a system (DETR, 2000), the site as a whole and the consequent reduction of pollutants.

The tensions between current mainstream building practice and sustainable development are both complex and far reaching (Edwards & Pawley, 2000). Many see sustainable development as an idealistic moral high ground, rather than a serious mainstream option (Edwards & Pawley, 2000; Serchuk, 2000). For the Government to overcome this, the publication, "*Building a Better Quality of Life*" (2000) aimed to stimulate sustainable development and detailed those aspects that the Government associated with sustainable development. This by no means overcomes the problems associated with the practical application of environmental developments, but is a sign of increasing awareness and a step forward.

The research proposes that using a **balanced passive solar design** (see section 3.3 for definition of this term) within a **more sustainable development** will enable current aesthetic and spatial approaches to housing to take on an enhanced level of environmental acceptability.

It is hypothesised that a resolution of the tension between current methods of housing construction and environmental methods, such as passive solar design, lies in the combination of the following;

1) Addressing issues of long-term land value through planning;

2) Improved government driven incentives for passive solar dwellings which take account of the density imperative; and

3) Improved information on the benefit to the purchaser of passive solar homes and the reduction of CO_2 emissions.

This research project has concentrated on a part of this wider hypothesis by studying issues of planning and development density.

1.4 RESEARCH AIM

The main **aim** of this research has been:

"To produce an environmental site assessment strategy for the optimisation of passive solar detached housing layouts in a development during the planning process."

It is hoped that the production of such a strategy for passive solar and detached, speculative housing, can act as a model for future strategies and decision making tools in other aspects of sustainability and the built environment.

1.5 RESEARCH OBJECTIVES

- **To** determine the potential impact and limitations of the various definitions of Passive Solar Design.
- **To** identify the pertinent monetary and environmental costs and benefits of Passive Solar Design.
- **To** investigate the methods currently used for planning major housing developments.
- **To** determine the optimum density of alternative passive solar designs on sites and compare with densities achieved on current speculative developments of mass housing.
- **To** determine the energy performance of a range of passive solar designed homes, and of current conventional spec-built dwellings on sites.
- **To** determine an objective method of measuring the effectiveness of passive solar designs in order to establish a balance between site layout strategies for simple site layout alternatives. This will provide a framework for the development of a design tool with future research.

2 Historical Development of Solar Design

2.1 INTRODUCTION

We build because little that we do can take place outdoors. We need shelter from sun, wind, rain and snow. We need dry, level platforms for our activities. Often we need to stack these platforms to multiply available ground-space. On these platforms, and within our shelter, we need air that is warmer or cooler, more or less humid, than outdoors. We need less light by day, and more by night, than is offered by the natural world. We need services that provide energy, communication, and water, and dispose of waste. So we gather materials and assemble them into the constructions we call buildings in an attempt to satisfy these needs.

Source: Allen (1999)

Early buildings exhibited characteristics still prevalent today; floors, walls and roofs. However modern buildings have become many times more complex than those first simple shelters. The evolution of our civilisation is reflected in what we build; in essence the evolution of civilisation and our buildings are intrinsically linked. New building technologies are constantly changing, superseding those of previous generations, until the present day where our buildings are surpassing our previous needs and are quickly becoming life-support systems which can satisfy our every want (Allen, 1995; Marsh, 1977 & Allen, 1969).

As Allen (1999) points out above, a home has to meet certain criteria in order to meet the basic objective of shelter that is both welcoming and healthy as well as meeting present societal needs. Solar design is an important part of the basic needs of any home and, arguably, the higher the level of development, the more important solar design becomes. Early cultures embraced their local climate; using it to provide better homes for heating or for cooling but in recent centuries the reliance on environmental methods for creating healthy homes has declined, despite the fact that modern environmentally friendly homes can cut heating costs and emissions significantly.

The decline in the use of environmental design (sometimes also referred to as green design) can be blamed on many aspects, not least among them being technological and social change – we have many new 'toys'. In terms of housing, there are four main reasons for the loss of our ability to assimilate with nature.

1) The methods and complexity of building has changed.

2) Architecture as a cultural icon and style as a statement has caught on in the past few centuries. This is not always the case, but it is certainly true that style and appearance is often more important than the health and an environmental soundness of a building (Allen, 1999 & 1995; Robbins, 1997; Kostof, 1985).

3) The politicisation of the planning process and the misperception of what many term 'green' design.

4) Finally, the reliance on new technology rather than traditional design strategies is a problem. For example, the reliance on non-renewable, inexpensive methods of heating rather than more energy conserving and environmentally friendly methods.

The history of solar design will be discussed in this section, which describes the different types of solar design and how, historically, the sun was used both to heat and cool a building in different climates, by different cultures. The difficulty lies in applying these historical solar design principles into modern living and modern housing.

This section will also detail the historic development of solar design and aims to establish the various reasons why environmental design has decreased in importance for new and refurbished housing. Recently, however, the UK Government has increasingly been interested in the environmentally friendly housing since housing emissions form a significant proportion of total CO_2 emissions (Behling, 2000). Through environmental initiatives and the like, sustainability and other environmental issues have encroached upon the cultural aspect of architecture.

Over the past 3 decades, issues affecting the environment have resulted not only in a drive to produce ever more radical, energy efficient buildings, but have expanded to incorporate a whole series of other aspects of the environmental agenda in a quest for what has come to be known as *'sustainability'*, a complex topic which influences all aspects of development (Jackson, 2003; Edwards & Pawley, 2000). This may be the only way of allowing issues such as passive solar to become part of the mass manufacture of housing. Modern housing, which incorporates these many aspects, will be introduced in this section.

The majority of housing in the UK are built to minimum building regulation standards. Of those projects, which exhibit elements of environmental design, the UK housing industry favours visible technologies. The UK housing industry currently ignores the more subtle environmental concepts if it can, or at least emphasis is laid more heavily on more visible methods of environmental design. This issue is discussed in chapter three, but it is important to note the historical development of simple housing shapes and orientation, as it is here where the greatest environmental benefits may be found as a foundation for a more sustainable housing development.

2.2 THE HISTORY OF SOLAR DESIGN

2.2.1 EARLY ARCHITECTURE AND DESIGN FOR THE SUN

When one has completed the necessary .... one immediately comes upon the beautiful and the pleasing.

Source: Voltaire[1] (Taylor, 1997)

Behling (2000) states that solar power has been of, "fundamental importance since the very origin of the human species". Behling argues that solar power influenced evolution, with climate change and agriculture being the catalysts for our dependence on the sun. By climate change Behling does not mean the global phenomenon about which there is so much debate today, rather he refers the change in climate caused by the ancestral move away from our savannah origins to more temperate climates, caused by population increase. The migration to different climatic regions caused by the population increases resulted in innovative methods in insuring that basic needs were achieved, and this was also expressed in the built environment. Also, a ready supply of food could not be wholly guaranteed if hunter-gatherers where to remain hunter-gatherers and agriculture became relied upon more as a reliable source of food. Conversely, urbanisation could not exist without first having a reliable agricultural basis.

With population movement into different areas, small groups of dwellings developed, engaging in farming and trade. These early centres relied on solar power to feed, house and clothe them. From these beginnings, solar design grew (Behling, 2000; Butti and Perlin, 1980).

Taylor (1997) states that architecture has historically been influenced by four factors, these are listed below. What is significant, Taylor explains, is that the cultural factor plays a much more significant role in modern architecture than in earlier counterparts, which relied more upon environmental impacts and available resources. It is this change in emphasis that marks environmental design as being a difficult concept to adopt in modern construction.

- **Environmental Impacts** - Climate, geography, and wildlife, including farm animals, pests and predators.
- **Available Resources** - Building materials, as well as energy and skilled labour.
- **Human Needs** - The space required for specific uses.
- **Culture** - The combined effects of beliefs, superstitions, social and political structures, conventions and fashions.

Taylor adds that the culture factor has certainly shaped architecture in recent centuries, but the building has also exerted, "a profound influence on the culture" in many ways. This circular argument is not an aspect that would promote the first three factors listed above, and is indeed self-sustaining, meaning that culture will remain the dominant force of the four.

Behling (2000) states that, *"agriculture is the basis for a sustainable community"*. This was true when, around 3500 BC, the first cities developed, Egypt being the prime centre of development, and their size was dependent on how much food could be provided. The town of Arbela[2] is offered as an example, it has been occupied for more than five thousand years - is this the first sustainable solar city? Probably not, longevity is not synonymous with sustainability, but ancient developments can provide some insight into the development of modern cities.

One such insight may be obtained from Mohenjo Daro[3] in the Indus valley. This site in Pakistan shows a clear north-south orientation of the buildings, with a central arena provided for religious focus. What is important from this city is not so much its orientation, though it was ideal for passive solar heating/cooling, but that it was a planned settlement, which emphasized the need for a good food supply, sited in a place that could provide the city this basic need (Behling, 2000). This emphasis on environment, resources and social use describes a holistic development, with syntheses of needs providing the basic model for a sustainable city.

Egypt was probably the first society to architecturally design their buildings, states Coulton (1977), Kostof (1985) & Robbins (1997). Drawings and models that took the form of layout plans based on squared grids also with pictorial perspectives of the building and the structural development have been found where aspects of the sky (night and day) played important (if not central) roles in the design of Egyptian buildings.

In general, the sun and the moon formed an important symbol, often of religious significance, and buildings were planned and built with orientation of the sun, moon and stars clearly delineated. The sky was interpreted within a building, as in the pyramids, with drawing and mathematical astronomy having prominent positions both on the building site and politically. At this time environmental aspects of building had predominance over other cultural aspects. It should be noted that the architect / builder of these developments were highly regarded members of their society, often spiritual leaders.

The Egyptian architect Imhotep, explains Kostof (1985), had many fields of learning in which architecture was but one. Imhotep devised the stepped pyramid for his patron, King Zoser[4], by constructing a model. The model was created using several mastabas[5] into a 195 feet tower that would both display his 'idea' and simultaneously be easy for the workers on the pyramids to re-create. A model would also be used to visually demonstrate to a patron the buildings relationship to a given god/deity, of which the sun played an important role. The model was used as a decision making tool to ascertain and visualise the various environmental design issues of the new idea. The most modern method using this principle is Geographical Information Systems (GIS), which can ascertain special relationships of a variety of complex issues similarly to the physical models used historically.

Using Imhotep as an example, the physical model created can clearly show shadow, alignment with important constellations, among other important environmental phenomena. The people at this time were also extremely aware of their environment, and models expressed their beliefs and their relationship with the environment before large-scale construction began, also expressing ideas to illiterate workers clearly.

Behling (2000) states that most Chinese cities of this era were based on an orthogonal grid with a north-south orientation. The Chinese usually try to make sure that their homes; villages, towns and cities are given the best possible omens. Notably, through the likes of Feng shui, such omens still exert a strong influence on the position and orientation of buildings and how they are constructed, and in most cases these buildings face south, not specifically for passive solar purposes but for the well-being of the home and the occupants.

This influence is may also be seen in many of the buildings, towns and cities of early civilizations, during and after the Egyptian period. South American civilizations, for example in Teotihuacan[6], show a strict, planned urban settlement where modular units were placed around a central axis. The axis, as in other areas, provided links to religious ceremonies, in particular to the pyramids of the Sun and Moon. In North America the housing in Pueblo Bonito[7] (located in a desert climate) adopted passive solar cooling, using characteristics that are still used today such as thermal mass; grid-patterned room-layout; strategic siting of doorways (for ventilation as well as security) and; air-vents (Behling, 2000; Butti and Perlin, 1980). Similarly, the Annansazi[8] used strategically placed crevices in south facing cliffs to provide passive heating and cooling without significant changes within the buildings themselves. That is to say the site was specifically chosen to provide for heating and cooling; passive heat in winter; shading and cooling (through natural updrafts up cliff face) in summer (Taylor, 1997).

What early construction illustrates is that the sun provided much of the basic needs for every human in any location in all climatic regions. Indeed, some solar principles had become embedded into religious activities, of which some practices have lasted unto the present day. Many early civilizations have built developments along these lines and many of these early principles can be used today. The Annansazi in particular also show that it was important that developments relied on local climate and careful siting. The simple designs created by early civilizations where based on local climatic knowledge and expertise, which is important to note when building during the present day. Latitude and climate will dictate the form of housing in the UK.

Early models were used to test new ideas on environmental concerns, cultural development and providing worship, illustrating planning and the need to express ideas before construction. The early planning of developments was critical in producing the more sustainable cities and innovative methods were found to benefit from the free source of energy from the sun in various climatic regions.

2.2.2 GREEK & ROMAN ARCHITECTURE

> *Based on principles of solar orientation and ventilation, ancient Greek cities represent the ideal solar city for a true democratic society. Apart from communal facilities, all buildings are laid out equally and solar.*
>
> *Source:* Behling (2000)

Greek cities give examples of well-planned, solar developments. Priene[9] was developed in western Asia Minor in 400 BC as a new, entirely Hellenistic city, states Behling (2000). As in earlier development, the centre of the city was dominated by communal and religious buildings, with the south of the city being dominated by recreational buildings. All the residential buildings had almost identical plans, sections and elevations. Every dwelling was accessed via a gatehouse from an east-west feeder street, itself accessed by a north-south main-street. Once through the gatehouse, the mono-sloped roof allowed the sun to fall upon a courtyard, and continue into the main building, which had a porch. The porch acted as a heat sink during the winter, storing the heat, and provided shade in the summer when the **sun is at it's highest angle**. The following figure illustrates the well-planned nature of this city (Behling, 2000).

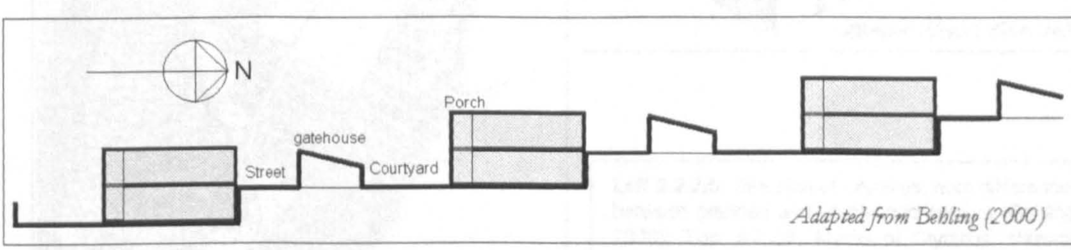
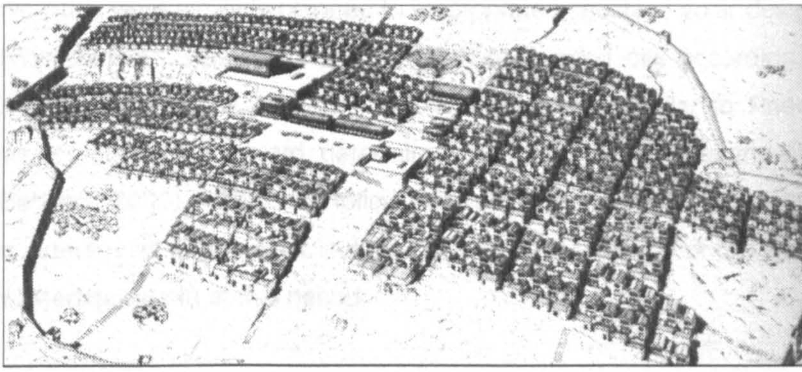
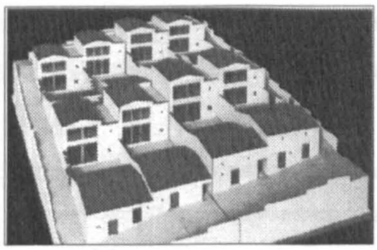


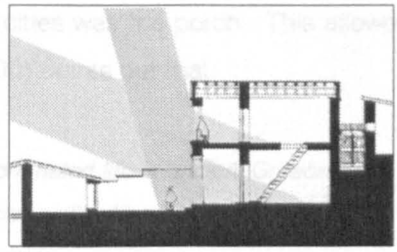
fig : 2.2.2.1 Section of Priene

PRIENE

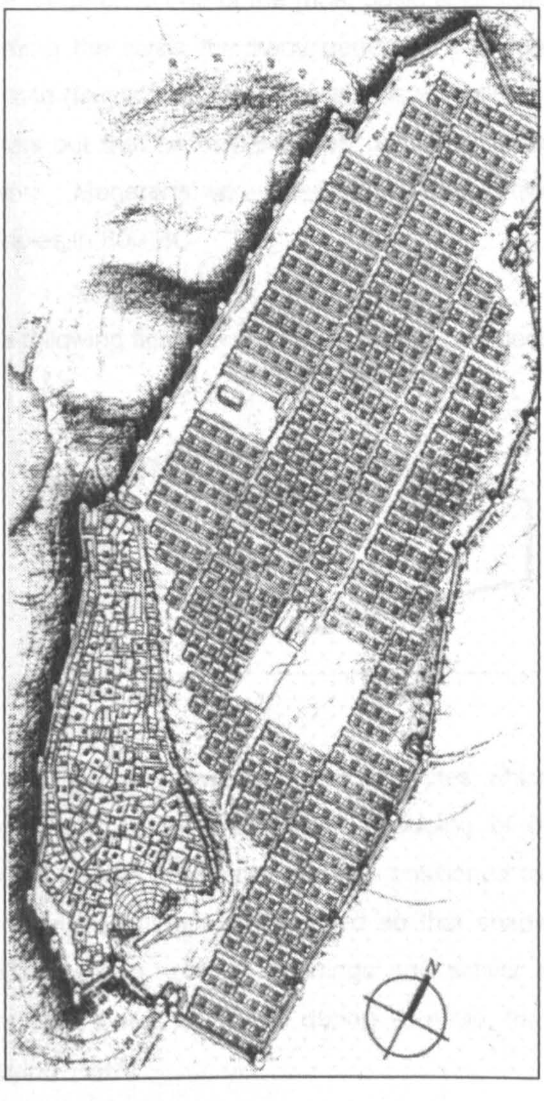
Top 2.2.2.2: Perspective of Priene, note that the site chosen for development favours passive solar designed homes (Behling, 2000); **Bottom left 2.2.2.3**: Model of Priene, showing the glazed solar collectors, the home acts like a megaron (Behling, 2000); **Bottom right 2.2.2.4**: Section through a Priene dwelling showing winter and summer sun lines (Behling, 2000).

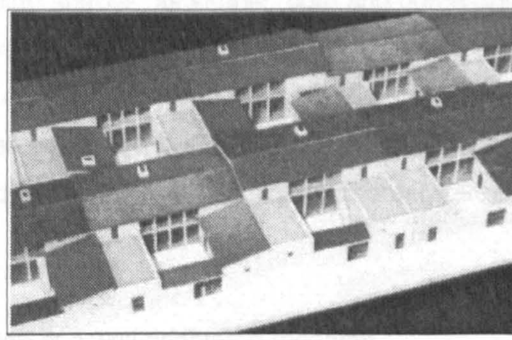


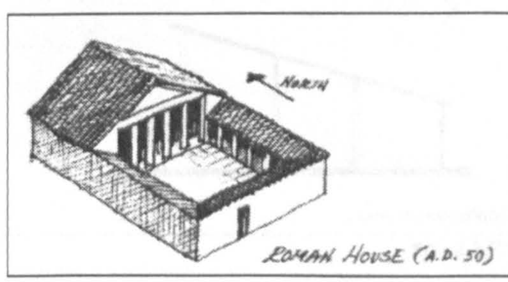




OLYNTHUS







Left 2.2.2.5: Site plan of Olynthus, note differences between planned and un-planned sectors (Behling, 2000); **Top 2.2.2.6**: Model of Olynthus, showing the glazed solar collectors and the typical courtyard design (Behling, 2000); **Above 2.2.2.7**: showing the design for a typical Roman House, note the similarities between Olynthus and this design (Taylor, 1997).

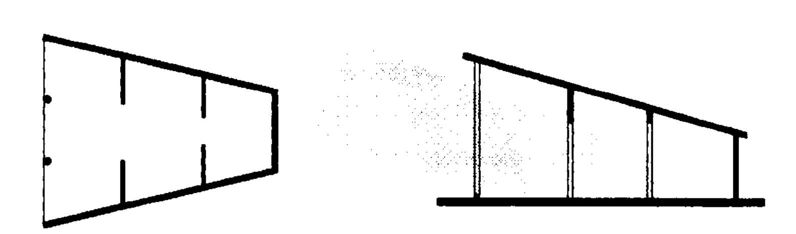
Priene (fig 2.2.2.1 and pictures 2.2.2.2-4) is by no means a shining light in this period of civilisation, most Hellenic cities were similarly planned to incorporate aspects of solar design. The Greek architect Hippodamus[10] was important in creating planned city according to geometric layouts. Olynthus (pictures 2.2.2.5-7)[11] was one such city, similar to Priene, where each dwelling was set around a courtyard, determined in size by geometrical grid-plan of the development (Behling, 2000). This city followed a strict geometrical grid, which divided the town into quarters, with small roads linking each section, this type of city being common throughout the Mediterranean at this period.

The important aspect of each individual dwelling in these cities was the porch. This allowed sun access in winter, and shade in summer. Behling (2000) points out that;

> *The need for shade in summer and sunshine in winter dominated life in ancient Greece. The monumental temple architecture for which classical civilization is revered grew from the modest origins of the megaron with it's simple porch.*

The megaron is one of the most basic solar building shapes, its simple room and porch unit forming the basis for many generations of more sophisticated structures, for almost any climate (Behling, 2000). Socrates is sometimes credited with its invention, however Behling points out that he was probably describing a well orientated building that had existed long before. Megarons were used for worship, providing the plan for the first and larger, Greek temples in 800 BC.

The following figure illustrates both plan and section of a well-orientated megaron.



Source: Behling (2000)

fig : 2.2.2.8

The Megaron[12] shows that solar principles, which were shaping even the simplest of designs during this period though the grouping of dwellings was also important. The Greek courtyard also used solar design, positioned to gain the maximum benefit from the winter sun, and planting was arranged so that shade was possible during the summer (Taylor, 1997; Behling, 2000). Awnings and similar artificial shades were extensively used, the emphasis being on shade during summer, the awnings being detached during the winter (Taylor, 1997).

In the most eminent buildings, the temples, Behling (2000) argues that the main solar principle of the design for the temples was to provide shade during worship. In effect, Behling adds, the columns of the main entrance of the temples act as a giant brise-soleil, which is a screen placed on the outside of a building to shield from direct sunlight.

The planned, geometric shapes of dwellings were, of course, not the only significant development in building during this period. The buildings, significantly the prominent and affluent buildings, were getting more ornate, this being due to construction taking a more prominent role in culture. The business of building was becoming more professional, and more complex, requiring significant time, cost and craft-work. Buildings during this period were central to the cultural identity of its people.

As Coulton (1977); Kostof (1985); Bowyer (1993) & Robbins (1997) all explain that simple geometric forms were important to architects during this period rather than more formalised design techniques. Bowyer further emphasising that geometry was important for both the Romanesque and the Greek architects. To the Greeks, geometry was closely linked to the interior perfection of a home to provide a healthy interior environment. Being similar in many aspects to Chinese Feng Shui, geometry in buildings was interested in the relationship between space and the human body – a system for seeking perfection. The space of a room was directed by the perfect proportions of the human body and was supposed to seek comfort and peacefulness, a reflection of their society (Tomlinson, 1995).

Solar design, and design drawing itself, was improved during the prominence of Rome. As Behling (2000) describes below, the warmth of the sun and shade from the sun was refined;

> ***Solar design reached new levels of sophistication in ancient Rome as comfort became a key concern. The Romans created monumental surroundings blending space, shade and cooling breezes. Recreation played an important role in Roman society, baths and heating systems marked the emergence of active comfort systems.***
>
> *Source:* Behling (2000)

The Pantheon[13] of Rome displayed the dramatic use of daylight using an oculus to allow sunlight to enter, not only for aesthetic use, but for practical use as a sundial. The Pantheon was not the only Roman building to use daylight dramatically, Trajan's Market was a cultural and commercial centre providing retail, recreation and commercial facilities. It had a semi-circular arcade centrally, while at other levels roof-lights and openings allowed daylight and cross-ventilation down to the lowest levels (Behling, 2000).

Solar design also influenced the design of many recreational facilities, bathing, for example, required cold, intermediate and hot pools. At the baths at Caracalla, the hot pool faced south, gaining as much heat as possible (water being far better at conducting heat than air), while many other Roman baths had their sweat rooms facing south/south-west. These Baths had enormous windows and a sand floor that absorbed the heat as thermal mass (Taylor, 1997; Behling, 2000). Other recreational buildings that were influenced by the sun were arenas, the Colosseum being an example. A sophisticated device was used to create shade for the many spectators using long poles, ropes and awnings called '*vela*', meaning sails.

It was the Roman architect Vitruvius, however, with his ten books of Architecture who displayed the wealth of knowledge of this era. With their larger dwellings, the Romans displayed many ingenious methods of utilising the sun for passive heating and cooling. The following extract exhibits some of the extensive understanding the Romans had of room layout, with regards to orientation (Cradick, 1999).

> *The proper exposures of the different rooms;*
> *The special purposes of different rooms require different exposures, suited to convenience and to the quarters of the sky. Winter dining rooms and bathrooms should have a south-western exposure, for the reason that they need the light, and also because the setting sun, facing them in all it's splendour but with abated heat, lends a gentler warmth to that quarter in the evening. Bathrooms and libraries ought to have an eastern exposure, because their purposes require the morning light, and also because books in such libraries will not decay.*
> *Dining rooms for spring and autumn to the east, for when the windows face that quarter, the sun, as he goes on his career from over against them on the west, leaves such rooms at the proper temperature at the time when it is customary to use them. Summer dinning rooms to the north, because that quarter is not, like the others, burning with heat during the solstice, for the reason that it is unexposed to the suns course, and hence it always keeps cool, and makes the use of the rooms both healthy and agreeable. Similarly with picture galleries, embroiderers work rooms and painters studios, in order that the fixed light may permit the colours used in their work to last with qualities unchanged*

Source: Marcus Vitruvius Pollio[14] (Cradick, 1999)

The Romans were also aware that climate, topography, orientation, local- and micro-climate factors were key aspects of passive solar buildings. The Romans had found a way to overcome extremes of climate, and tried to maximise air-tightness and thermal mass while optimising of the sun's energy.

Up until the Italian Renaissance period, in terms of solar design, there had been little development from the Greek and Roman period across the developing world. Those buildings that were generally designed to encompass solar principles were large scale, often prestigious developments. In addition, such solar designs were not applicable to northern climates, being based on a heavy reliance on passive cooling.

In Japan and China, buildings were still designed to encompass the local environment, but emphasis was on shade and ventilation, and often designs were seasonal in nature - many buildings of this period being unbearable in winter (Behling, 2000). Although these buildings show solar principles such as open plan, the interface between exterior and interior space, and the overall quality of space, they lacked the means of retaining heat.

Other solar designs for this period pertain more to passive cooling than to passive heating. The Ali Qapu Palace[15] in Persia is a notable example, where much of the more pleasurable pursuits in the palace evolved around the heat from the sun, in particular providing shade and ventilation (Behling, 2000).

2.2.3 RENAISSANCE ARCHITECTURE

It is the renaissance, which starts to adopt more artistic influences in the design of buildings. Many of the architects of this period were previously artists and were well-educated. They had limited knowledge of the construction of buildings but relied on the study of early (Greek and Roman) buildings (Kostof, 1985 and Allen, 1993) to inform them how to build. The study of historical buildings, however, may not tell the architect why they were built, however. In short, the renaissance heralded the beginning of a more artistic form of architecture without wholly adhering to environmental issues.

Morosi, *etal,* (1996) state that, " ... *they* [architects and builders] *exhibited a deep rooted ability to observe and reflect - thus, different cultures have developed by trial and error*". Allen (1993) adds that the efforts to, *"design constructable details can lead the designer into explorations of building craft that may yield substantial aesthetic rewards."* Allen (1993) also states that what we have come to 'enjoy and admire' about ancient buildings can always be traced to the skill and a deep understanding of craft, be it stone masonry or otherwise, that is evident in their details. Allen gives an example of such in gothic vaulting, "whose form sprang from the craft of stonemasonry."

Evidence of this can be found in Kostof (1985) where it is found that Leone Battista Alberti[16] (*1404-72*) *"freely admitted that he looked at the remains of Roman architecture in the first place because he wanted to find out whether he could learn from them anything for the present"*. Kostof continues to say that Alberti travelled extensively to many Roman remains then proceeded to note forms, measure and proportion what he found and explore, *"building techniques and [demonstrate] them graphically as well as verbally"*. Allen (1993) further confirms this statement by stating, *"they [the structure and construction of buildings] represent an accumulation of centuries of wisdom about what works in building construction and what does not."* In short, what has worked in the past will work in the future.

Coulton (1977) & Kostof both concur that this was a regular practice of many architects at the time, Filippo Brunelleschi[17] (*1377-1446*) being one of the first Italian architects to use this method during the Renaissance. In fact, many Italian architects came from a background that included painters, sculptors, etc, and found architecture as their calling after studying the remains of architecture in Rome. The study allowed for a basic knowledge of building but it does not mean that principles and aesthetics were simply copied, though the proportions of the buildings may have been.

Brunelleschi, who like Alberti had come from a background in sculpture and painting, was one of the first to study the, *"excellent and highly ingenious building methods of the ancients"* (Kostof, 1985), but could not entirely rely on drawings to guide his design (Robbins, 1997). Manetti (1970), Brunelleschi biographer in the fourteen eighties, describes the construction of the Ospedale in Florence when Brunelleschi had to leave for a period;

> *He [Brunelleschi] presented a drawing precisely scaled in braccia. . . . In it are many various and fine considerations and the reasons are understood by few. He explained it orally to the master builder, the stonecutters, certain citizens, the leaders of the Guild and to workers assigned to the undertaking since he had to be absent for a time.*
>
> *Source:* Robbins (1997)

As scaled drawing had not been firmly established at the time, continues Manetti, the instructions given by Brunelleschi were 'deliberately ignored' leading to an 'inferior building' (Robbins, 1997). The influence of design and detail drawing was to replace the need for skilled, experienced builders. This design technique was also making each building unique and individual. From this, divisions between architect and builder, and their relevant roles in the construction process were beginning to surface. The lack of communication during the planning stages and the increased ornamentation of designs for buildings led to the decline of environmental considerations in developments.

Kostof (1985) notes that the forms of buildings took a new system of proportions due to the study of ancient remains by the Italian architects, who moved away from the gothic design. Consequently there was a period were architects had to work more closely with the master mason. At this time the master mason was required to participate with the introduction of 'new' details due to the architects study of Roman remains.

Robbins (1997) further ascribes the Renaissance with the first changes in the architectural practice where the drawing took hold as the dominant instrument of design and as the 'symbol' that makes the architect different. The Renaissance also created many of the tensions that exist in modern architecture and contribute significantly to the difficulties experienced when adopting environmental, sustainable practices in current construction.

Solar design during the Renaissance was usually an addition to a design rather than being incorporated as a holistic principle of the design, as an example, the Arcades of the Procurate Vecchie on the Piazzetta di San Marco in Venice. Much of the shading was created through awnings. Although these were temporary they provided flexible and adaptable spaces according to the time of day. An example of solar design during this period is the Villa Rotunda, which had a loggia, designed as a functional external space and shading device, also acts as a buffer zone against the heat of the day (Behling, 2000).

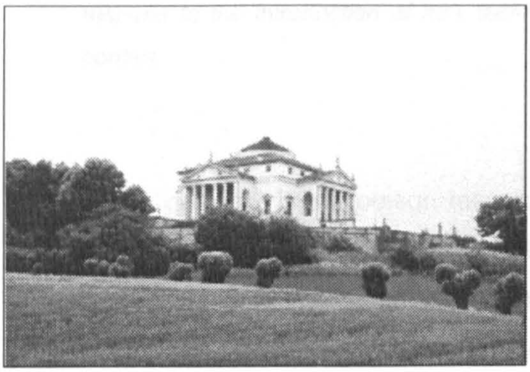
Not all architecture of the Renaissance was aesthetically driven; Palladio combined good aesthetic design with environmental design, making Palladio one of the most influential architect in history (Gable, 2000). In his Villa Rotunda, Palladio combined the aesthetic with the practical using the Loggia, which is a shaded porch based upon the principles of the Megaron. The Loggia, when faced south, can provide good shading and seasonal heating to the building, but it also provides good views (Behling, 2000). Of the Villa Rotunda, Palladio[18] details;

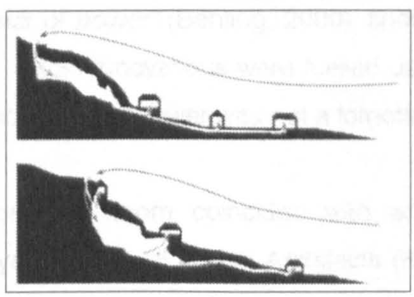
> *It is upon a small hill with easy access ... and it is encompassed with most pleasant hills, which look like a very great theatre, and are all cultivated ... and therefore, as it enjoys from every part most beautiful views, some of which are limited, some more extended, and other that terminate the horizon, there are Loggias made for all four fronts.*
>
> *Source:* Behling (2000)

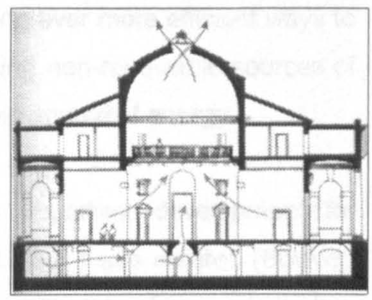
Behling (2000) also describes another cooling system at the Villa Rotunda (fig 2.2.3.4), drawing cooling air from the cellars channelling the air through the well open-planned building until it exits via the roof. This combination of passive systems is an important aspect of many modern environmental designs, and demonstrates an understanding of the holistic environmental design.

Examples of other types of cooling can be seen near Vicenza, the Costozza Villas (fig 2.2.3.3). These Villas were specifically built over natural caves, and the cool air from these caves is used as ventilation for the villas in much the same fashion as the Villa Rotunda's cellar. Palladio was fascinated by this system, and this natural phenomenon is probably expressed in the Villa Rotunda (Behling, 2000). Palladio demonstrates admirably that much can be learnt from the natural environment.

VILLA ROTUNDA







Top (left 2.2.3.1 and right 2.2.3.2): Villa Rotunda showing clearly the Loggia's on each facade (Top Left: Gable, 2000; Top Right: Behling, 2000) ; **Bottom left (2.2.3.3) and right (2.2.3.4)**: A section through the Villa Rotunda showing the ventilation techniques Palladio observed from the natural caves of the Costozzo Villas (Behling, 2000).

Between the Renaissance and the 19th century, there was insignificant progress in the development of passive solar design either through cooling or heating. Dwellings, which were built during this period, relied on the tried and tested methods of previous building generations. This was a result of the lack of development in alternative building forms but there were some showcase passive solar developments during this period.

Behling (2000) states that Louis XIV styled himself the 'Sun King' but this design did not apply solar principles that were a significant step in a solar building evolution, his buildings being orientated south but little else. Similarly Sans Souci was built in Potsdam by Frederik the Great to provide himself with wine, using passive heating in a northern climate. This was achieved by stacking glasshouses that faced south, in order to provide a luxury, indicative of the fact that passive solar was being used only for the wealthy, since glazing was so expensive. (Behling, 2000).

2.2.4 EVOLUTION TOWARDS MODERN DESIGN

> *The last two centuries have witnessed profound changes through advances in industry and technology. Dramatic societal changes have taken place that both reflect and respond to the introduction of new technologies and the power associated with their control.*
>
> *Source:* Behling (2000)

The modern designer is the person responsible for interpreting brief, designing, specifying and planning of a project. As such he or she is fundamentally integral to almost every aspect of a building. In the last two centuries, as Behling (2000) points out above, innovative technology was the driving force of change. Throughout the nineteenth century engineers were, *"engaged in the pursuit of power"* (Behling, 2000), finding ever more efficient ways to create power for the home. Most innovations were fuelled using non-renewable sources of energy, and they still are, though solar power was not a forgotten source of energy.

The engineering / technological boom coincided with an important development for architects; in 1840 the Royal Institute of British Architects (R.I.B.A.) was created (Bowyer, 1993), and they held their first general conference to discuss a variety of topics including professional practice and education. To the members of this organisation their professional respectability was an increasing cause for concern, much more so than professional technical qualifications. This may be seen, arguably, as a key factor in the lack of the adoption of simple environmental principles.

In 1855 the RIBA stipulated that members must undertake examinations in drawing ability and design, mathematics, physics, professional practice, materials, construction, and history and literature. This development formalised what had previously been an artistically driven role and (arguably) encouraged architects to explore a design holistically. Powell (1996) explains that as a result of the introduction of the RIBA and the increasing role of the architect in the construction industry a; "slightly more businesslike approach began to supplement earlier artistic leanings and somewhat routine work took on a fair proportion of the total carried out in architects offices." In theory, and coupled with the innovative development with regards to industry in general, this suggests that architects were taking a more holistic view of building.

There was a boom in solar technologies during the latter part of the nineteenth century (Behling, 2000). Augustin Mouchot,[19] for example, developed a number of, "solar collectors and motors, ovens and even a still to make brandy", describing a wide range of applications, with varying degrees of moving parts. Clearly with further development, it may have been possible to conclude that energy from the sun could have been the dominant power for our numerous machines: this was not to be.

Significantly Behling (2000) also points out that John Ericsson[20] predicted as early as 1868 that fossil fuel is a finite resource. Regardless of the finite nature of fossil fuels, almost a century later housing uses these resources almost exclusively to power the home with only cursory consideration of environmentally friendly alternatives.

Powell (1996) states that the, *"rise of contracting and large projects emphasised a host of legal and financial matters such as contract procedure, insurance, costs and arbitration."* As a result of this there was an increasing demand for evidence of intent on behalf of the architect, which resulted in the need for further written documentation for increasingly more complicated buildings. As Powell (1996) explains, design drawings, details and specifications were needed for accurate estimations, it also suggests that architects were under increasing pressure from patrons/clients to provide 'working' buildings - the consequence of failure being fines, paying to make good and/or expulsion from RIBA. The increased risk and pressure in architecture was, and still is, a major cause of tension and permeates throughout the construction industry, and coupled with tight profit margins in many cases, meant a restriction in innovation.

Since this period the greater demands on architects have increased their responsibilities even further. Larger projects and structures, new materials, different methods in contracting and procurement, and specialisms (planning supervising to name but one) and the role of planners require fresh technical knowledge and management ability (Powell, 1996). In addition more stringent demands require more knowledge of law, administration, buildability and function of building envelopes; demands that include legislation on structural stability, fire precautions, energy conservation, safety, ergonomics and so on, which increase design times and negotiations (Powell, 1996; Wakita & Linde, 1999). All these demands on the designer mean greater risk of failure, and with little demand for environmental design the balance does not favour the use of solar principles when constructing housing.

The result of so many more building materials compared to just a handful (building stone, timber, earth, sun-baked bricks) gave more choices and therefore a greater selection of design alternatives and decisions. The result of total control by the architect over the design provides tension between architect and builder.

2.2 MODERN SOLAR DESIGN

2.3.1 PRE WORLD WAR II

The architect must be a prophet ... a prophet is the true sense of the word ... if he can't see at least 10 years ahead, don't call him an architect.

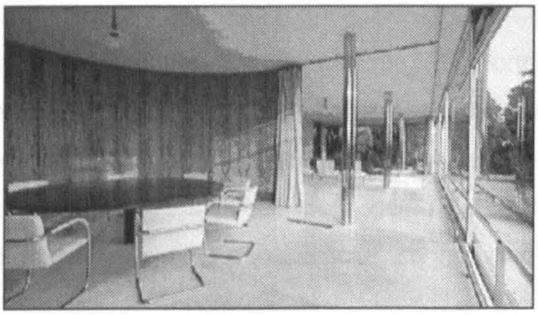
Source: Frank Lloyd Wright (Delmar, 2001)

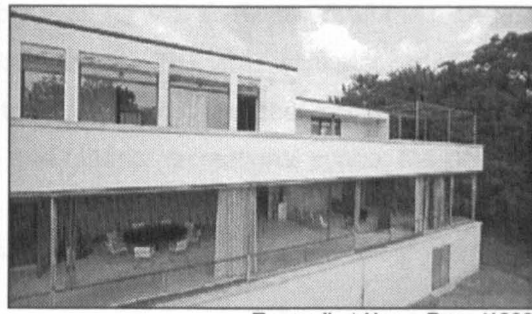
The late nineteenth century had many housing related problems. As Behling (2000) points out, appalling living conditions in many of the major towns and cities of the industrialised nations were caused by rapid industrial and urban development. The housing received poor sunlight and had poor ventilation, Behling (2000) describes, conditions that encouraged ill-health. Modern problems in the provision of mass housing in the twenty-first century results in urban sprawl, but the opposite is the problem for the industrialised cities in the 19th and early 20th centuries where homes were little more than space, with no amenities.

Changes to urban planning and housing type were necessary with industry playing an integral role. It was recognised that the physical and Psychological effects of the poor housing conditions were reflected in workforce productivity. These changes to housing were reflected in, amongst other 'model' communities created by industrialists, Port Sunlight on the Wirral and Pullman, near Chicago (USA) (Behling, 2000) providing homes near the workplace with a number of communal amenities though by no means where these cutting edge homes.

Beall (1997) and Davey (1965) also states that with the onslaught of the industrial revolution emphasis shifted to iron, steel, and concrete construction rather than stone as a structural building material and from this the modern movement grew. The invention of Portland cement in 1824, refinements in iron production in the early nineteenth century and the development of the Bessemer furnace in 1854 turned the creative focus of architecture away from stone masonry, and the classical style approach of architecture. Collins (1965) similarly states that, *"it was impossible for a truly new universal architecture to establish itself before the invention of new structural systems and this only occurred in the 1890's, with the commercial development of steel and reinforced concrete frames."* Collins (1965) further adds that architects had been craving originality and a move away from classical architecture, adding and adapting existing architectural ideals so as to ensure, *"the dates of their buildings would never be confounded."* That is to say, a building had become a signature for a particular architect, a means to reinforce an architect's identity through building. What resulted is an explosion of styles, not many reflecting the earlier classical background and only rarely encompassing **holistic** environmental values.

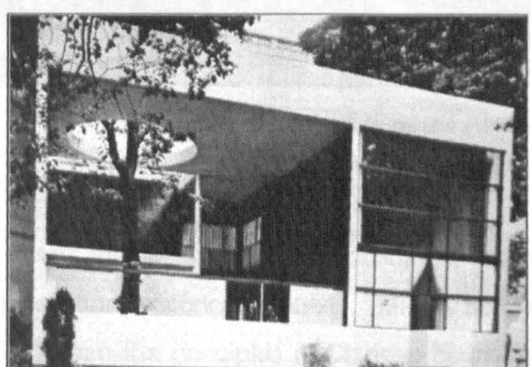
As Beall (1997) points out, the change in structural material had a heavy influence on architecture, allowing much more individuality in the appearance and spatial design of buildings. Siegfried Gideon's[21] book 'Befreites Wohnen (1929), highlighted 'light, air and opening' as new values of living (Behling, 2000). Although one of many styles at the time, Le Corbusier[22] and Mies Van Der Rohe[23] made this style known, expressing the style using glass walls, terraces and outdoor 'green' spaces (Behling, 2000). It was Van Der Rohe, states Porteous (2002), who first used the concepts of light, air and space in the Tugendhat Haus in Brno (1930) (Brecht-Benze, 2004).





Tugendhat Haus, Brno (1930)
Source: Brecht-Benze (2004)

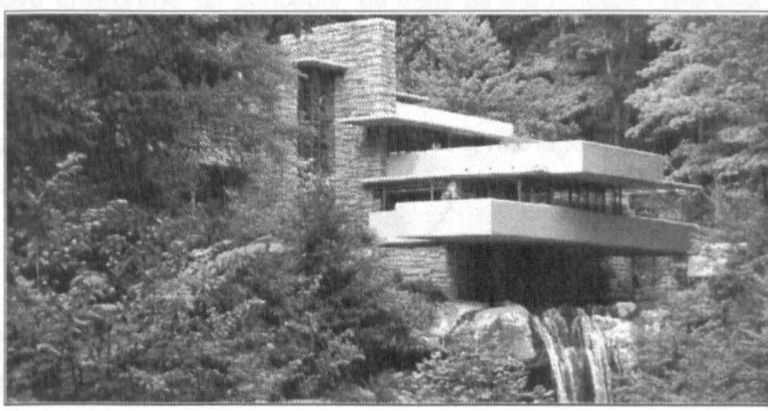
Porteous (2002) and Behling (2000) describes the modern movement as wanting to create better quality and healthier buildings, sunlight and passive solar design being an important component in achieving these objective, something not typical of the urban environment at the time. Behling adds that the strong desire for sunlight, if not passive solar principles, was integral to the modernist movement, being based in the cool, temperate climate zone. Porteous (2002) claims that if the modernist movement is examined, then the origin of environmental design may be found. In many respects this is true but it was daylight, however, and not the holistic concepts of passive solar, which was the main concern for the modernist movement. What the modernist movement tried to achieve in many cases was a healthier home, and aesthetics were at the core of this belief, maybe at the expense of the function of the spaces. In a few cases, homes were created that were, arguably, healthier than what had preceded at the time but they were the few.



pavillion de l'espirit (1924)
Source: Behling (2000)

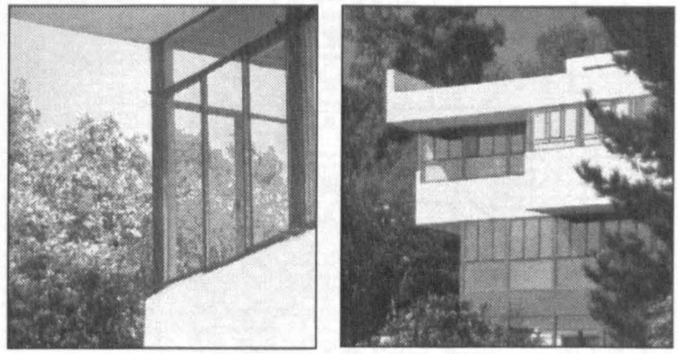
Even though passive solar design did not play a significant role in the modernist style of architecture, it did have some influence, as glazing forms an integral part in the modernist movement. Most modernist homes, therefore, had passive solar gains but without adhering to many of the other concepts of passive heating and cooling *holistically* therefore these homes performed poorly in relation to their operational energy use. Orientation, glazing, room layout, shading, ventilation and topography of site, common principles of passive solar, were commonly used in these designs, though not commonly together. Immeaubles villas in 1922, and consequently Pavillion de l'Espirit, for the Paris exposition of 1925, by Le Corbusier demonstrates this. A belief of Le Corbusier, as with some others at the time, was that, "a house is a machine for living in" (Porteous, 2002). The villas were stacked in blocks with garden terraces, and encouraged day-lighting, perceived to increase occupant quality of life. The villas also sported hotel style service and outdoor recreational space; the physical and psychological needs were being catered for, but passive solar was not full explored (though elements of passive solar are included).

Fallingwater (1937) situated in Bear Run, Pennsylvania, (USA), as with much of Frank Lloyd Wright's[24] architecture, uses 'bio-climatic' design (Delmar, 2001). The house uses modern structural materials, (reinforced concrete), to place it atop a waterfall, adding to, rather than detracting from, the natural environment. The house is using similar concepts adopted by Palladio, in the summer months the coolness of the water enters the building via the staircase (Behling, 2000) and the surrounding trees will offer shade and tranquillity. Again elements of environmental design are used but not fully utilised.



fallingwater (1936-9)
Source: Behling (2000)

As with Frank Lloyd Wright using environmental principles within his buildings, many modernist techniques were inspired and developed from historical contexts. Mies Van Der Rohe's courtyard houses were developed in 1932 from the principles of Chinese courtyard houses, (Behling, 2000). The modernists were therefore well aware of passive solar, keeping the elements of solar design that fitted with their style and disregarding concepts which did not. With Van Der Rohe's courtyard houses this meant that, though similar to their historical relatives, they were flawed in extremes of weather, notably winter (Behling, 2000).



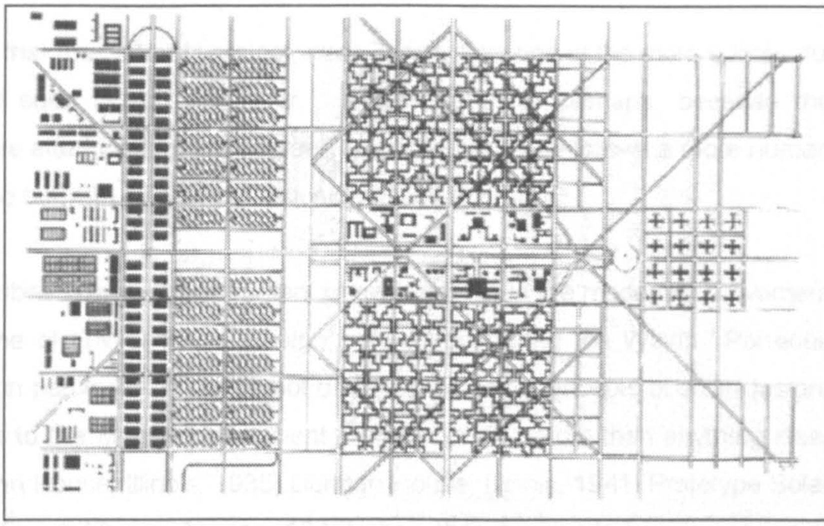
health house (1929)

Source: Behling (2000)

The modernist architects also believed that there was a link between the quality of housing and the psychological health of an occupant, solar design playing an integral role in this link. Richard Neutra[25] was an architect who believed in the link between housing design and the psychological health of the users (Behling, 2000). Neutra designed the Health House in 1927 for his client Dr Philip Lovell[26], a fellow proponent, on the basis of this philosophy (Behling, 2000). Using modern structural elements, large indoor spaces, large glazed elements and terraces; this house also shares some principles in common with solar design.

Buckminster Fuller[27] took the use of modern structural elements to their limits and combined them with the latest innovative environmental concepts, as early as the nineteen twenties. Believing that modern technological innovations could solve modern living problems, Buckminster Fuller designed aerodynamic skyscrapers and homes where occupants required little heating through the (possible) use of an early building management system to control insulation/heat loss, wind resistance, solar and ventilation (Behling, 2000).

Fuller was not the only architect believing that scientific innovation coupled with environmental design was critical, but these were usually not applicable to the mass housing market. Walter Gropius[28] tried to reconcile this in the urban context, using the principles of the 'Zeilenbau', in which parallel rows of apartment buildings were aligned along an east-west orientation to solve housing shortages in the inter-war period (Behling, 2000). The solar master plan had limitations, but has interesting layouts which Alexander Klein, another solar urban architect, tried to solve using innovative geometry's and building types (Behling, 2000).



ville radieuse (1931)

Architect and Source: Le Corbusier[29]

Le Corbusier was also influencing urban solar design on this large scale, developing his ideas for the 'Ville Radieuse' (Radiant City) from the principles of the heliothermic axis (see Priene and Olynthus), which determines the best orientation to optimise solar gain (Behling, 2000). The Congres Internationaux d'Architecture Moderne (CIAM) Athens charter stipulated a series of proposals for urban design, which were rigid and functional blocks separated by green-space (Behling, 2000). Their early attitude to urban planning can be summarised as follows;

> ***Urbanisation cannot be conditioned by the claims of pre-existant aestheticism; it's essence is of a functional order ... the chaotic division of land, resulting from sales, speculations, inheritances, must be abolished by a collective and methodical land policy.***
>
> *Source:* BBC/Open University (2002)

From this, the Athens charter proposed a rigid and functional city, through high, widely spaced apartment blocks separated by green belts. This city succeeds in theory, but physical examples exhibiting concepts of the Athens charter failed in the social context, being a separatist society. CIAM ended in 1956 with the realisation that belonging was a basic emotional need, pertaining to a person's identity. This is something that the short, narrow streets of the slum succeed in achieving, but the spaciousness of the modern development does not (BBC/OU, 2002). Many developments seem to fail on this principle and layouts deriving from solar design run the risk of similarly being branded separatist. There is the need, therefore, for modern developments to have a balance between housing quality and layout with the social context to create a sense of community if a development wishes to become a sustainable development.

Behling (2000) states that the Neubühl project, near Zurich, was one of the more successful examples of planned solar layouts, however. It is successful, perhaps, because the development pays more attention to the topography and the geometry follows a more human scale, being less dense but with a feeling of inclusion (Behling, 2000).

Porteous (2002) describes how the development of solar design in the modernist movement is central to the theme of environmental design before and during the WWII. Porteous describes four homes in particular which are not dissimilar to early concepts of solar design, being of similar shape to the Megaron of ancient Greece (p.16). More than anything else, these four homes (Cahn House, Illinois, 1935; Duncan House, Illinois, 1941; Prototype Solar House, Illinois, 1945; Brown House, Arizona, 1945) show that the simple housing shape of solar designs at this time have not significantly changed since the creation of the Megaron. What, perhaps, has changed is the technology and processes needed to manage the heat transfer in many different climates. After the war, it is this principle in solar design which is developed.

2.3.2 POST WORLD WAR II

> ***The middle class dream of the small house in the country sounded the death knell for traditional cities throughout the world and led to the development of urban sprawl with all it's side effects.***
>
> *Source:* Behling (2000)

World War II, states Behling (2000) had a significant impact on energy, nuclear energy being a development of this period, which was a source of energy that seemed cheap, plentiful and (therefore it seemed) limitless. There was also a significant increase in the number of appliances in a home, which were heavily marketed after WWII (and still are). This had implications for electricity demand, however, the high energy demands of the modern US being the result of these excesses. For example, air-conditioning, especially in America, also took off after World War II (Behling, 2000).

The end of World War II in America and Britain signified a fresh start, states Behling (2000). The detached house with modern appliances became a high profile political statement. Built for the returning war heroes this was the catalyst for suburban growth, a modern problem termed urban sprawl, which saw a growth in semi-detached and detached homes.

Behling (2000) explains that the boom of modern appliances was due to many manufacturers previously involved in building tanks or planes requiring a new focus after the war, which had also been a base for creating fresh ideas and innovations. With the over-supply of willing manufacturers, appliance innovations were easily and quickly created, in great numbers. Particularly in Europe, with housing shortages critical, their was a need for these manufacturing processes to supply the construction industry with alternative innovations due to the lack of materials and skilled labour - prefabrication being an example of what was supposed to be temporary homes, but in reality were better built and had better amenities than many existing properties.

The expansion continued for over a decade before rising pollution and energy crisis scares signified that this expansion was reaching a zenith. The expansion however, though not as rapid as immediately after the war, continues into the twenty-first century. As Behling (2000) states, ownership of a pitched roofed, detached home, with garden, local amenities and proximity to workplace, remains a common aspiration.

In terms of urban planning, the major growth occurred, and still does, around the boundaries of major towns and cities. These developments are less dense and depend upon the car for transport, since transport by bus, for example, were often and still are, seen as unsuitable and impractical (Behling, 2000).

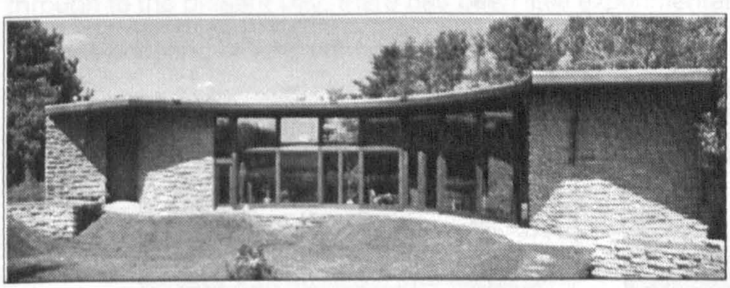
In terms of solar design there was a degree of innovation after the war also, due to the increased industrial activity and innovative construction techniques caused by the lack of affordable building materials, which were limited after the war. This resulted in some of the most 'elegant and balanced' solar buildings being constructed, expressing the new ideas of the articulation between inside and outside spaces (Behling, 2000).

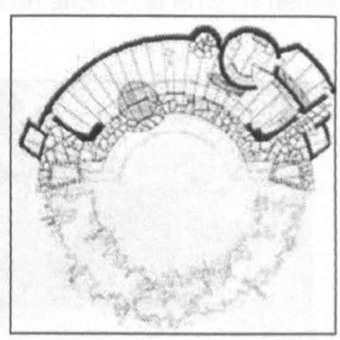
The industry had limited materials available so new building techniques such as prefabrication and standardisation were popular, benefiting from the wealth of manufacturing capacity after the war. At this time, economical construction methods and speed of construction due to the high demand for returning war heroes were the critical principles for mass housing developments, and at the time they were both successful and popular. Solar designs, however, were often only for the wealthy few and were never considered for mass housing developments. The Healy House (1948) in Siesta Key, Florida, USA, by Rudoplh and Twitchell is an example of a good bio-climatic and solar design, glazing (solar) gains being controlled by simple wooden slats. A home that was both expensive and not replicable in the mass housing market (Behling, 2000).

At this time, and for the next two decades (50's and 60's), Le Corbusier developed many large scale solar techniques for the control of solar gain, mostly through the innovative use of the brise-soleil. Le Corbusier still planned his projects densely, but the brise-soleil allowed large buildings to benefit from solar gain without overheating; the Unite building in Marseille displays the brise-soleil to its greatest advantage (Behling, 2000).

Unité d'Habitation (1946)
Source: Behling (2000)

Frank Lloyd Wright arguably designed the most dedicated design for passive solar use, based on a historical model, though again it is not applicable for use in the mass housing market. The house in Madison, Wisconsin, USA, 'The Solar House' mirrored a plan for the solar hemicycle, the house being a sixty degree sector of a circle (Behling, 2000). The house was designed to optimise the winter solar gain, and shade from summer glare.

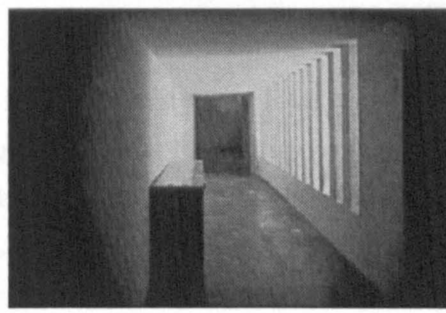




the solar hemicycle (1944-8)
Source: (Bill Taylor, 1998)[30]

The solar hemicycle home, in section, is still remarkably similar in concept to the Megaron of ancient Greece. The new materials of structure and novel ideas for ventilation, heat transfer and solar access, however, changed remarkably. This is illustrated in Le Corbusier's and Lloyd Wright's designs and can also be illustrated with the Trombe-Michel Solar Wall at Odeillo, France (1967) or the Solar School at Wallasey (1961) (Porteous, 2002). These developments exhibit the modern thinking towards solar design and the effect material changes where having to the form and appearance of a solar home.

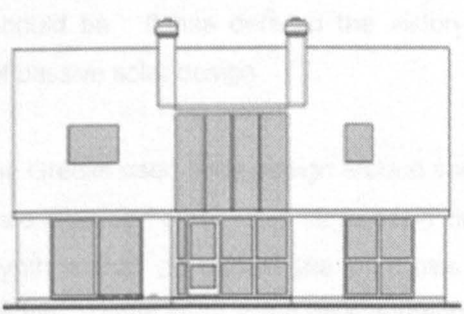
Similar to the situation pre-war, the post-war solar designs as mentioned were generally not adopted into mass housing developments. Luis Barraghan claims this is because our dependence on machines means that people are remote from the concept of environmental design, and hence solar design, despite natural housing design being perceived as providing better quality homes materially and psychologically. Barraghan has been responsible for designing environmentally in the testing environment of Mexico's hot, dry climate relying on ventilation, shade and mass. On the other end of the scale Alvar Aalto, in a testing cold climate, created environmentally responsive buildings in Finland, predominantly with the most sustainable of materials; wood (Behling, 2000).

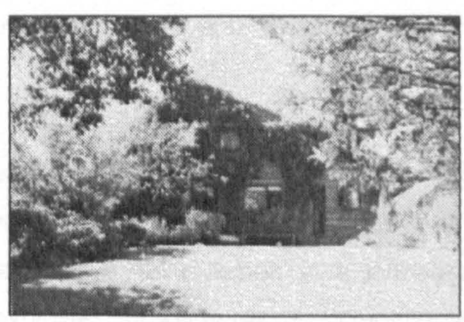


gilardi house, tacubaya, mexico city (1976-80)

Architect and Source: Luis Barraghan[31]

Development of solar principles into affordable mass housing projects has been limited in the 20th century, and despite energy scares and climatic revelations from the seventies through to the present day; there has been little experimentation on affordable environmental designs adopting holistic principles.





cooper[32] house 'solar cottage' (1982)

Source: Yannas ([1] and [2], 1994)

Yannas ([1] and [2], 1994) highlights case studies and research on passive solar homes in the United Kingdom. These homes begin to display, in the UK, the adoption of environmental principles holistically, and in particular the homes and site developments in Milton Keynes begin to use these principles. Though 'cutting edge' at the time, being vastly superior to building regulations minimum standards, they have become, compared to modern standards, obsolete (in terms of BR standards) in less than twenty years. These types of homes, however, offer far more than simply comparing them with modern standards. It should also be noted that these homes were built affordably.


the zero-heating house (1999)
Source: Deveci, *et al*, (2000)

It is suggested that the agenda for the solar house in the twenty-first century has to become more marketable and encroach into the mass housing market, addressing the economic led approach of modern developers. Recent housing advances have failed to accomplish this task, developing unaffordable 'showcase' homes, but there are a few developments that have attempted to tackle this issue. A home by Gokay Deveci attempted to combat the issue of affordability while adopting holistic passive solar principles (Deveci, *et al*, 2000). The principal aim of this home was to eliminate the need for a dedicated heating system, relying instead on passive solar and internal heat gains as a source of energy.

2.4 SUMMARY OF THE HISTORY OF SOLAR DESIGN

This chapter has highlighted the reasons why PSD is not currently used as frequently as it perhaps should be. It has detailed the history, main principles and obstructions to the adoption of passive solar design.

- The Greeks used solar design around some of their most innovative small and large scale developments. It is large scale developments in, for example, Prienne and Olynthus that developed the principles of passive solar design in a formalised fashion. These large scale developments exhibited grid-patterned, long regimented streets with south facing facades with the interior layouts created to trap the sun's heat in the winter and provide cooling in the summer. This style of housing was replicated on many sites in Greece, depending on whether sites were South facing. These developments were restricted to the material specification of the day, and are therefore dependant on South facing slopes.

- The Romans developed the solar ideas of the Greeks. The Romans built more complex buildings, and developed solar design into commercial and leisure facilities, most notably in their bathing amenities. The Romans also developed other environmentally friendly features for ventilation and shading for many of their buildings. Although cooling is more difficult to achieve than the heating of buildings in this climate and therefore restricts the benefits that can be accrued by using PSD, the Romans were beginning to use a more holistic approach to achieve their housing needs, and considering a variety of environmental aspects to increase internal comfort levels.

- Solar design could not change from the classical proportions without a change in the architectural process. Industrialisation was the catalyst for a change in emphasis in architecture and brought a growth in the number of building materials available to the architect. Classical (Greek based) styles of architecture that had been previously dominated by stone and earth based materials with, for example, restrictive window sizes, changed. More recent developments in material science have seen the introduction of thermal efficiency, an important aspect of modern solar design. The basic form of a solar home, as exhibited by the Megaron (2.2.2.8), had not changed significantly by WWII. After WWII, innovative methods of ventilation and heat transfer aided by new technologies at the time, changed solar design to such an extent that housing needs could mostly be met the full year round by solar gain.

Solar design, despite the advances in technology and innovation throughout the architectural process, has not taken significant hold of the construction industry. Today large-scale residential developments using passive solar are rare, though globally there are a few exceptions. Generally, solar design is similar in principle to the Greek and Roman models but in the modern era solar design is limited to 'show-houses' or individual private developments. These projects go to show what can be achieved but are unaffordable for much of the housing market. The general perception by consumers is that environmental design is unaffordable, and considerable capital cost is needed in order to adhere to environmental principles. There is little practical evidence to dispute this claim. Awareness of what a solar design costs, in monetary and non-monetary terms, is often limited by these one-off showcases, something that needs to be overcome before passive solar housing becomes acceptable and sustainable.

CHAPTER 2 : ENDNOTES

1 Voltaire (François Marie Arouet), 1694–1778, French philosopher, historian, satirist, dramatist, and essayist.
2 Arbela, town of ancient Assyria. Arbela is the modern Erbil, Iraq
3 Mohenjo Daro; An archaeological site in Pakistan, near the indus river: six successive ancient citires were built there
4 Zoser - fl. c2800B.C.,Egyptian ruler of the 3rd dynasty.
5 The mastaba was the common burial platform of early Egypt - cited from Kostof (1985)
6 Teotihuacan; The ruins of an ancient Mesoamerican city in central Mexico, nr Mexico City, that flourished AD c200-c750.
7 Pueblo Bonito is one of the nine great houses whose ruins are to be found in Chaco Canyon, New Mexico.
8 North Americans of the Annansazi culture, found in the canyons and on the Mesas of the US Southwest (11th-14th Cent)
9 Ancient Ionian city of W.Asia minor, near the mouth of the maeander (now menderes) river, an example of carefully planned city.
10 Hippodamus; 5th century BC; Greek architect, b Miletus, he was the first to plan cities according to geometric layout.
11 Olynthus; Ancient city of Greece, on the peninsula of Chalcidice (now Khalkidhiki), NE of Potidaea.
12 Megaron Definition: (in pre-Hellenic Greek architecture) a building or semi-independent unit of a building, generally used as a living apartment and typically having a square or broadly rectangular principal chamber with a porch, often of columns in antis, and sometimes an anti-chamber or other small compartments.
13 Pantheon: a domed circular temple at Rome, erected a.d.120–124 by Hadrian, used as a church since a.d.609.
14 Vitruvius; from the ten books of Architecture (1st century BC) Book IV, Chapter IV
15 Ali Qapu Palace, Isfahan: A city in central Iran: The capital of Persia from 16th into the 18th century.
16 Alberti, Leone Battista, (1404–72), Italian architect, musician, painter, and humanist. Alberti was the first architect to argue for the correct use of the classical orders during the Renaissance.
17 Brunelleschi, Filippo, (1377–1446), The first great architect of the Italian Renaissance, a Florentine by birth.
18 Palladio, Andrea (Andrea di Pietro della Gondola) 1508-80, Italian architect famous for his widely translated 'four books of architecture', 1570.
19 Mouchot, Augustin (1825-1912) French Mathematician who in 1861 patented the first solar motor.
20 John Ericsson (b.1803-1889) Vermland, Sweden, was more famous for his propeller but also refined solar motors.
21 Giedion, Sigfried (1883-1968) Swiss Historian of Architecture
22 Le Corbusier, Charles Edward Jeanneret (1887-1965) French Architect, b. Switzerland
23 Van Der Rohe, Mies (1886-1969) US Architect born in Germany
24 Wright, Frank Lloyd (1867-1959) American Architect, b Richland Centre, Wis.
25 Neutra, Richard (1892-1970) US Architect, born in Austria
26 Dr Philip Lovell was an influential neuropath of the 1920's
27 Fuller, Buckminster (1895-1983) American architect and engineer
28 Gropius, Walter (1883-1969) German Architect
29 For more information see: http://131.175.34.19/tesi/036bis/ci4.htm Date Visited: 05/04/04 15:39
30 For more information see: http://www.inmadcity.com/solarhemicyclo/jacobs2.htm (Bill Taylor, 1998). Date last visited: 10/03/01 13:45
31 For more information see: http://www.pritzkerprize.com/barragan.htm Pritzerker Prize website, Hyatt Foundation. Date last visited: 07/10/03 17:51
32 For more information see: http://www.coo-res.co.uk/, Cooper Research. Date last visited: 07/04/04 12:46

3 Defining Passive Solar Design

3.1 INTRODUCTION

This chapter will examine the research to date on passive solar design and will discuss the terms surrounding environmental design in general and passive solar design in particular. A wide range of variables influence passive solar design, many of which are central to the foundations of energy-efficiency and energy conservation. This chapter will discuss the variables appropriate to this research and define the elements applicable to this research. This chapter is also intended to highlight areas where passive solar design has either not been fully developed and offer suggestion as to the way forward for passive solar design so that PSD may be adopted into the wider housing industry.

3.2 BACKGROUND

Much has been said about climate change. Whether its cause is man-made or not, or whether fossil fuels will run out sooner rather than later, the fact remains that solar energy is still a powerful force for space heating and the day-lighting of homes, given appropriate design. Possibly an equally important factor is that buildings are consuming ever more energy and increasingly using more technology and appliances in the home. The off-site dependence for energy in the home, in the European Union, is constantly increasing (EC, 2000), with strategies for the on-site creation of energy for a home becoming ever more important.

The Commission of the European Communities paper "*Towards a European strategy for the security of energy supply*" (2000) reveals that the European Union is structurally weak regarding energy supply, with Europe's, *"growing dependence on energy"*. Though this report highlights all sectors of industry, the comments made are equally true, if not more so, in the built environment, a field which involves manufacturing and construction processes as well as consideration of the life-cycle of buildings, often for many generations. Many countries in Europe now highlight renewable and sustainable principles as part of their mainstream political agenda during elections. In places such as France, Germany, Switzerland and Scandinavian countries, for example, green party coalitions are becoming stronger, certainly in urban environments. The Commission of the European Communities (2000) stresses that without an active energy policy then the European Union will not be able to free itself from its increasing non-renewable energy dependence. This form of policy is critical to making changes to building in the European Union, and through this the UK.

In the UK, the Minister for Energy and Competitiveness in Europe (DTI, 2000) states that new & renewable energies are going to become one of the world's main energy sources in future years. The Minister states that renewable energy sources will provide new horizons for UK businesses interested in this area, and provides, *"a three-term "win-win-win" equation: encouraging the development of* ***new technologies****; creating new jobs; and tackling global environmental challenges"*. It could be argued that a competitive market will encourage the use of new technologies, perhaps suggesting that the UK industry in this sector is currently stagnant or unable to change. The 'new technologies' mentioned are of particular interest, though the definition of this statement is broad and it was not made about passive solar design, in particular. New technologies in recent years have enabled constructors of homes to build to better than Building Regulations standards for a relatively small increase in capital cost, making, for example, thermally efficient, energy conserving, building envelopes. Coupled with more efficient government driven thermal standards, from this standpoint it may be argued that, to some extent, modern thermally efficient building materials and systems may be used in the mass housing market, replacing alternative high cost renewable 'technology'. It is arguable which category PSD fits into. Despite this, the Federal Energy Management Programme in the USA (FEMP, 2000) still believes that passive solar can be the foundation of good building practices.

It is significant that advances and major changes in UK construction, which are not led by aesthetic fashions tend to be prescribed by law, for example increases in legislated minimum building thermal standards (DTI, 2000). In addition, most Government policy on energy has been aimed more towards the macro (off-site) energy supply side, rather than the micro (on-site) energy demand side of the individual building, where passive solar takes on more significance. For example, the UK Government aims to replace some fossil fuel power plants with renewable technologies, most commonly wind, marine, hydro, and/or (active) solar energy but also bio-mass and geothermal as potential energy sources. Often such policy misses the energy demand side, where large numbers of relatively low-tech solutions applied holistically may help to radically reduce energy costs in the built environment.

Renewable sources of energy make an important contribution to secure, sustainable and diverse energy supplies and renewable energy is an essential element of a long-term cost-effective climate change programme. The Government is proposing that 5% of UK electricity needs should be met by renewable sources of energy by the end of 2003 (which was not achieved) and 10% by 2010, as long as the cost to consumers is acceptable (Kirby, 2003 and DEFRA, 2000[1]). These targets are intended to act as a stimulus to industry and provide milestones for progress monitoring.

In short, the Government is more involved in the macro level of energy sourcing with the replacement of non-renewable power stations. At a micro level the Government is looking at photovoltaics and solar panels – technologies which are currently expensive initially making payback on expenditure long-term, most of their monetary cost being borne by the buyer, though there are some grants available. Passive solar design requires early incorporation into the design stage to achieve the greatest potential savings. PSD, in most cases, is often less costly to the homebuyer and has been of less interest to policy makers. One reason for this, perhaps, is the difficulty of measuring its output as a contribution to energy generation. In addition, passive solar design is, arguably, at the core of a more sustainable built environment, and co-exists with other renewable energy supplies e.g. active solar.

The UK Government Minister for Energy and Competitiveness in Europe suggests that 10% is an 'ambitious target' by 2010, but is it? Large reductions in energy targets are possible with current building technology. Deveci, *et al*, (2001) and Holloway (2000) both suggest significant cost and emission savings using passive solar design with little capital expenditure is possible, and when applied to the new homes planned in the UK, these can far exceed government targets. NEF Renewables (2000) also highlight the fact that a quarter of the UK 'primary' energy goes towards heating buildings and also that through environmental designs not only will annual heating bills be cut by a third but also carbon dioxide emissions will significantly reduce. As an additional bonus, increased day-lighting that a passive solar design creates will also reduce the need for electrical lighting. So it may be that the target of 10% is as much a political target (which the UK Government feels is achievable) rather than what is actually possible.

The Commission of the European Communities published the paper "*Towards a European strategy for the security of energy supply*" (EC, 2000), which further details the current extent of fuel consumption and outlines the way forward. Additional information may be obtained from Agores[2], the official European Commission website for Renewable Energy Sources, which has information on a variety of renewable energy topics in reports, journals and magazines as well as case studies.

3.3 DEFINITION OF PASSIVE SOLAR DESIGN

This section aims to collate, from a variety of sources, definitions that cover the key principles of passive solar design. This is in order to define and outline the scope of research in order to make quantitative measurements in this thesis. In arriving at such a definition it is important to recognise that all possible definitions of passive solar design encompass a very wide ranging set of variables and influences, not all of which are relevant directly to this piece of work. Any working definition will be to some extent incomplete and the need to achieve a focus in no way negates the importance of other passive solar variables.

A critical stage in the research and development of passive solar design was the work done by J Douglas Balcomb and his team at the Los Alamos National Laboratory (Balcomb, 1984 & 1992). His work from the early seventies aided in developing the guidelines for various climates many of which are still referred to, for example Holloway (2000). The modern definitions of PSD can therefore be traced back to this research conducted in the seventies.

It is difficult to find a definition, however, of passive solar design that covers all the aspects involved in such a strategy, which changes depending on climate and site. The following are some general definitions from selected research centres and funding agencies internationally.

The Department of Trade and Industry (2000) through NEF Renewables (2000), state that passive solar design is nothing new, and has been in common practice since the first building. The DTI, however, explain that people prefer daylight and appreciate the other benefits of windows, such as providing social aspects, such as views, and thus passive solar design is not always at the forefront of a designer's mentality when contemplating the design of mass housing. This is a viewpoint echoed by developers who have other, to them more important, agendas rather than just reducing heating and environmental costs. The same applies, to some degree, with local planning departments (BRECSU [1] 1997 & 1995). The DTI state that it is only recently, for various reasons, that the wider benefits of passive solar design have become increasingly appreciated.

There are a number of texts, such as Luce, *et al*, (2000); NEF Renewables (2000); EPSEA (1999); Kachadorian (1997); King (1995); Baird & Hayhoe (1993), which surmise that differentiating between a passive solar house and a conventionally built home is difficult, because, they claim, **every house is a solar house** to varying extents. The issue of what is a passive solar house and how to measure passive solar contributions is made the more difficult because of this. Interestingly some texts, most notably DTI (2000), try to quantify a passive solar home by stating that an average home will gain up-to 10% in passive solar gains (dependant on location). This is without the use of any passive solar strategies, and therefore DTI (2000) suggest that passive solar homes will collect more than the 10% over that which an average home will collect. Though it is unclear how the 10% was determined by the DTI (2000) it is interesting that a number of US sources quantify passive solar in a similar way - by how much heat gain the design will provide, and consequently how much money it will save. The US is also interested in active solar gain through the use of PV farms, or similar solar collection for electricity production. Parts of the US have the advantage of being closer to the equator, however. It also suggests it is true to say that for any home, regardless of orientation, shape, or climate, there will always be some solar gain through, "walls and windows".

NEF Renewables (2000) simply explains that, "passive solar design tries to **optimise** the amount of energy that can be derived directly from the sun". Optimising is the important point here, as it is unrealistic, even in a theoretically ideal site, that passive solar designed homes can replace conventional energy sources completely. What 'optimising' in this context also highlights is that, on some sites, 'trade-offs' are required between PSD and current methods of construction. Other than the immediate economic and environmental benefits of PSD, there is a variety of planning related issues to be dealt with, one of which is density. So rather than *replace* the current housing stock with augmented PSD homes, there is the need to *optimise* the use of PSD homes for specific sites, climate and further meet sustainability driven objectives. Marsh, *et al*, (2000) uses the term optimise in a slightly different context. They explain that a solar optimised home is one which requires s co-ordinated design process from planning through to engineering. This stems from a belief that passive solar is a core element of the wider concept of environmental design yet a home which is south orientated may also be passive solar. Marsh, *et al*, (2000) therefore highlight the difference between a passive solar design at the core of an environmental design and a passive solar house which faces south as being an optimised passive solar house. The optimised simply stating that optimised passive solar is a home with a collection of environmental concepts over and above the normal housing standard.

It is also important to stress that passive solar design is a collective of various different systems whose application are climatically and site dependant. As Niemeyer (2000) details *"Passive solar heating is just one strategy in a group of design approaches collectively called passive solar design. When combined properly, these strategies can contribute to the heating, cooling and day-lighting of nearly any building".* Passive Solar Design is a set of guidelines that achieve a site specific strategy for both the cooling and heating of a home, passive solar heating is an element of PSD that deals with homes in colder climates, homes that require significantly more heat than cooling. Passive solar heating, therefore, is appropriate for the climate of the North East of Scotland.

Shaw & Holt (1999) state that, "Passive Solar Design refers to the design of a house such that it makes good use of the features of its site so as to **minimise** heating and cooling requirements. It is necessary to admit and store the sun's heat when/where required and exclude or remove heat where not required". Shaw & Holt highlight the critical point applicable to this research, which is the need to balance the solar gain and heat loss in a house, in a site specific manner. Interestingly, the aim of PSD is to minimise, or rather reduce, the use of conventional heating and cooling technologies used in buildings, but not to replace them entirely. PSD could never replace conventional services simply because it is not practical to do so in most climates and on most sites. Heating and cooling in a building will require being of the same standard as a conventional home (that is the thermal environment of a home will require to be of a satisfactory standard) but PSD replaces some of the heating or cooling requirement.

FIRST (2000) offer a more simplistic version of the same definition, "A passive solar home is one where the design and construction of the home itself is made to keep the house naturally warm in the **winter** using the sun's energy. The design should also keep the house cool during the **summer**". Scotland has a milder climate than other countries at the same latitude with a lot of cloud cover ensuring that temperatures do not fall significantly below freezing. In this climate, PSD is ideal for collecting winter solar gains as a top-up heat source when the sky is clear and the moderate summer means less risk of overheating. It is important to mention that passive solar cooling methods can offer striking aesthetic changes in the appearance of a home, involving large overhangs and possibly exterior blinds, verandas, etc. In Scotland, as opposed to Mediterranean climates, the exterior facade will change less due to the climatic variations of the two climates, most shading could be provided easily by small but permanent overhangs and heavy curtains, as discussed in a later section. In Scotland, therefore, PSD does not need aesthetically to alter from the local vernacular as much as it would in a hotter climate.

The New Mexico Solar Energy Association is one of a number of solar agencies in the US that 'climatise' research conducted by the main research bodies to local areas. The NMSEA (1999) state that, "Passive solar design uses sunshine to heat and light homes and other **buildings without mechanical or electrical devices.** It is usually part of the **design itself** ...". The NMSEA describe what is meant by a 'passive' system, in that no mechanical or electrical devices are used, though this is a grey area for many passive solar designs. Active systems usually mean the use of solar water panels or photovoltaics, certainly when describing the utilisation of the sun. A passive system, by definition, uses natural convection, conduction and radiation and this is the reason why passive solar design is, 'usually part of the design' in order to benefit from natural processes (FEMP, 2000; Shaw & Holt, 1999).

Baird & Hayhoe (1993) further describe the difference between active and passive systems, although Baird & Hayhoe explain that the distinction between the two is 'blurry'. The basic difference between the two, they suggest, is that passive systems use integral elements of a building to capture solar energy and active systems are usually mechanical 'add-on' features, which distribute the captured solar energy.

Research into active systems, their benefits, limitations, etc, has been more common than passive systems. This is due to the complex building systems, and the variations at a climatic level, of passive solar strategies. Active systems, on the other hand, use mechanical processes and as a consequence they are easier to research, their output is known and therefore they can be modelled mathematically. As such, there is a large amount of research conducted by NREL, EREN and in the UK, by the BRE, on active systems.

The following definition by Olson (2000) is arguably more moderate definition than the one given above, *"Passive Solar Design is a group of building design strategies that can be utilised to reduce the need for **mechanical** heating, cooling and lighting."* Olson states that passive solar design reduces the need for mechanical (and electrical) systems, as in all designs, some type of mechanical and electrical systems will always be used either for back-up or simply because good building practice requires it in the appropriate building and planning standards. The Federal Energy Management Programme (FEMP, 2000) adds that there needs to be a 'synergy' between the different building systems in a passive solar design.

Hiu, *et al*, (1996) define passive solar design in much the same manner as those already listed but also adds that, *"Passive solar design is a broad term used to encompass a wide range of strategies and options resulting is energy-efficient building design and increased occupant comfort."* Hiu, *et al*, highlight the fact that passive solar design is not only aimed at reducing heating and electrical costs but also occupancy comfort, which is a highly complex phenomenon substantially beyond the remit of the current research, but no less important. It is a key reason for the use of PSD in modern developments.

In terms of the thesis of this research, a passive solar design is an integrated building systems approach, encompassing every aspect mentioned in the definitions listed, primarily minimising the need for heating services through the appropriate use of features of a site, year round. The aim is to optimise the admission and storage of solar energy when and where required, while excluding and removing excess heat as required, naturally if possible, in a site specific manner, not only for an individual home, but collectively in a development.

*"Passive solar **heating** is a holistic approach to building design, reducing the dependence on non-renewable methods of heating during winter without overheating during summer, optimising strategies of passive solar design to create more sustainable housing*

developments giving environmental, economic and comfort benefits over conventional methods of construction"

3.4 DESCRIPTION AND PROBLEMS OF PASSIVE SOLAR DESIGN

3.4.1 AIMS & ADVANTAGES OF PASSIVE SOLAR DESIGN

Having defined what a passive solar design entails overall, it is necessary to describe the constituent elements of such designs. Seiberling (2000) states that designers look to our architectural past for ideas on energy conserving, sustainable architecture, part of which includes solar design. History, however, may only be used to describe what worked then but at a macro level it can tells us many things about the local climate, local materials, vernacular architecture and how many problems associated with building homes were overcome for a lasting strategy. In terms of modern day passive solar, past architectural heritage cannot be relied upon as PSD is a climate responsive strategy (and the climate is changing), and living standards have changed (and living standards will continue to change), though basic principles may be applicable to some climate regions. The basic shape of the section of the Megaron (2.2.2.8), for example, is still applicable today.

Passive solar has a number of disadvantages, however, in its application in 'real' scenarios. It is true to say that we now look for different things in a home than we have in the past and the way we use our homes in the future will change again.

Since architecture is partly a social and cultural process, there are arguments against the adoption of historical design models. Socially we have changed - collectively our needs (and expectations) have evolved to higher physical standards, our technology in the home environment has expanded, and will continue to do so in the future. Consequently our housing will change, or should change, to meet our needs and therefore relying on past architectural designs and construction, in some cases, may not be the best alternative.

It has been suggested that the interior layouts dictated by passive solar design can be a disadvantage of this approach. Although this is dependant on the individual case, privacy has become an important commodity in modern mass housing, with a series of rooms entered through doors separating each individual space in a building, one reason for this is the use of central heating. Traditionally open plan homes were typical for much of rural areas in the highlands, where the heat from the kitchen stove/hearth often heated the entire house (Dualchas, 2000). The traditional home therefore offers little privacy but it does offer a number of good design principles, one of which is encapsulated in the following old Gaelic proverb *'An iar's an ear, an dachaigh as' fhéarr - cùl ri gaoith,'s aghaidh ri gréin.'* [East to west, the house that's best - back to the wind and face to the sun] (Dualchas, 2000). The siting, orientation and fenestration of traditional homes in the rural highlands are basically the same as the main passive solar principles.

Shaw & Holt (1999) and Borer & Harris (1998) describe the basic elements of passive solar gain as using the building elements in a home as a collector, storage and transfer mechanism. Shaw & Holt (1999) also state the important factors to be included in a passive solar design as being; local climate; the orientation and size of windows; the winds around the house and their cooling effect; the shading of the house and; the materials used in a home's construction. Similarly, the DTI (2000) highlight five factors, which will influence PSD as; Climate; House Orientation; Windows; Building Materials; and Insulation.

FEMP (2000) have a longer, more exhaustive, list of PSD variables and sub-variables, together with an additional sixteen energy-efficient strategies. They also state that these are sample variables and strategies, suggesting there are more. It is interesting that of the authors offering definitions of PSD only FEMP (2000) refers to the very many variables involved in PSD and does not attempt to hide the fact that PSD is a series of complex issues. Homes in the UK, which have adopted PSD, tend to over simplify lacking a holistic approach to solar design. This is a problem shared by many professionals in the construction industry and may be one reason why passive solar homes have been stereotyped as homes with big windows, as if that is the only element. Significantly it is the main 'visual' element of a PSD home, and arguably reduces the privacy of a home. Due to the belief of estate agents and homebuilders that first impressions are the most important, passive solar homes may be too much of a risk for homebuilders for this single reason.

So why adopt PSD? Research from a variety of sources suggests there are five main advantages of employing passive solar design strategies;

1. **Increased Comfort** - Solar homes provide a comfortable environment in the winter and can be cool in the summer, when combined holistically with energy conserving and energy efficient systems, to make them healthier and increase productivity (in industrial and commercial properties in particular) in many buildings (NCSC, 2000; Olson, 2000; Borer & Harris, 1998, Deveci, *et al*, 2000; FEMP, 2000; Fuch, *et al*, 2000; Niemeyer, 2000; NMSEA, 1999; EPSEA, 1999; Heckeroth, 1999; Christensen, 1994; EREN, 1994; Baird & Hayhoe, 1993)

2. **Lower Economic Payout** – For a little additional economic outlay, homeowners receive a quick payback and an additional selling point for their home as real estate. It is important to

look at the whole life costs of passive solar designs and, of course, alternative environmental designs also. (NCSC 2000; Olson 2000; FEMP, 2000; NEF Renewables, 2000; Fuchs, *et al*, 2000; Niemeyer, 2000; Heckeroth, 1999; Christensen, 1994; Baird & Hayhoe, 1993).

3. **Increased Durability** - Low maintenance materials are commonly an aspect of passive solar designed buildings, and are built to higher standards than current methods, through increased air-tightness and insulation, for example. This may be a debatable point of view, though it is, generally speaking, a likely scenario. Increased durability of environmentally friendly homes, however, is as much the result of the care and dedication of the homebuilders as it is through the material specification. That is to say, if many of the environmental homes built were available to the mass housing market and built by speculative housing developers, durability of materials and the home may decrease. In general, a sustainable timber window is more durable than UPVC windows, in most scenarios. however (NCSC, 2000; Olson, 2000; NMSEA, 1999; Christensen, 1994).

4. **Attractively Designed Buildings** - Solar homes are full of light and are well connected to the outdoors. This factor, in addition to open plan layouts and use of natural resources, may aid the re-sale value of a home (O'Sullivan, 2003; NCSC, 2000). Of course, it is always down to the individual homebuyer as to what attracts them to buy any one building.

5. **Environmentally Responsible Buildings** - Solar homes not only make efficient use of our limited reserves of energy, but correspondingly save on emissions and encourage the careful selection of materials, reduce embodied energy (NCSC, 2000; NEF Renewables, 2000; Borer & Harris, 1998; FEMP, 2000; Fuchs, *et al*, 2000; Niemeyer, 2000)

As mentioned previously, point four in this list is contentious, depending wholly upon the individual homebuyer. There is research that suggests the productivity and efficiency is increased in workplaces that use passive solar techniques and that homeowners have a greater tolerance of fluctuation in temperature and humidity in passive solar homes (FEMP, 2000). That is to say, homeowners in passive solar homes often exhibit less use of the heating systems and accept colder average temperatures. Having said this many housing developers claim that there is a lot of anecdotal evidence to suggest that passive solar homes are difficult to sell, the aesthetics and perceived cost of such homes detracting from the value.

3.4.2 GENERAL PRINCIPLES

In the seventies, J. Douglas Balcomb and the research teams at the Los Alamos National Laboratory set up a number of passive solar test cases (Balcomb, 1992). These ultimately resulted in a set of guidelines for direct and indirect solar design guidelines, which covered air-tightness, insulation, materials, glazing, and orientation issues among others. Many of these guidelines need interpreting for different climatic areas, such as that adopted by Holloway (2000).

FEMP (2000) cautions that there are no, "generic solutions or rules-of-thumb" in passive solar design because of the many combinations and system interactions that are involved from site to site (Seiberling, 2000). The basic principles, taken from a number of sources as listed, of a successful passive solar design are as follows;

Admittance and collection of solar energy - generally through windows, though possibly through roof and walls, arranged in such a fashion as to increase the amount of daylight, so reducing the need for artificial lighting. Orientating buildings, laying out rooms and distributing glazing in a way that allows the interior to be heated by solar radiation. (DTI, 2000; Niemeyer, 2000; Shaw & Holt, 1999; Borer & Harris, 1998)

Storage of collected solar gain - Through high thermal mass, insulating envelopes and air-tightness. (Niemeyer, 2000; FIRST, 2000; Shaw & Holt, 1999; Borer & Harris, 1998)

Exclusion of excess solar gain - Through the placement of windows away from the summer sun in combination with internal and/or external shading, while minimising heat losses from shaded facades and maintaining thermal comfort of the building's interior spaces. (DTI, 2000; Niemeyer, 2000; Olson, 2000; Shaw & Holt, 1999; Borer & Harris, 1998)

Removal of excess gain - Through cooling and ventilation using natural ventilation, which allows solar heated air to assist natural convection, so minimising the need for mechanical ventilation and cooling systems. (DTI, 2000; Niemeyer, 2000; Shaw & Holt, 1999; Borer & Harris, 1998)

The importance of the above principles is directly influenced by the climatic evaluation of an individual site. The most critical element in the northern hemisphere would be the admittance of solar gain through south-facing glazing as it is not only vital to the success of a passive solar design, it is the most aesthetically visible principle listed. The solar collector changes the appearance of a home from the conventional aesthetic, whatever that may be, to a recognisably 'solar' aesthetic.

The remaining principles are regarding the control and distribution of solar energy, so as to ensure that the captured solar gains will keep the building heated throughout the night and, if needed, the following day (FIRST, 2000). Thermal mass is an important controller and distributor of passive solar heating. Holloway (2000) recommends the use of thermal mass extensively over the largest practical area, commonly the floor. Without such methods of control, a passive solar home has a high risk of overheating on sunny days in some climates and/or difficulty in cooling during the summer (FIRST, 2000; Olson, 2000).

Olson (2000) states that shading devices are required for the summer months when the sun is at a high angle, which may take the form of internal, intermediate or external devices. NMSEA (1999) further adds that cooling can be achieved in summer with the use of natural convective air currents, though depending on the size of the house and the internal layout, small mechanical extract fans may be required.

The University of Hong Kong (2000) has also completed research into passive solar design principles as has Christensen (1994), published in 'The Sustainable Building Source Book'[3], which covers most topics and offers guidelines specific to Texas, though various aspects are applicable to most climates. In addition the EECA (2000) covers most of the general principles of passive solar design for the southern hemisphere. Similarly, the Australian Greenhouse Office[4], through the Australian Renewable Energy Website, offers introductory information on solar energy topics.

3.4.3 A CHANGING WORLD

Introduction

> *"Without the environment there can never be the kind of development needed to secure a fair deal for this or future generations. It would be disastrous to ignore the picture painted."*
>
> *Source*: Klaus Toepfer, the UN Environment Programme executive director (Brown, 2002)

The first and foremost criterion for the optimisation of passive solar is an evaluation of the local climate (Seiberling, 2000). Heckeroth (1999) states that different climates require emphasis on different passive solar strategies, and offers general suggestions for a range of three different climates; sunny & dry; hot & humid, and; mixed & cold climates. The suggestion for colder climates is for additional insulation in the building envelope.

NMSEA (1999) and Borer & Harris (1998) state that colder climates are ideal for the use of passive solar not only because of the clear, sunny days in winter but because during summer natural ventilation and shading devices may eliminate any need for mechanical cooling. Baird & Hayhoe (1993), in a view mirrored by English & Morris (1998), state that, *"the amount of useful solar energy reaching the ground* [the same area of the house] *in the winter is greater than the daily heating requirements of a well insulated house."* This is based on a home in Canada, and though a British home may expect more cloud during winter the same applies here, given that both countries have similar latitudes though admittedly different climates. Deveci, et al, (2000) describe a successful Scottish passive solar home which provides the majority of the heating during the winter without the need for a dedicated heating system. In this home, the only means of heating in the cold Scottish climate is a wood burning stove.

The development of an environmental tool must take account of the effect of climate change and global warming. As such this section highlights the main concerns and briefly discusses the problems that can result from this issue. This section also highlights the main agencies and policies that are trying to overcome this problem.

The effects of population increase and climate change

Increasingly, the technological advance of the developing world has had significant effect upon the environment on a global scale, as a result climate change is now a fact of life (Nichol, 2000). The 'markets first' approach (Edwards, 2000) of developed countries has, for over a century, completely ignored the social and environmental effects their actions have resulted in (Brown, 2002). A report made to the World Summit on Sustainable Development in South Africa in 2002 paints a bleak picture of our changing world. This report claims that before 2050 the population will have increased by two billion and 70% of the world's populace will be in urban environments, the consequences of which mean that half the world will be short of water, even without the complicating effects of global warming being taken into account due to the demand placed on limited resources (Brown, 2002).

Brown (2002) states that if Governments worldwide do not form a collateral agreement to stabilise human growth the consequences will be disastrous for global communities and wildlife, areas of immediate concern, states Brown, are coastal locations where growth in the human population is the greatest. Brown (2002) does offer positive models, pointing to developing countries that have reducing levels of pollutants in water and air and increasing re-growth of species and forests. Brown's predictions are aimed to "shock world leaders" into taking seriously the World Summit on Sustainable Development, held in South Africa in August 2002. One of the key aims of this summit was to discuss alternative energy supply.

The effect of the changing world causes many problems for many communities globally, but may also be the main cause of climate change. Climate change has a direct implication for types of building form and standards and it is exacerbated by the increasing demands on energy. Climate change and global warming are the main reasons behind UK government targets, set by global objectives taken from the Kyoto Protocol[5], of CO_2 reduction and sustainability. The cause, be it industrialisation or a natural process of the earth's evolution or a combination of both, is not covered in this research but the effect of these changes on the environment is important to understand and be aware of in the housing industry.

The gloomy statistics reproduced by Brown (2002) are listed as follows (fig : 3.4.3.1);

Fig 3.4.3.1 : The bad news:

- In 30 years 70% of the Earth's surface will be suffering severe impacts of man's activities, destroying the natural world with roads, mining and cities
- 1,183 species of birds, around 12% of the world's total, and 1,130 species of mammals, about a quarter, are threatened with extinction
- One third of the world's fish stocks are depleted or overexploited
- Concentrations of carbon dioxide in the atmosphere could double by 2050. The number of people affected by weather related disasters has risen from 147 million a year to 211 million in 10 years
- There are 2.2 billion more mouths to feed than in 1972, and there will be another 2 billion in 30 years
- Already 40% of the world is short of fresh water, in 30 years this will rise to 50%. In west Asia this rises to 90%
- At least 15% of the Earth's surface is already degraded by human activities
- Overgrazing causes 35% of soil degradation, deforestation 30%, agriculture 27%
- More than a billion urban dwellers, mostly in Africa, Asia and Latin America, live in slums. Another billion people will be living in cities by 2010
- Half the world's rivers are seriously depleted and polluted. About 60% of the 227 biggest are disrupted by dams and other engineering works
- There are 4 billion cases of diarrhoea causing 2.2 million deaths a year
- 2 billion people are at risk from malaria, and 2 million die a year
- Contaminated shellfish causes an estimated 2.5 million cases of infectious hepatitis annually, resulting in 25,000 deaths
- A fifth of the world's population is responsible for 90% of consumption. Two thirds of the population, about 4 billion people, live on less than $2 a day

Brown (2002) also offers some good news, listed as follows (fig : 3.4.3.2);

Fig 3.4.3.2 : The good news (Brown, 2002)

- The hole in the ozone layer is being repaired because of an 85% reduction in use of harmful chemicals in 114 countries
- The number of people with improved water supplies increased from 4.1 billion to 4.9 billion in the last 10 years
- About 10% of the Earth, 12.18m hectares, is in protected areas like national parks, five times as much as 30 years ago
- A moratorium on commercial whaling since 1986 is allowing species to recover
- The amount of water abstracted for public supply in western Europe fell by 10% in 10 years because of efficient use
- Emissions of most air pollutants in Europe have declined since the early 80s

For example, the UK Climate Impact Programme, managed by the Department of the Environment, Food and Rural Affairs (DEFRA, 2000), develops 'scenarios' for the effect of varying CO_2 emission levels upon the environment. The effect these scenarios will have upon an average home or development needs to be established (Phillipson, [1], 2002) in future research. Phillipson adds that, "construction is one of the few areas of UK industry where design decisions made today will be directly affected by the climate over the next 50 to 80 years. So these scenarios are also essential reading for building professionals and clients who can now start making positive decisions to improve the built environment in preparation for the future." Sanders and Phillipson (2003) go further into the detail on the effect of climate change in the built environment. They state that climate change will increase the humidity in the UK, causing mould growth, especially in winter, in housing and as a result many homes may become 'sick'. The mould growth, they state, will be difficult to control through ventilation alone and it may be suggested that homes, which reduce humidity rather than require air-conditioning should be promoted. A home with a passive solar design would reduce humidity and also homes with hygroscopic materials.

Passive solar design relies not only on direct sunlight, but also diffuse daylight, a preferable type of day-lighting as it avoids glare. The effect of changing seasonal patterns on a passive solar design is high. In short, the changing climate means a design created **today** must incorporate consideration of the changes to climate, which may be significant, in as little as fifty years from the present assuming accurate predictions - current methods of construction do not.

Climate change affects all aspects of construction, however. The insurance industry, for example, is aware that the changing climate may result in increased frequency of flooding, forest fires, severe storms and coastal erosion. Crichton and Salt (2000) have produced a report to highlight the implications to the insurance industry of climate change, and what the risks are to the construction industry. In future, climate change could have a direct effect on many homeowners by the increasing of insurance premiums. Sampson (2001) echoes this opinion and calls for insurers to become involved in the planning of residential developments to avoid future catastrophes such as has been recently attributed to climate change.

The climate changes predicted by the various scenarios (Phillipson, [1], 2002) have direct effect on the sustainability of housing and these may include:

- By the 2080s the average temperature across the UK will be between 2°C and 3.5°C warmer.

- Higher summer temperatures may be expected, with extremely hot summers (surpassing the summer of 1995) possibly occurring one year in every five by the 2050s and three years in five by the 2080s.
- Winters will become wetter and summers drier throughout the UK.
- Heavy winter rainfall will become more common.
- Sea levels will continue to rise, with extreme sea levels being experienced between 10 and 20 times more frequently by the 2080s.

Recent climate changes have encouraged the adoption of climate forecasting software to discover different future scenarios. The scenarios were developed by the Met Office Hadley Centre[6] and the Tyndall Centre[7] at the University of East Anglia, using assumptions about future greenhouse gas emissions developed by the Intergovernmental Panel on Climate Change (IPCC).

So what is the Government doing to combat climate change? Not as much as they could do according to the Royal Commission on Environmental Pollution 22nd report (2000). The report suggests that some of the government's 'cornerstone' efforts for reducing CO_2 emissions are not enough. The Royal Commission suggested, for example, that the climate change levy (for business users only) should be replaced by a tax on all non-renewable fuels to all sources, be it homes or similar. A fuel tax is a positive step for the construction industry (MacKenzie, 2001). The report is also doubtful that the 20% reduction in greenhouse gases that the government has set to achieve by 2010 is in fact achievable using current tactics and whether the UK can maintain these levels beyond 2010, itself favouring a 60% reduction using more radical tactics. The Royal Commission called for radical change to policy, and points out that the construction industry needs to be at the forefront of this change.

Pout ([1], 2000) echoes this conclusion regarding the Government's set target for emission reduction by 2010. Pout ([1], 2000) states that more stringent targets should be set in order to reduce energy use, and the voluntary use of energy efficient appliances does not ensure their adoption on the scale needed. Immediate and radical action, it is claimed, is needed **now** since buildings built now will remain in use during the major climatic changes of the next 50 years. The BRE favour compulsory regulations for achieving targets and believe that raising awareness of emissions from buildings is as important a criterion as trying to achieve industry wide reduction targets. A more direct approach such as that recommended by BRE would act as a stimulus for innovation and cost efficiency in the renewable energy market, creating jobs and reducing costs (Pout, [1], 2000). The EU has also re-expressed their desire to reduce CO_2, among other emissions, to reduce global warming (Radford and Black, 2001).

In Scotland, Scottish Homes (now Communities Scotland), in line with UK Government objectives, intend to ensure their funded projects have the following criteria to combat climate change (Nichol, 2000);

- Require all the new houses it funds to be much more energy efficient in future. Higher energy ratings applied to new grant applications from September 1 (2000).
- Give higher priority to projects in brown-field sites rather than green-field development.
- Carry out environmental impact assessments of all projects and make sure developers are committed to this initiative.
- Ensure developers minimise movement of earth on site, water needs during construction and production of waste.
- Maximising recycling and re-use of materials and local sourcing of materials and;
- Help both house builders and consumers with best practice guides and research.

Nichol (2000) adds that to support the agency's latest policy, two practical tools have been published that hope to assist all developers to produce more sustainable housing. The 'Sustainable Housing Design Guide' and the 'Housing Quality Assessment Programme' (Stevenson & Williams, 2000) are complementary publications with the aim of assessing the quality of housing developments at all stages. This policy will reduce the impact on the environment of their housing over their life cycle but also to provide benefits to the housing consumer through affordability.

In short, climate change offers many challenges and is implicitly linked to sustainable housing. Climate change requires radical reductions in all emissions and in the construction industry it means current methods of construction will quickly become obsolete and incapable of meeting the needs of future generations. To meet emission targets set by Government and World Organisations in housing, for example, better design quality and standards, increased insulation of the building envelope, community heating systems and alternative methods of fuel need to be specified for the mass housing market. It means that if climate is to change, as previously suggested by Brown (2002), a change towards reducing waste, water efficiency, building performance, among others, will need to occur. It means if housing is to become sustainable, design and planning change is needed now to meet future needs.

3.4.4 TYPOLOGY OF PASSIVE SOLAR DESIGN

Passive solar designs include a number of basic design typologies, which can change the technology and appearance of a home, and depend on climate. For example, Energetic Designs (2000) suggests that direct gain passive solar strategies should be used in cold to moderate climates, while sun-tempered designs should be used for moderate to hot climates. Baird & Hayhoe (1993) discuss the main topics of interest for direct or in-direct types of passive solar homes. Types of passive solar design are described by King, (1995), and Hui, *et al*, (1996), who highlight some of the advantages and disadvantages of typologies of passive solar design. Depending on the amount of solar gain desired, the site location and climate, a number of design strategies have been developed in the past fifty years, some of which are detailed below.

Sun-tempering

Sun-tempering can generally be described as homes purposely orientated to take advantage of solar gain, but which usually do not use other passive solar strategies, and are basic passive solar designs (NMSEA, 1999). As NCSC (2000) describe, "sun-tempered homes with no internal solar thermal mass should have south facing windows with a glass area of no more than 7% of the heated floor." This is compared to, NMSEA (1999) state, a conventional home, which normally have a quarter of the homes windows facing south amounting to between three and five percent of the house's total floor space.

As a consequence, energy savings are modest with this system, but sun-tempering is very low cost (NMSEA, 1999). The disadvantages of this system are that they are susceptible to extremes in climate. That is they may suffer from under-heating and over-heating during a typical year in some climates. Marsh, *et al*, (2000) describes these homes simply as passive solar designs, which are **not** optimised to incorporate holistic passive solar strategies.

Direct gain

The most common passive solar types are direct gain systems, where sunlight through windows will directly heat the interior space of the home (NMSEA, 1999). As described previously, direct gain systems can have between 12 and 20% of the glass to floor area ratio in south facing windows (NCSC, 2000; NMSEA, 1999; Balcomb, 1992). NMSEA (1999) describe how, during sunlight hours, this heat can be stored in thermal mass incorporated into the floors or interior walls incorporating adobe, brick, concrete, stone or water. The heat held by the thermal mass will continue to radiate into the space after the sun goes down.

In general terms, designing a direct gain system includes calculating how much window area and how much thermal mass are required to provide the desired quantity of heat for the space (NMSEA, 1999). The thermal mass and open plan spaces of the homes will overcome extremes in climate, avoiding under-heating and over-heating. Yannas ([2], 1994) offers examples from a British perspective and Borer & Harris (1998), Vale (2000) offer further examples of direct gain systems.

Sun-spaces or Greenhouses

A simple passive solar addition is a sun-space or greenhouse, which is a direct gain system isolated from the main volume of the home (King, 1995). NMSEA (1999) and EREC (1994) state that when built onto the south wall of a structure, a solar greenhouse or sun-space provides an insulating air cushion between the outside and inside of the building, lowering heating bills in the winter. NCSC (2000) adds that sun-spaces only have vertical glazing to prevent overheating, while greenhouses are usually fully glazed (NMSEA, 1999). Both systems, but especially greenhouses, are prone to overheating, though sun-spaces are more practical areas as living spaces, (Vale, 2000; Yannas, [1], 1994).

Sun-spaces are referred to as "isolated gain" passive solar systems because the sunlight is collected in an area which can be closed off from the rest of the house (NMSEA, 1999; EREC, 1994). During the day, the doors or windows between the sunspace and the house can be opened to circulate collected heat, and then closed at night, and the temperature in the sunspace allowed to drop (NMSEA, 1999).

Unlike sun-tempered designs, sun-spaces and greenhouses use thermal mass, usually in the floor or the common wall, and natural ventilation, through convection, radiation and conduction, to transmit heated air around the building (NMSEA, 1999; EREC, 1994). NMSEA (1999) recommends (as a minimum) double glazing for these types of building, with Yannas ([1], 1994) providing further advice on this type of passive solar in the UK. Vale (2000) offers a practical guide in the construction of this type of building in the UK.

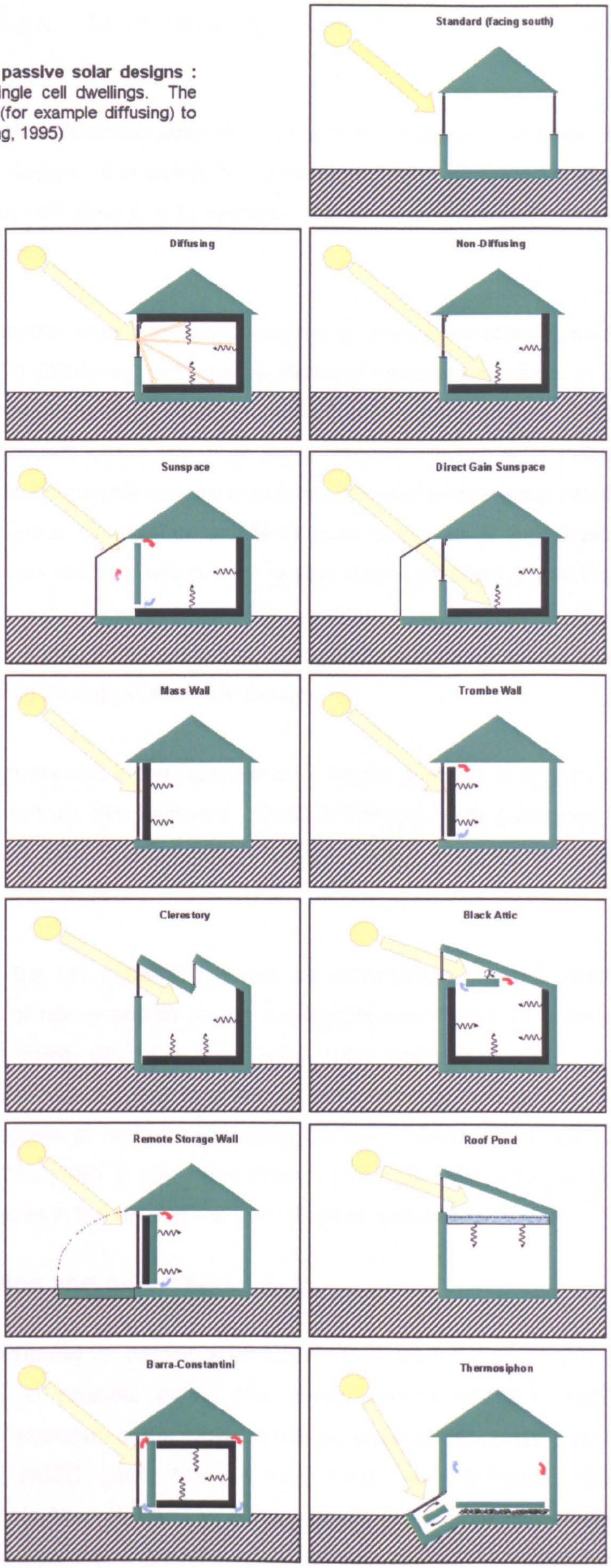
Trombe wall

A trombe wall is an example of an indirect passive solar system, King (1995) provides further examples. NMSEA (1999) asserts that a trombe wall, constructed of either masonry or water, is a technique used to capture solar heat that was developed by French engineer Felix Trombe. Balcomb (1992) provides some of the best information on trombe wall performance and construction, as does the Centre for Alternative Technology (CAT), some of these projects are covered by Borer & Harris (1998). In addition, NMSEA (1999) covers the background of the use of trombe wall effectively.

Underground / Earth sheltered

Shaw & Holt (1999) state that Underground dwellings such as dugouts or earth sheltered houses provide one solution for stabilising internal temperatures. These types of houses will experience a stable climate and little temperature variance due to the large thermal resistance of the earth. Together with a passive solar design, they can combine excellent heating with high thermal properties, though this is an expensive method of construction (Borer and Harris, 1998).

Fig : 3.4.4.1. Different types of passive solar designs : basic passive solar designs for single cell dwellings. The typology ranges from direct types (for example diffusing) to the in-direct types (trombe wall). (King, 1995)



3.4.5 PASSIVE SOLAR MATERIALS, SYSTEMS AND SITE LAYOUT

The materials and systems of construction used to build homes are easier to analyse and research than passive solar design. It is easier, for example, to ascertain the advantages and disadvantages of a brick wall, than it is to ascertain the consequences and output of utilising passive solar techniques.

There are a many research centres around the world involved in innovative material research and development. The EETD (2000) at the Laurence Berkeley National Laboratory in the USA has information on energy efficiency, windows, indoor environment and air quality, which include research conducted under the Vital Signs Project: Project Brief (1999)[8] (Benton, 1999), which aims to incorporate matters of building physical performance into the education of architects. It seeks to instil in architects and designers a fundamental awareness about the numerous ways in which their design decisions affect a building's physical performance - from energy use and conservation, to indoor environmental quality, to occupant well-being. In other words, they seek to instil value through design – an important concept for the future of housing through sustainable design.

Energy efficient non-profit organisations in the USA provide a helpful guideline of appropriate materials, usually in respect to their own backyard. EPSEA (1999) provide guidelines for their area as do the EECA (2000); NCSC (2000); NMSEA (1999); Fung, *et al* (1996); Christensen (1994) as with many others.

European, and in particular the UK, governing bodies for construction give only limited guidelines (usually without regional variations) on the appropriate specification of materials for environmentally friendly or energy efficient homes. King (1995) and Marsh, *et al*, (2000) offer guidelines and practical advice as well as introducing terminology in the European context and particularly in regards to northern European climates. Deveci, et al, (2000), Borer & Harris, (1998), BRECSU (1997 & 1995) and Yannas ([1] & [2], 1994) offer practical demonstrations offer case studies in the UK and the North East of Scotland.

Building siting, orientation and over-shadowing

The main objective of **site planning** for passive solar homes is to allow the south side as much un-shaded exposure as possible during the winter months (NMSEA, 1999), something which requires consideration at the earliest possible stage of design (DTI, 2000; FEMP, 2000; EECA, 2000; NCSC, 2000; Shaw & Holt, 1999; Borer & Harris, 1998; Yannas, [1], 1994; Baird & Hayhoe, 1993). The EECA (2000) advise that narrow sites should be avoided, as should sites that slope steeply to the north or south, dependant on hemisphere, small irregularly shaped sites, or sites with obstructions such as buildings and tall trees to the south. Fuchs, *et al*, (2000) add that it is harder to design for the sun on north facing slopes, areas exposed to winter loads, and low areas where cold air settles. In real terms, therefore, ideal passive solar sites are unlikely to occur and part of the aim of this research is to explore many sites listed for development in the North East of Scotland face site related problems.

Building siting and road planning are important aspects, especially if PSD is to work effectively to provide year round savings, but this area is not thoroughly researched by applying them to realistic site scenarios, (Shaw & Holt, 1999; NMSEA, 1999). Littlefair, *et al*, (2000); Marsh, *et al*, (2000); BRESCU, (1997); BRESCU, (1995); (Yannas, [1], 1994); and, Littlefair (1991) all provide some advice on the appropriate layout in the UK, but only on model or large sites.

In the UK, NEF Renewables (2000) have a set of guidelines, which allows a designer to optimise direct solar gain, and provide an example layout. Fuchs, *et al*, (2000) also provides a checklist for orientation and site planning issues.

Yannas ([1], 1994) provide further advice on passive solar site layouts by stating that trees, plants and other objects that would block the solar radiation on the south side of the building need to be minimised. On the other hand, it is good to provide landscaping on the other sides to provide shelter from the prevailing winds and shade to block from the early morning and late afternoon sunlight.

FEMP (2000) states that the **orientation** and south facing glazing, though key aspects of capturing the warmth of the sun, are not the only strategies that aid a passive solar design. They add that the use of, *"natural light (daylighting), appropriate insulation, high-performance window glazings, optimum building layouts ... [and] thermal mass, such as tiled floors and trombe walls"* are important strategies. FEMP (2000) add that the immediate local climate will effect the combination of each of these strategies. In this case orientation simply means the direction the solar collector faces in plan (south, north, etc); tilt or solar angle is the vertical angle of the sun in relation to a building (Borer & Harris, 1998; EREC, 1994; Yannas, [1], 1994; Littlefair, 1991).

Ensuring that the orientation of glazing is due south is not critical, however. The solar gains from windows facing 25 degrees off due south are only slightly lower than the maximum solar gain possible (Borer & Harris, 1998; BRECSU [1], 1997; BRECSU [2], 1997; BRECSU, 1995; EREC, 1994; BRE, 1991; Littlefair, 1991). Research by the BRE (Cradick & Buckley, (1999); Yannas ([1], 1994 and Littlefair, 1991) also states that a design does not need to face directly south, to benefit from passive solar gains, and offers guidance for passive solar layouts. The further north the site, the closer to due south the orientation requires to be, however. This has a consequence for the geographical form and location of a development, in addition to orientation. In real terms an ideal site, that is a site that complements a passive solar design, is unlikely to occur.

As stated above, BRESCU ([1] 1997 & 1995; Yannas ([1], 1994; Littlefair, 1991) suggest that a building does not need to face directly due south, as twenty-five degrees off due south, either towards the west or the east, does not significantly affect the efficiency of a design. Olson, (2000); FIRST, (2000) and; NCSC (2000) confirm this and add that the benefit of facing due south depends on climate, the warmer the climate the less need there is to face due south. Out-with these boundaries, not only is the performance of the building at risk, but mechanical ventilation and heating needs increase. If south facing is a problem, for whatever reason, south-east is preferable than south-west orientations (NMSEA, 1999).

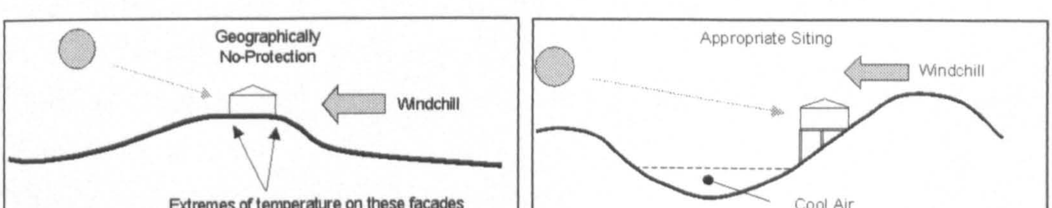
The significance of orientation, however, is highlighted by BRECSU [2] 1997, which states that if a site does not lend itself well to passive solar house design, then a conventional home (meaning in this case a typical home from their standard portfolio) with super-insulation is a better alternative. This highlights the misunderstanding in the UK of what a passive solar design includes. A PSD requires significant amounts of super-insulation to provide both thermal mass and to retain the heat gained. In short, a home with both passive solar design and super-insulation as part of a holistic, optimised passive solar design should save more energy and be economically and environmentally more effective than simply super-insulating a house.

This report also states that the normal privacy distance between dwellings is commonly 21m, but because of the latitude of the winter sun in many parts of Scotland, two-storey dwellings would need to be as much as 40m apart at some latitudes for lower ground windows to gain solar energy year round. In fact, with 21m spacing in Aberdeen (on a flat site with two storey houses with pitched roofs) would provide a ground floor window with only solar access for nine months (6 Feb - 6 Nov) of the year. When the heating is required in winter, there is no solar access, indicating that at latitudes all over Scotland overshadowing is the main nemesis of passive solar design. There may be a case for using the typical Scottish method of housing the second storey within the roof, commonly termed the 'habitable roof'. This would cast less of a shadow than the two-storey dwelling mentioned above and therefore allow a shorter distance between dwellings. Nevertheless, in Aberdeen the privacy distance between dwellings would still be greater than the average privacy distance stated as 21m, thus a passive solar building development will require a larger site area than a conventional mass housing development. The research looked further into this in an attempt to overcome and quantify the extent of this problem in the North East of Scotland (in chapter six).

As stated previously, and emphasised by Olson (2000), to take advantage of the heat and light provided by the sun, a building should have its orientation, with a large portion of its windows, towards the south. This is particularly relevant to cold climates. This means that a home should have an elongated shape (not square, but rectangular), with its longest dimension on an east-west axis. This scenario means that there are restrictions on building footprints, which coupled with overshadowing problems in the North East of Scotland reduces the density of a site, at a time when the Government is calling for higher densities. NMSEA (1999) adds as a practical matter, if the house's short side has good southern exposure it will usually accommodate sufficient glazing for an effective passive solar system, provided that the heat can be transferred to the northern zones of the house. This situation, however, requires active measures to transfer the heat, making it more costly and less passive. BRESCU [2] (1997) highlights three problems of over-shadowing, which should be eliminated at the design stage, these are; self shading; high pitched roofs and; garages on the south side.

FIRST (2000) also state that some obstruction to the south may be permitted, as long as this avoids blocking more than twenty percent of total solar gains. NMSEA (1999) states that where possible, the house should be positioned on the site to take advantage of prevailing winds (in summer), and this source gives guidelines for free vent area. NMSEA adds that ceiling fans will often save more energy than any other mechanical ventilation plant.

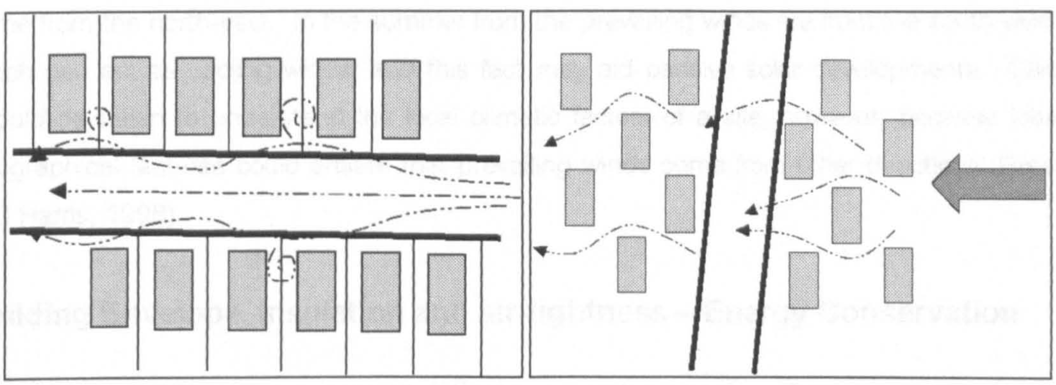
Environmental site layouts rely on the ratio between heat loss and heat gain. Scottish homes[9] have historically been sited to avoid the winter storms. They are of restricted height and buildings are contour hugging with no sharp ends at the eaves, gable and ridges (Dualchas, 2002). In these homes heating was from the sun, body heat and a centrally placed fireplace. Large scale modern development of these principles would result in low density housing layouts, however, but the principles should remain the same.



Figures 3.4.5.1 and 3.4.5.2; sheltered and un-sheltered housing sites (Taylor, 1997)

Passive solar design preferably requires a sheltered site avoiding wind-chill, with good access to solar gain with the option for cool air in summer. Sites open to the wind, sites without shelter or on north facing slopes, will be severely restricted in providing protection from the elements (Yannas, [1], 1994).

The prevailing wind will affect the site layout also - a house without shelter from the prevailing winds will have an additional 10% heating cost compared to a sheltered home (Yannas, [1], 1994). Long linear streets can act like a tunnel if set into the prevailing wind direction, if the site is without a shelter against the prevailing wind. This can result in focused areas of cold spots on a site or make passive ventilation of a home difficult by trapping pollutants inside a house. If shelter from the prevailing winds is not possible, a dispersed housing site may be advisable, where the houses themselves aid to break strong winds between them and the road layout is such that they do not channel the wind (Littlefair, [1], 2000). Rural areas in particular suffer from heat loss through ventilation as much as four times more than urban areas where shelter from adjacent buildings restricts air flow (Ross, 2002).



Figures 3.4.5.3 and 3.4.5.4; The affect of wind on linear street layouts and dispersed street layouts (Behling, 2000; Taylor, 1997; Smith, et al, 1982)

Wind is a particular problem for groups of housing on sites, but can also be a problem for the individual home (see figures 3.4.5.3 and 4, Borer and Harris, 1998). An environmental design promotes good quality building construction, so a home owner is assured an air-tight, draught free home, but a home is not just about the internal environment, the external is important also. Thorough consideration of shape and the effect on prevailing wind should be considered for each individual home, and further research has been done by Smith (2003).

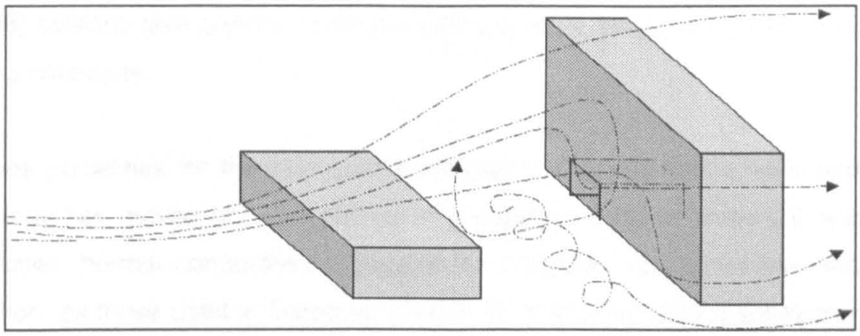


Fig : 3.4.5.5; Typical air flow pattern in mixed use development (Smith, *et al*, 1982)

The Government sees mixed-use development as a key factor in sustainable housing, but this can add to problems for site layouts with regard to wind. Ross (2002) notes that adding higher storeys around low rise buildings does effect the ventilation and heat loss of the upper storeys. Notably in a passive solar development where a mixed-use development is used, the lower-rise buildings are on the southern boundary to reduce over-shadowing with the higher-rise buildings on the northern boundary. In general, the UK coldest winds in winter come from the north-east. In the summer from the prevailing winds are from the south-west, which can act as cooling winds, and this fact may aid passive solar developments. Care should be taken to understand the local climatic factors of a site, however, because local geographical features could ensure that prevailing winds come from other directions (Borer and Harris, 1998).

Building Envelope, insulation and air-tightness – Energy Conservation

When the principles of passive solar design are adhered too, a further complementary component of most passive solar designs should be the appropriate selection and careful construction of a thermally efficient building envelope. This energy conserving envelope is particularly important for environmentally responsible designs seeking to balance the heat load through the reduction of heat loss. Olson (2000) highlights the key features, which require meticulous attention to detail, to produce lower energy bills, a healthier indoor environment, increased comfort and greater building durability. The key features, which Olson recommends are;

- A well-designed, dry and warm foundation system;
- Full coverage, continuous interior vapour/air barrier; carefully installed.
- Thermally efficient U-value (insulation);
- Full coverage exterior weather barrier; energy-efficient and condensation resistant windows and doors;
- Whole house mechanical ventilation system;
- Safe and efficient heating and cooling systems and;
- Efficient and safe appliances and lighting.

Borer & Harris (1998) similarly give general recommendations, for a variety of house types, on energy conserving envelopes.

Balcomb (1992) gives guidelines for the appropriate insulation levels for floors, walls and ceilings, but technology has moved on, with natural and organic insulation materials and systems providing lower thermal conductivity compared to inorganic, non-renewable and fossil organic insulation, as those used in Balcomb (1992). Fuchs, *et al*, (2000) states that insulation can be seen as a jacket around the building envelope, which slows down the heat loss in winter, and keeps the house cool in summer - a key component of low-energy design.

FIRST (2000) and NMSEA (1999) state that air tight construction is an important feature of PSD (Olson terms this feature a vapour/air barrier), as a prevention against heat loss, though this is only ensured during construction by rigorous site inspections and adherence to good building practice. A conventional home, for example, typically leaks a whole house volume of air, if not more, within an hour (FIRST, 2000).

NMSEA (1999) further adds that the air tightness of a house is measured in the number of air exchanges per hour (ACH). A good, comfortable, energy conserving house will have approximately 0.35 to 0.50 (building regulations recommend a minimum of 0.50 for a conventional home) air exchanges per hour under normal winter conditions. Increasing the tightness of the house beyond 0.35 may improve energy performance, but it may also create problems with indoor air quality, moisture build-up, and inadequately vented fireplaces and furnaces. If the project requires a lower ACH then it is advisable that mechanical means of extraction must be added to the home. Fuchs, *et al*, (2000) and NMSEA (1999) provide an infiltration checklist, displaying the points in a building where further attention is required in order to obtain suitable air exchange rates naturally. Borer & Harris (1998) however advise that it is always good practice to provide mechanical ventilation on or near points of 'pollution', that is in the kitchen, fireplaces, bathroom and/or ridges. There are modern (mechanical) ventilation systems that also provide heat recovery facilities.

As a final note, NMSEA (1999) adds that, because of the increased thermal performance of passive solar homes, care is required when designing a heating system. Over-sizing of a back-up heating system will result in increased capital investment, with increased temperature fluctuations, increased costs in fuel and emissions, and a loss in the comfort of a dwelling.

Internal Layout

Externally, a passive solar home requires gables on an east-west axis, with the longest facades facing north-south (FIRST, 2000; Fuchs, *et al*, 2000; NMSEA, 1999; BRECSU [2], 1997). Deveci, et al, (2000), Borer & Harris, (1998) and Yannas ([2], 1994) offer practical demonstrations of this in the UK. FIRST (2000) also recommends a roof pitch of forty-five degrees, so that electric panels or solar hot water panels may be added, and the space this provides can be used as a habitable roof-space.

The internal layout of a passive solar design may be quite different from conventional homes. The main aim of the re-arrangement of the interior layout in a PSD is to allow the circulation, naturally as much as possible, of heat (NMSEA, 1999). The internal layout of a passive solar home requires, some sources claim, an open floor plan, both horizontally and vertically. The heat gained from the sun also requires strategic openings in the ceiling so as to allow the heat to circulate vertically, through natural convection, termed 'thermosiphoning' (Holloway 2000; NMSEA 1999). The open floor plan method is not wholly endorsed by the EECA (2000), the reason stemming from the occupational use of the building rather than for any physical reason, however.

There are a number of design guidelines that may be used in this area, dependant on whether direct or indirect passive solar is used, which should consider occupancy and room layout (NCSC, 2000; NMSEA, 1999). Yannas ([1], 1994) suggests that high use areas such as living areas, kitchen/dining, bedrooms, etc should be located on the south side with low use areas such as storage, hallways, stairs, etc, located on the north side. Contrary to the suggestion by Olson, NCSC (2000) and publications by the BRE, BRECSU [2] (1997) for example, state that the kitchen, as a heating source in itself, should be on the north side. In addition the main entrance should be through a protected space, such as a draught lobby or small hallway, so as not to compromise air-tightness (Deveci, *et al*, 2000; Olson, 2000). NMSEA (1999) further suggest that the clustering of bathrooms, kitchens and laundry will save heat loss from water pipes. This is of course applicable to all buildings, though commonly ignored.

The amount of direct and indirect solar gain required and the consequent thermal mass dictate the design of internal walls. NMSEA (1999) advise, for internal walls, a north-south direction so they may be 'charged' on both sides. Olson (2000) and NMSEA (1999) add that there may be scope to add clerestories to charge the north zones of the house if necessary. Case (1983) in his thesis and Energetic Design (2000) bring together a range of passive solar case studies in order to find the most common internal layout of passive solar designs.

Windows, sizing and shading

In a passive solar design, optimisation of view, daylight and winter thermal gains are the objectives of windows (Shaw & Holt, 1999). In addition, shading is designed to protect against glare and excess solar energy in summer, without restricting winter penetration (Shaw & Holt, 1999; Borer & Harris, 1998)

In a cold climate, Olson (2000) advises that major window areas should be on, in the Northern Hemisphere, the south, south-east and/or south-west of the building, dependant on the internal requirement of each space. Borer & Harris (1998) suggests that facing within 5 degrees of true south is preferable to avoid overheating in summer and gaining the maximum potential from clear winter days.

Glazing provided on the south side should allow solar radiation, but retain the thermal integrity of the building. This may be achieved, suggests Olson (2000) and NCSC (2000), by specifying windows with low U-values and a shading coefficient, typically a window with Low-emisstivity. FIRST (2000) disagrees that south facing glazing should have low-E, though this assumption is based on a different climatic level. Deveci, *et al*, (2000) uses triple glazed, Low-E on a south facing facade of a house in Aberdeenshire.

FIRST (2000) states that the glazing on the remaining sides not facing the sun should be minimised, Olson (2000); Kachadorian (1997) and Yannas ([1], 1994) confirming this and added that these windows should have a low U-value in order to resist heat loss. NMSEA (1999) add that windows on the north side of a building will inevitably lose significant amounts of heat energy, and will be permanently shaded in winter, and thus there size must be small, with lower U-values than the other sides of the house if possible. In addition, NMSEA (1999) states, if east and west glazing is not also minimised, though the heat loss problems are not as acute as with glazing on the north side, the need for mechanical ventilation will increase as there is potential for overheating. NMSEA provides some guidelines for the appropriate selection of windows. This may not be a problem, however, for buildings in northerly climates such as the North East of Scotland.

Borer & Harris (1998) suggest that tilted or pitched glazing will collect more solar radiation per unit of area than vertical wall glazing. The source states that pitched glazing can increase the temperature fluctuations within the building and can be difficult to shade and thus control. NMSEA (1999) further adds that vertical glazing, due to the fact it is less likely to overheat and is less susceptible to damage and leakage, is a better year round solution.

Balcomb's (1992) research also gives advice for maximum size of windows, dependant on the local climate. FIRST (2000) interprets these guidelines by suggesting that a south facing window area greater than fifteen percent of the floor area would provide the heating needs for a passive solar home, though as little as eight percent provides savings over conventional homes. Luce, *et al*, (2000) states that PSD homes should not have glazing that is more than twelve percent of the floor area, however, due to the different climatic models each site uses. Investigation of housing in Scotland shows that a typical conventional home has between 12-15% glass to floor area, which is comparable to a passive solar design such as that described by Deveci, *et al*, (2000). More usually the glazing to floor area ratio is around 20% in passive solar buildings exhibited by Vale (2000); Borer & Harris (1998) and Yannas ([2], 1994).

Providing overhangs over south facing windows is another method for controlling solar radiation. FIRST (2000); Olson (2000) and NCSC (2000) display the mathematical method for the calculation of the proper overhang geometry, for site specific purposes. Fixed overhangs are the preferable option as they require no maintenance by the homeowner and are inexpensive to install - they need to be carefully designed, however (NMSEA, 1999). NMSEA (1999) further adds that a combination of overhangs and shading devices on the other facades can provide an effective solution. The fixed overhang is more common in the UK (Borer and Harris, 1998) however it is notable to add that the West coast and Islands of Scotland (especially in Shetland and Orkney) tend to avoid overhangs completely due to the local climate (Dualchas, 2002). It is best, therefore, in some situations to adhere to the local vernacular.

The choices for shading devices are external, intermediate and internal – these can be the first barrier for moderating solar gain during the summer (Yannas, [1], 1994). External shading allows better control of solar energy entering the building, intermediate shading devices allow some heat to enter the building but can also be semi-intelligent and internal shading requires homeowner knowledge but is, initially, the least expensive option (NMSEA, 1999).

NMSEA (1999) state that "natural cooling" refers to techniques which aid a home to stay cool in the summer but which require little to no energy. Strategies such as shading, thermal mass, high insulation and Low-e windows are critical in providing a shield against un-wanted heat gain in the summer months. Cooling is, of course, more applicable in hotter climates than the UK and in this research the concentration is on passive solar heating rather than passive solar cooling.

In the seventies and eighties, when much of the research on passive solar occurred, PSD homes aesthetically looked different from conventional homes. With much of the glazing restricted to facing south, for the sole purpose of collecting solar energy, the problem for developers was whether they could sell these homes, which looked radically different compared to conventional aesthetics. A developer in the US[10], which specialised in providing solar homes, states that with the onset of inexpensive insulation and new window technologies, it is possible to create designs that do not look '*solar*'. For a self proclaimed passive solar developer to claim that they have successfully built solar homes which do not look solar (presumably because they have had feedback from previous home-buyers) seems contradictive. They add, however, that without the need for solar glazing facing directly south, designs that are driven by client needs and preferences, rather than ecological or sustainable needs, are achievable. NMSEA (1999) add that homeowners want windows for reasons other than energy gain, so a good, but modern, design will incorporate the **wants** of the client together with the **needs** of the environment.

Thermal Mass

Another key component of passive solar design is the need for thermal mass (NMSEA, 1999; Kachadorian, 1997, King, 1995, Yannas, [1], 1994), which will store the solar energy gained from south facing windows, also covered by Balcomb, (1992). Fuchs, *et al*, (2000), state that buildings without thermal mass only rely on the sun for the heating of a home. As air is an inefficient heat store, when direct sunlight is restricted, such as at night or cloudy days, air-cools down rapidly, requiring a back-up heating system, resulting in a poor level of comfort. Thermal mass stores heat from the sun for longer, releasing it when the sun is restricted.

The aesthetic problems associated with PSD homes concerning their windows, are not a problem with thermal mass. Thermal mass requires having some unrestricted area in tandem with the south facing glazing, however. As NCSC (2000) explains this is not always possible because of the desire of clients for furniture and floor coverings. NCSC (2000) add that carpets, wallpaper and furniture can reduce the effect of thermal mass, and it is wise to plan in advance to match the system to room use. In direct gain systems, performance is insensitive to the locations of the storage mass in the room, however, though comfort is increased if the thermal mass is spread evenly in the room. Vertical mass storage areas, out-with the direct sunlight, can store the excess heat provided on the hottest days, thus reducing temperature swings (Luce, *et al*, 2000; Kachadorian, 1997; Yannas, [1], 1994). Generally, thermal mass is complementarily part of the structure of a building and also can provide fire protection, working with the building as an integrated whole (NMSEA, 1999).

As with almost everything in a PSD planning, there is a critical point in the use of thermal mass, a balance between too much and too little. As NMSEA (1999) states, from a solely energy viewpoint it would be difficult not to add too much thermal mass in a building as in warm climates it may provide cooling during the day and in cold climates can maintain heat during the night. There are physical costs in adding thermal mass in a building however, therefore adding too much thermal mass will be unnecessarily expensive and have a detrimental environmental impact (Marsh, *et al*, 2000). Luce, *et al*, (2000) suggests that thermal mass (in terms of surface area) should be approximately six times the area of glazing, with depth of the thermal mass around 100mm or greater. Yannas, ([1] 1994); and, Balcomb, (1992) provide more accurate calculations for site specific purposes.

Olson (2000) states that thermal mass is required in cold (northern) climates to release stored heat during the night and on cloudy days. The thermal mass may use either water or masonry as thermal storage. The thermal storage capabilities of a given material depend on the material's thermal conductivity, specific heat and density (Smith, *et al*, 1982).

3.5 IMPACT, VALUE & COSTS OF PASSIVE SOLAR DESIGN

"The applicability of PSD and the scale of energy savings achieved through it depend on the building type. If incorporated at the design stage, the space heating requirement of individual houses can be reduced by around 1000kWh/year through the adoption of simple PSD measures."

Source: DTI (2000)

There are many cost and value aspects to a PSD that are different in comparison to current methods of construction. Green design may cost more initially, in most cases, but this section aims to highlight the fact that, long term, PSD can offer greater value over current methods of construction and can be applicable to the affordable housing market and not just 'showcase' developments.

The main aim of passive solar heating is to reduce the demand on the heating in an average home. The main benefit of this will be the reduction of both heating, often significantly, and lighting costs in a good design since windows facing South will ensure that the main living spaces are 'lighter' during more of the day than a conventional 'standard' home. Holloway (2000) boldly states that a small initial investment of as little as ten percent additional capital costs can reap a heating bill reduction of seventy-five percent compared to a conventionally built home of the same square size. Notably, however, Deveci, *et al*, (2000) achieves significant long term reduction in energy costs of around 70% in the UK without any additional capital expenditure. This achieved by eliminating the need for a dedicated heating system and using an affordable construction technique. Deveci, *et al*, (2000); FIRST (2000); Borer & Harris (1998); Yannas ([1] & [2], 1994) in general, however, confirm that the payback time is between 8-20 years, given a balanced design.

There remains, of course, a critical point where initial investment becomes excessive and the payback time is such that the building, if only the physical monetary costs were to be taken into account, becomes unfeasible (Luce, *et al*, 2000). FEMP (2000) states, however, that an increase of only two to four percent over conventional homes is commonly regarded as acceptable economic outlay for a sustainable, low energy design. Research funded by the US government upon the marketability of solar water heaters, however, suggests that homeowners would not invest in such technology without at least a fifty percent reduction in capital costs, suggesting that clients may still be unwilling to pay more initially, to get more long term.

FEMP (2000) states that in evaluating potential design strategies, it is important to think in terms of life-cycle costs. Luce, *et al*, (2000) highlights three areas of investment that need to be balanced to achieve the smallest overall life-cycle cost. The first two areas cover the initial investment, with the third point covering the life cycle payback;

1. **The cost of conservation** - insulation, high quality windows, etc
2. **The cost of solar** - extra window area on the south side, extra masonry inside (for thermal mass), etc
3. **The cost of heating and cooling over the long term**

Although there may be a critical point where, monetarily, a passive solar design is undesirable, Lece, *et al*, (2000) states that it is actually better to over-invest initially, because some over-investment provides a number of non-monetary benefits that are no less important than physical costs, and are, possibly, critical to a sustainable home or development. This may be the case for a private home owner who is willing to pay extra, but for the mass housing industry the economic cost of a home is intrinsically important. Increased investment could benefit a home by providing, "*better insurance against sharp increases in heating and cooling costs, lower environmental impacts* [and] *improved comfort and improved ability to function during power cuts*" (Lece, *et al* , 2000). For the mass housing market and the housing developer who will not benefit directly from greater initial investment, this scenario is unlikely to occur affordably.

Inevitably the question is asked, how much extra will green design cost? Currently, environmentally designed housing has tended to be one-off, showcase projects that illustrate possibilities, but these are too expensive and 'different' to be fully adopted by into the mass housing market (Horrigan, 1997). There are many reasons why green design is not specified for mass housing. Bordass (2000), for example, explains that there is conflict between, "cost and value" of green design, which has resulted in many in the construction industry perceiving green design as being a riskier venture.

So why are green buildings not being built? Bordass (2000) offers some explanations. Developers believe that an energy efficient scheme will cost more and is more complex. Bordass also indicates that developers feel that if the environmental design looks different then there will be problems with its retail. Bordass notes that designers will not encourage their clients to adopt energy efficient designs as they assume that it will take longer (for themselves) to design without extra payment. The owners or buyers claim that they do not feel the need for energy efficient homes as they are sceptical as to whether they work and they do not add value to the property.

Almost all decision making during the planning of a development, however, is through the housing developer - the homebuyer is not involved in this stage. Housing developers' business driven objectives of value are significantly different from the value objectives of the homebuyer, despite claims by industry of customer satisfaction. Arguably, two points can summarise a consumer's viewpoint when buying a home. Firstly, customer satisfaction is a misleading concept, as there are no comparison between alternatives, which is to say 'satisfied as compared to what?' Secondly, homebuyers are not aware or have not been educated to understand the importance of alternatives in the home building industry.

Most homebuyers do not know, however, how to build a house, let alone the significance of planning a housing development to incorporate environmental housing strategies. In fact, most homebuyers' only knowledge of what to look for in a home when aiming to buy a home, is to rely on experience, word of mouth and/or depend on the estate agent/surveyor, which is not always practicable or accurate.

Most notably, environmental designs are distinctively different from current forms of construction and there are not many green buildings that have been built and widely studied. Their uniqueness is a resistance to their use in mass housing as they challenge the norm (Brinkley, 2001; Horowitz and Johnston, 2000; Bordass 2000). In addition, the housing market since it is driven by fashions and styles more than concern for the environment, and this is difficult to overcome (Brinkley, 2001; Smith, [1], 2001; Bordass, 2000). Though for industry sustainability has become a buzzword, in modern practice, for a homebuyer, it is difficult to choose between even the simplest elements of an energy conserving building. For example, the choice of kitchen floor finish over an energy efficient fridge is symptomatic of the preference of aesthetics over function (Smith, [1], 2001). Modern living promotes short-term gain rather than long term, and this is expressed by the ever increasing value of 'optional extras' in housing. These are seen as adding value to the property more so than many green features that are integral to the design of the building (as opposed to add-on features like PV and solar panels).

As stated previously, the housing developer is more interested in the return on investment, the practicalities of greener design are ignored in favour of cost minimisation, past experiences and the need for a fast track construction sequence, leaving little time during the feasibility of a project for green features to be incorporated (Bordass, 2000). To overcome resistance Bordass (2000) states that certifying green buildings with a BREEAM certificate may ensure that the value of a green design is comparable to current methods of construction, but it may decrease the resale value of some projects. In Austin, Texas (USA), however, the first certification scheme is in place that can differentiate and standardise green design (Horrigan, 1997), a concept that may be welcome according to some US homebuyers (Roberts, 2001; Horowitz and Johnston, 2000). Monahan (1999) notes that British consumers also want their homes rated on a, "green scale" noting that there is a vast difference between a toilet with grey water recycling and a home encompassing green design principles. In short, Monahan is suggesting that there is a need for the layperson such as the homebuyer to know simply and effectively how environmentally friendly a home is. Bordass (2000) adds, however, that it is still location, appearance and specification that will add value to homes, while at the same time limiting the building types. There is a conflict here. If a home is in an excellent location (however that excellent location may be defined) but has a poor environmental 'rating', what is dominant? Is it the location or is it be environmental friendliness.

Bordass suggests the latter and to make progress towards adopting environmentally friendly homes we need (Bordass, 2000):

- A changed mindset: Greeness will only improve rapidly when it becomes a major priority in procurement, investment and building management
- A focus on ends rather than means, with better means of keeping projects on course, e.g. with design brief management for the client, and independent 'reality checks' at critical stages
- An understanding that we need to look at process and players, and not just product
- Seeking to put more in the 'fit and forget' box, while making sure that the remaining problems are 'owned' by the players most capable of dealing them [refers to figure in paper]

- Greater visibility of intentions and outcomes: supported by better information, benchmarking and feedback; and expressed in ways that all can understand
- A marketing approach which can smooth the transition to greener buildings and reassure agents, investors and occupiers that both short and long-term risks are being effectively managed
- Mechanisms which can deliver virtuous circles of continuous improvement

A method that encourages building consumers to have an environmentally friendly design, and encourages housing developers to build them, is yet to be fully realised, however. Government grants are available through the Energy Saving Trust,[11] which encourages environmental features such as photovoltaics, but the grant scheme fails to encourage changes to development methods or design principles.

Manufacturers and housing developers, it is claimed, are becoming more aware of customers dissatisfaction in their housing, however (Smith, [2], 2001) and Smit, 2001). Smith highlights the fact that housing developers are becoming more aware that by adding quality to the home as a product, it will create a better return on investment. This is, of course, a reflection of the state of the housing market at the moment. Homes are becoming, therefore, unaffordable for those on a tighter budget than ever before. There are grants available to aid the provision of affordable homes, especially for first time buyers and rural ownership (for example through Communities Scotland[12]) and Timms (2000) adds that the Government, through DEFRA, intends to expand its support for energy efficiency through the Home Energy Efficiency Scheme (HEES), now renamed as The Warm Front Team. This scheme intends to aid the, "fuel poor". Housing developers, however, are turning to other methods to increase the value of their homes.

Horowitz and Johnston (2000) and Roberts (2001) discuss the cost and value consequences from a survey of American residents and builders, and have come to a number of conclusions. The main conclusion from these surveys of builders and homebuyers in the US illustrate a general willingness to pay extra for green features that protect and enhance the environment of a project. Horrigan (1997), however, emphasises the need for affordability as well as sustainability, and offers examples where these two have been combined. Horrigan notes that a 'moderate' green design which can include, "extremely energy-efficient windows and such features as a ground-source heat pump, a solar hot water system and radiant floors" will cost 10-15% above the normal price for a typical US home (though these homes will save over 50% on operational costs every year). This, Horrigan adds, is not affordable to the average homebuyer. But with conscientious planning by architects and developers, energy conserving homes can be built for low-income homebuyers – but these enterprises (whose building developer and architect may need to be willing to sacrifice profits) are a rarity in the US and the UK mass housing market (Horrigan, 1997).

Horrigan (1997) notes that most homes are built on a 'tight budget'. This also means for the vast majority of the mass housing market most green features are simply too expensive. Horrigan suggests more compact green homes but this is not replicable throughout the UK. It is this issue of affordability that has architects and housing developers worried, neither are interested in providing affordable homes without incentives (Pout, [2], 2000). Horrigan (1997) offers examples of how these problems can be overcome, including the simple technique of building smaller through standardisation using cellular building systems – and increase in size as and when you need to.

One of the key principles of each and every affordable design would be the need for inexpensive forms of energy, something which passive solar design adequately provides. Passive solar offers this from the sun. Monahan (1999) notes that the first and key priority of green design is positioning and orientation on site especially in temperate or cold climates, with passive solar accounting for over 50% of the heating cost. Monahan (1999) and Allinger (1996) note that passive solar coupled with efficient technology provides for significant lower operational cost that will quickly offset any capital expenditure.

3.6 IMPACT OF MODERN TECHNOLOGICAL ADVANCES

In the past two centuries, building professions and the methods of construction of changed dramatically. One of the main causes of the changes in architecture in recent history is the increased choice of building materials for structure and building envelope. The increased variety in the choice of building materials gives an architect a diverse choice of styles and this has restricted environmental development and innovation. The increased choice for the designer can also, however, aid the introduction of environmentally friendly principles. This section aims to highlight both these aspects and illustrate the benefits of new technologies for developments that incorporate PSD.

Innovation in building materials and systems has changed many aspects of construction including aesthetics, structure and methods of construction. It is interesting to note that environmental features which use high-tech, modern approaches, such as photovoltaics and wind farms, are popular and incentives by the UK government for their adoption are provided. Yet more basic concepts, such as solar design, are not as popular without any incentives for their adoption. It is solar design, however, which is the more affordable.

The gap between minimum building regulation standards and the energy conserving home are closing and are likely to get closer in oncoming years in regards to the heating of a home. In recent years the thermal efficiency standards have increased, restricting heat loss. There may become a stage in the near future where the thermal standards in regulations meet or even exceed the standards currently set for environmental design. Already minimum standards are at a level which, fifteen to twenty years ago, was considered cutting edge. There is an argument therefore that the techniques of passive solar design could quickly become superseded by building standards using modern materials and this raises the question: Why use a design principle which may become obsolete in the near future?

The energy supply from the sun is direct and costs nothing, to the environment, builder or the homeowner; it is also a renewable source of energy. Other renewable energy technologies are available, and more will be available in the future, that can achieve the levels of benefits available from passive solar. Their affordability compared to passive solar designs is key, however. Rosenberg (1994) covers the types of renewable energy on the market, in addition to The Office of Energy Efficiency and Renewable Energy, US Department of Energy[13]; the DTI Sustainable Energy Programmes[14] and; The European Commission[15].

What this means is that, if new standards are adopted with new technologies, housing layouts need not change. This scenario has many advantages over passive solar design. Adopting a passive solar design requires changes to the early development phases of a construction project to adopt the main benefits, unpopular with the planners of developments.

The government also aims to make the process of connecting renewable schemes (electricity from wind farms) to the national grid simpler, which should broaden the market for renewable technology and make PV, for example, more economically viable state DEFRA (2000) and DTI (2000). There are also grants available from the government for these types of environmental technology.

Super-insulation and increased air-tightness of buildings can achieve the same financial benefits as PSD. Insulation is a key method to reduce the need for non-renewable fuel and this method does not require the re-orientation of a home. Insulation is an important aspect of PSD, it retains the heat gained from the sun within the house, and is capable of storing it overnight through thermal mass, though this is not the most efficient form of thermal mass. But if enough insulation is specified in the building envelope then it is theoretically possible that no heating contribution is required at all (Deveci, *et al*, 2000; Jones, 2000).

If a home is super-insulated to the extent where indoor air quality becomes a problem, appropriate whole house ventilation is required to provide a healthy home and this is an additional indirect cost. In addition, air-tight homes will require special attention to the specification of interior materials and the use of toxic paints, fibre boards, glue, gypsum and plywood, for example, should be avoided. (Borer and Harris, 1998)

Pout (2001) highlights the fact that 45% of heat loss from buildings is through walls and increasing the insulation, "provides householders with warmer and more comfortable homes and fuel savings, as well as helping to reduce overall UK energy use and greenhouse gas emissions." Pout (2001) adds that insulating all buildings to the appropriate standards, "the cumulative national savings would amount to 49.4 million tonnes of carbon dioxide per year. In addition, sulphur dioxide emissions would be reduced by 58,000 tonnes, and financial savings of £1.8-2.5 billion would be made." This is a moderate figure and can be more than trebled if the passive solar specification in Deveci, *et al*, (2000) is adopted. Jones (2000) adds that with the more efficient heat pumps and more efficient electrical appliances, the annual consumption of households are set to reduce. Jones (2000) also adds that homes with these new technologies to reduce household consumption can still benefit by maximising passive solar heat gains, highlighting an additional 40% saving through the use of passive solar.

Glazing is another component of passive solar design that is undergoing technological innovation, which may see PSD becoming obsolete. Inappropriate glazing can account for a large proportion of a building's heat loss, emphasising the need for glazing design to be as energy efficient as possible (Motavalli, 2000). The recent building regulation changes in 2001 (2002 in Scotland) aimed to overcome glazing air-tightness problems by lowering the u-values of glazing units. Innovations to glazing could also aid passive solar designs with coatings for glazing that could provide vast improvement in the control of heat gains and the overall u-value of glazed components. What could be perceived as small innovations, however, such as coatings on buildings and glazing for example can have huge impacts in energy saving terms. Ma, et al, (2001) describe an intelligent building coating that reacts to the glare of the sun, responding to solar exposure.

Part L of the regulations has changed, the following lists how it will affect windows (Pearson, 2001);

- Double glazed units will have to be better insulated. The width of the air gap between the panes will be increased to trap more air. Wider glazing units with a cavity width of 16mm will be the norm.

- For gas-filled glazing, the type of gas in the cavity between the panels has an impact on a windows thermal performance. The cheapest way of filling the gap is with air; other gases such as argon are better insulators; but more expensive.
- Coated glass will be fitted as standard. Low-e glass is treated on one surface with a coating that helps trap heat in a room.
- Frames will be thicker to accommodate the increased air gap in the glazing units and to allow for insulation improvements in the frame. Aluminium units will be most affected, as the width of the plastic isolator between the inner and outer framing profiles will have to be increased. Older style aluminium frames with a resin thermal bridge will no longer be used.
- The style of windows may change: single large glazing units will become more common to keep frame areas to a minimum. If a number of smaller units are used, frame areas are larger.

The cost of glazing has reduced because of changes to building thermal requirements, and currently triple glazing is only 15% (based on housing tenders in 2000) more expensive than double-glazing and single glazing is now obsolete. There are also alternatives to glazing, fabric membranes are being popularly used in the millennium project 'The Dome' (PTFE) and The Eden Project (ETFE). Further changes to glazing are coming through 'smart' windows, as Motavalli (2000) states "that can adapt their light filtering properties in reaction to frequently changing ambient temperature. A second "active" type now under development uses a small electric current to alter its transmission of light." Still, the simplest way to make sure that the window is efficient is to ensure that there is no significant heat loss through the glazing and the frame of the unit.

The changes in technology in regards to insulation and glazing (the examples given here) can achieve the benefits of PSD without requiring changes to layout. They can also aid PSD. Passive solar design, as stated previously, is a holistic method of environmental design including many different environmental disciplines. Insulation and glazing are important components and the new technological advantages can provide a much better internal environment if adopted as part of a PSD. Better insulation and the better insulation qualities of glazing allows for greater heat retention in a PSD home, important in winter. In addition, the same benefits ensure that in summer the building envelope excludes much of the heat gain. This provides a quality and control of the internal environment previously unobtainable.

Edwards (2000) states that quality of design reflects on quality of life, and Long (2001) notes that quality of design is now becoming a 'money spinner' and architects are beginning to look at more sustainable types of housing. This means that passive solar, which as a holistic and flexible design, may yet again see a re-emergence during this century using innovative materials. Passive solar, as previous sections have noted, also has additional advantages over any other method of construction, innovative or current, in that it provides more comfortable internal environments.

What this section has highlighted is that new material technologies that have and are being developed may make PSD obsolete. Technological innovations in construction and Government targets are reaching the point where most modern houses are almost comparable to the energy performance of an earlier generation of passive solar home. There are advantages to passive solar, however, that can never be duplicated, such as quality of space and health. O'Sullivan (2003) highlights, for example, that the vast majority of people "enjoy" solar access into their homes, adding that improves the quality of living in these homes. PSD is the only environmental principle that adopts benefits other than monetary over an entire life cycle, providing a sustainable home economically, socially and environmentally.

3.7 ANALYSIS & DESIGN TOOLS

The aim of this study is to create a framework for a tool to determine the benefits of passive solar over conventional homes in a housing developer (the tool to be developed through future research). The aim is to establish the necessary trade-offs required in order for the passive solar home to meet set density targets so that the objectives of the housing developer are met while creating a home beneficial to the home owner and the environment. There are, however, tools currently available which can calculate various aspects of a project, a home, or an element, though there are no formal tools that can be used to calculate the effect of groups of houses.

Despite there being no formal tool, Russell (2001) explains how developers are uniquely placed to understand their consumers, in that they know the address of previous and current customers. In addition, they should know the attributes of their housing stock and this relates to area. This, therefore, should make the development of a tool more straightforward, but housing developers do not readily collect this information.

Crawford (1995) offers sun chart software that maps out the sun's position as a function of day and time, thus allowing the solar designer to engineer optimum solar collector design. Kahl Consultants[16] provide IPSE and SolArch - a design tool for architects, which is intended for professionals who are familiar with passive solar energy. Energy-10[17] and SolaCalc are other design tools, which utilise climatic data, in the case of Energy-10, and utilise life cycle cost modelling in the case of SolaCalc[18]. NES ltd[19] provides software that calculates energy demand and costs for the UK market, and can provide information on a number of energy related topics. The UK is dependent on a number of BRE developed software packages which determine costs of individual homes (SAP) and the environmental impact and WLC of large projects (ENVEST[20]). The SAP packages are developed by a number of software developers creating software such as JPA Designer[21], it is SAP calculation method developed by the BRE and utilised as part of JPA designer that this research has used. There is not a software package, however, that can look holistically at the environmental effects of whole projects and this research will look to develop this idea.

In Scotland, Stevenson and Williams (2000) have developed simple software tool to comparatively analyse how sustainable a development is. This is a tool developed through a Communities Scotland, a Scottish Executive agency, initiative. The Housing Quality Assessment Programme using design data for this calculation and attempts to simplify the many concepts of sustainability into easily definable aspects of a development. It is this sort of product that could aid planning development officers in establishing what constitutes a sustainable development and, more importantly, how it compares with other developments.

3.8 PASSIVE SOLAR DESIGN: A STEP TOWARDS SUSTAINABILITY

3.8.1 INTRODUCING SUSTAINABLE DESIGN

Passive solar design has key advantages over conventional construction, as highlighted in the previous section. The main advantage to PSD is the ability to use free energy from the sun so as to benefit from environmentally friendly methods for heating and cooling. PSD will also benefit from the additional daylight, which anecdotal evidence suggests is a major component for creating a healthy home. With the additional benefits PSD has over current methods of construction, it could be argued that PSD could provide a more sustainable housing environment, if built affordably.

Behling (2000) offers a number of historical criteria that require solving before a settlement can be considered sustainable, the key criteria being the potential for continued access to food and water through appropriate siting. When these are met, the potential for commerce and security need to be addressed. The fulfilment of the basic needs is what dictates the sustainability of towns and cities. Passive solar design was integral to the sustainability of early settlements, and it this ethos that should be followed in order to achieve sustainable housing design.

Edwards (2000) states that, "*no society is balanced in harmony with nature unless housing is sustainable*". "*The housing market is stagnant*", claim Meikle & Connaughton (1994) and it would seem, from these two statements, that current methods of housing are not sustainable. Smit (2001) notes that, "*a lot of design in house building is done by marketing people. They look at what their competitors are doing and bring designers in too late.*" Edwards (2000) adds that the quality of housing is comparable to the quality of life, that is to say there is a link between quality housing and social behaviour ('happiness'), a view mirrored by Behling (2000). In order, therefore, to create sustainable housing it would seem that good quality design is a fundamental principle and a change is needed in the current method of planning developments.

How is sustainable housing achieved? The following figure illustrates eight elements needed in order to create sustainable housing. The nature and inter-relationships of these eight elements highlight how difficult a task it is to build sustainable housing.

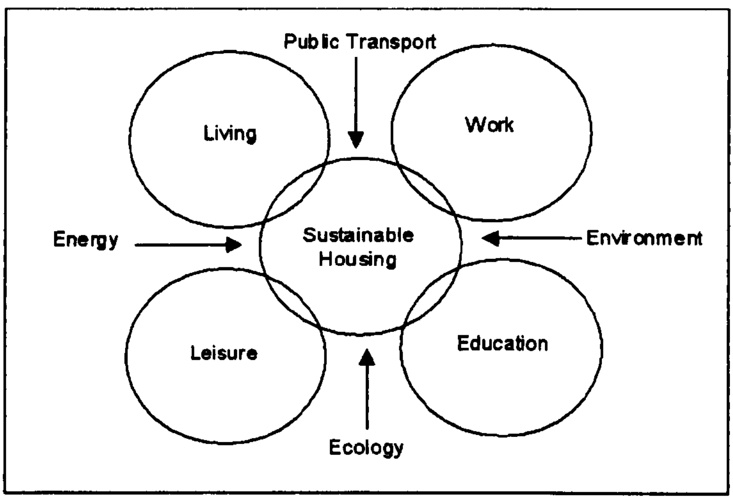


Fig : 3.8.1.1 the arrangement of the complex issues surrounding sustainable housing; ***Edwards (2000)***

Why does housing need to be more sustainable? Behling (2000) and Edwards (200) both state that the relationship between housing and occupant health, and the importance of space and internal environment, is the main result of more sustainable housing. On a wider scale, the effect of housing on the environment globally through emissions alone dictates that more should be done to achieve sustainable housing. The Government publications, "*Quality of Life Counts*" (DETR, 2000) and, "*A Better Quality of Life: a Strategy for Sustainable Development in the United Kingdom*" (DETR, 1999) aim to provide high quality existing and new housing, though little from these initiatives will be enforced. Without a progress towards more sustainable housing, there will be, "little genuine social progress" claims Edwards (2000). The provision of sustainable housing will also aid in combating a reduction of harmful gases in the atmosphere.

In the past century, the provision of socially responsible housing has been hit and miss (Edwards & Turrent, 2000) and these lessons need to be understood for housing to move forward in the next century. As Edwards (2000) states, "sustainable housing requires team effort and the ethos of partnership". Communication between parties planning a project is important but equally important is being aware of the needs of the homeowners and knowing the errors of past housing developments, if sustainable housing is to be achieved.

The privatisation of the housing market does not aid sustainable housing as there is no longer a client providing affordable homes. This does not mean the obligation to provide sustainable homes has been ignored, there are some examples of innovative housing, which take a step toward a more sustainable built environment but these are few. Edwards (2000) puts forward 'local accountability' as the first tool in creating more sustainable housing, emphasising a, "community first approach rather than a markets first approach" to development. This simply means that social objectives in housing, rather than housing market issues, through quality in design and planning should influence developments. Edwards adds that this approach should encompass all aspects of a development - design, construction method and layout, a view echoed by Phillipson ([2], 2002) who highlights the Scottish Executives desire for a long-term approach to the use of resources.

Sustainable housing has a myriad of complex issues and is far reaching as discussed in chapter one and by Edwards & Pawley (2000), Serchuk (2000) and Dunster & Williams (2000). What should be highlighted here is that the construction industry is unlike any other industry, having so much more social and economic influences making the application of principles of sustainability far more difficult. Construction, however, can become ***more*** sustainable than it currently is, and the construction industry should be striving towards providing more sustainable methods throughout the construction process.

For sustainable housing the issue of brown-field or green-field is also a problem. Edwards (2000) favours the brown-field sites in urban areas, which have suffered at the hands of green belt expansion in recent decades. Suffering from traffic, polluted air and water problems it is clear a sustainable strategy for urban brown-field sites is needed but the inherent advantages of location means that potential of 'urban villages' and their marketability is high. The use of brown-field sites is an important component of sustainable housing in urban areas, as urban renewal forms much more of our housing stock than new housing (Edwards, 2000). In urban areas, therefore, brown-field development is seen as more green (environmentally friendly) than green-field development. To highlight the problem, Allen and Hinks (1996) state at the time that some 639,000 vacant properties (public and private) in the UK and the majority will be in city centre areas. Allen and Hinks surmise that a sustainable strategy for the utilization of existing resources is required rather than the policy of replacing the existing housing stock. In addition, Allen and Hinks point out that a significant majority of the vacant properties are from the private sector, therefore a sustainable method of maintenance similar to the public sector is required, the lack of maintenance in the private sector simply exacerbating the problem. Edwards (2000) notes that so much poor quality housing has been built, or housing has been neglected to the point of dereliction, that any sustainable housing strategy must equally encompass this along with new housing.

In terms of this research, however, only new housing, either on green- or brown-field sites, is to be investigated, the retrofitting of passive solar design on existing housing stock being a separate, but no less critical, research area. Careful consideration, in dense, urban areas in particular, of the applicability of passive solar in brown-field sites is needed. Passive solar design is difficult to adopt in such areas, over-shadowing being the main obstacle, and this is where further development of the tool used in this thesis may be required.

Edwards (2000) notes that case studies are excellent ways to bring attention to sustainable housing, but there are a number of ways in which this fails. Demonstration projects, which encompass sustainable principles, are often site specific, rely on the local environment and transportation links, therefore where one project is a success in one location, it may not be in another location. The idea that a house is a product and re-sale value is a key component of this, is very strong.

A key problem for the adoption of sustainability, and for environmentally friendly issues as a whole, is the misperception of the value that these issues can provide. Transport issues, for example, have created tensions between government and public, which need addressing so that the same tension does not occur with housing. Levitt (2000), for example, suggests that the current trend to provide less area for cars than is needed in order to encourage the use of public transport is "*deeply patronising*", adding that the aspiration to own a car is unlikely to diminish soon. Dorrell ([3], 2002) notes that professional practices are sceptical, suspicious or unaware of sustainability issues perhaps believing that the term is a political or media buzzword. Bordass (2000) states that the perception is similar with homebuyers most of whom believe that sustainable (environmentally friendly) design is '*special*', and are sceptical as to whether the issue will last or has any tangible benefit to them. In addition, media coverage is not always favourable towards sustainability as exhibited by MORI surveys in 1999 and 2001 conducted for the brick industry.

There is, therefore, a need to make clear and concise, the benefits of sustainable housing design in layman terms. An environmental site assessment can reduce the misperception surrounding sustainable housing, giving a designer/planner an idea how their design will affect the site; what the full potential of the site can be; and, what the ideal density is.

3.8.2 DEFINING WHAT IS SUSTAINABLE HOUSING

The Government broadly defines sustainable development under three key headings; Environmental; Social; and Economic. The most widely used definition, and a suitable foundation for any definition of sustainable development is the 'Brundtland' definition (cited in Cullingworth and Nadin, 2002), which refers to 'development that meets the needs of the present without compromising the ability of future generations to meet their own needs'.

The sustainability appraisal of the Aberdeen and Aberdeenshire Structure plan 2001-2016 (CAG, 2000) states that, 'Sustainable development is about *meeting the needs of current generations without putting at risk the ability of future generations to meet their needs*'. These aims are probably unlikely to be realised in a construction industry that currently uses mass amounts of unsustainable materials. Lime mortar, concrete aggregate, hardwood timber, metals manufacturing, glass manufacturing, clay bricks and tiles are all from non-renewable resources or use industrialised processes with high emissions during manufacture.

Edwards (2000) points this out, and offers a definition for sustainable housing thus, "housing that meets the perceived and real needs of the present in a resource efficient fashion whilst providing attractive, safe and ecologically rich neighbourhoods" and you could add, 'for present and future generations'. A key component of this definition, which is directly applicable to the construction industry, is the need for a resource efficient construction industry. Though, as Edwards (2000) points out, construction will never be 'zero impact', it should have methods and processes to limit the use of non-renewable resources. Sustainable housing therefore should look to encourage this aspect of construction, and reduce construction waste on-site through appropriate planning to be more sustainable.

Edwards surmises that for housing there are five distinct fields that sustainability must address, these are (in order of targets to be achieved);

- the conservation of natural resources (land, energy, water)
- the sensible re-use of man made resources
- maintenance of eco-systems and their regenerative potential
- equity between generations, peoples and classes
- provision of health, safety and security

A sustainable housing development is not considered 'sustainable' without significant reduction in emissions compared to a typical home. That is not too say that other issues have been disregarded, but the reduction in emissions has taken on ever greater importance as evidence that a development is sustainable. An optimised and holistic passive solar design for a housing development should inherently mean that housing designed to these standards is more sustainable than current standards.

In the terms of this research, the key objective is to be 'more sustainable' than current methods of construction, and passive solar can take significant steps to achieve this. Briefly, for a sustainable development to be realised passive solar design may be used, in northern climate, as a method for a free source of heating. As a renewable source of solar energy, a home with a PSD will be significantly less dependant on non-renewable sources of fuel. Generally, this means that passive solar designs in this research will be more sustainable compared to current methods of development, both socially and economically. It is for this reason that PSD is used as an exemplar for sustainable housing.

3.9 SUMMARY

3.9.1 PASSIVE SOLAR DESIGN

After analyses of a variety of definitions of passive solar design, the research focuses on passive solar design as follows;

*"Passive solar **heating** is a holistic approach to building design, reducing the dependence on non-renewable methods of heating during winter without overheating during summer, optimising strategies of passive solar design to create more sustainable housing developments giving environmental, economic and comfort benefits over conventional methods of construction"*

The emphasis of passive solar design is on heating in northern climates. Therefore, in relation to the climate of Scotland, passive solar heating is the more important than the passive solar cooling used in lower climates. The chapter goes further and describes the different aspects of passive solar design.

The critical time to deploy a passive solar design is when the building(s), or addition to a building(s), are first conceived (DTI, 2000; Borer & Harris, 1998; Yannas, [1], 1994). Shaw & Holt (1999) go a step further in stating that consideration of the division of the land is required at 'the town planning stage' and needs taking into account before design of the building is undertaken, when employing passive solar measures. The aim is to have suitable areas outlined for housing development and road orientation, which take advantage of solar gain and orientation but also optimise wind control (Yannas, [1], 1994; BRECSU [2], 1997). Passive solar heating requires a holistic approach to achieve an ***optimised*** performance (Marsh, et al, 2000) and this includes being implemented at the planning stage.

Climate Change is offered as a reason for the need of change in the housing industry. The UK government, as part of their commitment to reducing CO_2 emissions by the Kyoto Protocol, are leading the way in reducing emissions throughout industry in the UK. Housing is one option that is being tackled due to the emissions (of the collective house industry) from this source (Behling, 2000). Passive solar designed homes utilising passive solar heating which reduces the dependence on dedicated heating systems will reduce emissions, if adopted, of new housing in the UK.

Passive solar design encompasses most of the aspects needed for a development to become sustainable. Passive solar heating of a home is both economically viable (affordable and can reduce heating costs) and environmentally conserving (emission reducing). It is not suggested that passive solar design **is a panacea**. This research will only use passive solar design as one example of sustainable housing. What this research does propose is that by using passive solar design more readily for the mass housing market, the construction industry will become **more** sustainable than it currently is

3.9.2 THE WAY FORWARD FOR PASSIVE SOLAR DESIGN

The following points detail the required basic changes in planning housing developments:

- Given the fact that there are so few passive solar developments, internationally, it is safe to state that there has been a reluctance to use passive solar design and estate layouts in mass housing schemes. There are a number of developments in the UK, most notably the Greenwich Millennium Village, which claim to use PSD techniques, but do so in a limited way. The main aim of Greenwich is sustainability, however it falls short of this in comparison to showcase developments in other countries such as Sweden, who's Ecological City of Tomorrow, in Malmo, offers 100% renewable energies, far in excess of the London equivalent, despite having broadly similar objectives. The most significant similarity between these projects is the early decisions, before construction, concerning environmental concepts - the period that may be described as the planning process stage, a significant period where environmental strategies may be optimised for significant benefits. It is argued that changes in the planning processes of housing developments are required if environmental principles are going to be adopted in mass speculative housing.

- There are three key issues involved in introducing PSD at the planning process stage. Firstly, it is argued that the methods of housing zoning, orientation and road layout are unlikely to change without foreseeable benefit to the parties involved or change in planning policy. Secondly, the fact that passive solar techniques, in order to optimise environmental and monetary life cycle cost benefits, should be applied during initial planning. Thirdly, it is difficult for planning officers to determine what is, and what claims to be, an environmentally friendly design. The planning process of most modern developments shows little knowledge of the use of passive solar techniques, in particular, and sustainable concepts in general, for whatever reason. This is evidenced by the lack of housing schemes which use these principles. This is only changing with pressure from Government, which is concerned enough to encourage the concept of sustainability in many fields of industry in an attempt to reduce emissions and boost efficiency. There are a number of developments in the UK which attempt to tackle the issues of sustainable design admirably well, yet they are often showcase developments and give examples of what can be achieved. These developments are rarely affordable to mass housing markets and they are not intended to be. For sustainable designs to become affordable all the main parties involved at this stage (the client; local authority; architect; developer; and others) need to have a fuller knowledge and appreciation of the techniques and issues involved. For the latter reason listed above, a tool is required for planners of developments, which could overcome some of these problems.

- The UK construction industry is about to change its goals due to Government pressure, with environmental concepts coming to the fore. This has not been lost on many suppliers, contractors and developers who are switching to supplying manufactured prefabricated units, increased specification on technological aspects such as glazing, and increased R&D through, for example, post occupancy evaluation of consumers. Yet PSD is a concept still dealt with as second preference to more visible add-on features (such as wind power or photovoltaics), in the sense that it is yet to be seen as a holistic set of measures to improve the environmental and sustainable characteristics of developments, and this needs to change.

- The economics of green design is a concept included in this research aimed at overcoming the perception that environmental principles are costly. It is readily accepted that most environmental principles will save money in the long term and benefit a home in non-monetary fashion. Concepts of whole life costs are not ignored in this research, but initial adoption into the mass housing market will not be achievable without the element of initial affordability. There is evidence which details a willingness by building consumers to pay extra in order to gain a better and more healthy home, green design being seen as more durable and cost efficient than current construction methods. Affordability is a key aspect of sustainable design, however, and case study evidence is provided to show that passive solar homes need not cost more than current housing. The Government recognises that affordability is a key requirement of the proposed large number of dwellings needed in future in the UK. Affordability, therefore, is a key component for passive solar design.

- The key premise of the research is to create the framework for a site assessment tool, using passive solar design as an exemplar. This tool can be used at the planning stage of a development, and will compare various levels of PSD against current more conventional designs, using developments in the North East of Scotland as sample sites. Where site densities are such that passive solar designs become prohibitive, trade-offs between current and environmental methods will be determined to ensure that both maximum benefits for home buyers are achieved without the creation of a significant reduction on return in investment for home builders.

CHAPTER 3 : ENDNOTES

[1] For further information on UK Government targets, go to the following website: http://www.defra.gov.uk/environment/climatechange/index.htm. Date visited: 08-04-04 13:42
[2] For more information see: http://www.agores.org/. AGORES. Date visited: 12/10/02 12:18
[3] Full document may be found at: http://www.greenbuilder.com/sourcebook/ Date visited: 08/04/04 15:33
[4] For more information: http://www.greenhouse.gov.au/renewable/ Australian Greenhouse Office. Date visited: 08/04/04 15:31
[5] For more information see: http://unfccc.int/ United Nations Framework Convention on Climate Change. Date visited: 08/04/04 15:48
[6] For more information see: http://www.metoffice.com/research/hadleycentre/ The Hadley Centre. Date visited: 08/04/04 15:53
[7] For more information see: http://www.tyndall.ac.uk/ The Tyndall Centre. Date visited: 08/04/04 15:54
[8] For more information see: http://arch.ced.berkeley.edu/vitalsigns/ The Vital Signs Project. Date visited: 09/04/04 11:47
[9] Dualchas Building Design, The Blackhouse of the Highlands, Dualchas Building Design: Architecture, Interior &
[10] For more information see: http://www.sunlighthomes.com/ Sunlight Homes. Date visited: 09/04/04 13:30
[11] For more information see: http://www.est.org.uk/, Energy Saving Trust. Date last visited 08/10/03 12:44
[12] For more information see: http://www.communitiesscotland.gov.uk/web/site/home/Home.asp Communities Scotland. Date visited 09/04/04 14:06
[13] For more information see: http://www.eren.doe.gov/ (last visited 09/08/02 12:20)
[14] For more information see: http://www.dti.gov.uk/renewable/ DTI, Date visited 09/08/02 12:24
[15] For more information see: http://europa.eu.int/comm/energy/index_en.html Energy Thematic website; Date visited 09/08/02 12:28
[16] For more information on this software visit: http://www.kahl.net/software/. Kahl Consultants. Date last visited 17/02/04 15:35
[17] For information on this software visit http://www.nrel.gov/buildings/energy10/ Date last visited 17/02/04 15:43
[18] For information on this software visit http://www.solacalc.freeserve.co.uk/. Date last visited 17/02/04 15:30
[19] Information on this source may be obtained from http://www.nesltd.co.uk. Date last visited 03/09/03 11:46.
[20] For more information on this software visit http://envestv2.bre.co.uk/. Date last visited 13/06/04 13:34
[21] For more information on this software visit http://www.techlit.co.uk/. Date last visited 13/06/04 11:10. For a list of similar software based on the BRE framework visit the BRE website.

4 Development of a framework tool for an Environmental Site Assessment Strategy

4.1 INTRODUCTION

The previous chapter has identified that the planning and feasibility of a development is the ideal stage to adopt passive solar principles. This chapter, therefore, identifies the problems associated with the planning aspect of developments and how these need to be overcome. Planning applications for projects suffer from delays and relies on the support from the local public. Since planning consents for environmental designs are critical to their acceptance in mainstream construction, the problems, possible solutions and changes to the planning system are central to the use of an environmental site assessment (ESA).

The previous chapter also highlights the fact that it is difficult, for a variety of reasons, to adopt environmental designs. This research, therefore, is developing the framework for an environmental site assessment strategy, to be used by planners to determine the costs of a development in regards to LCC and emissions. This chapter, therefore, is primarily collating the information needed to develop a planning tool, termed the environmental site assessment tool. Although the term 'environmental' covers a variety of aspects of housing design, in this case it has been simplified down to just aspects of passive solar design. The tool's main objective is to overcome restrictions to the adoption of more environmentally friendly practices, in this case passive solar design. This can allow planners to make judgments on aspects of sustainable development. In order to achieve this, the housing development will need to be reduced to simple geometric shapes and forms. This means that, housing design, though admittedly more complex in practice, will need to be displayed using simplified notations. This type of tool, if adopted by planners, could perhaps enable the speeding up of the planning process for environmentally enhanced designs, which would appeal to building developers, with the benefits of such a system being finally passed to the home buyer.

Passive solar design, as stated previously, is used as an exemplar for a more sustainable development. Passive solar design is a holistic environmental principle adopting many characteristics of low energy design, benefiting from a free source of energy. This may also be achieved without significantly changing the aesthetic or interior layout of current housing.

Passive solar design, therefore, may often be found at the heart of a 'sustainable design' given the appropriate site.

4.2 THE PLANNING OF A PROJECT

> ***Better planning that puts home, work, services and leisure together can improve quality of life, revitalise Scotland's communities and reduce the negative impact of excessive congestion and pollution***
>
> Source: Scottish Executive (Phillipson [2], 2002)

4.2.1 INTRODUCTION TO HOUSING LAYOUTS

There are many possible reasons why environmental designs are not introduced voluntarily into the building industry. The following figure attempts to list the various criteria that may explain why environmental designs are not more readily adopted. These reasons have been categorised into four different areas; Environmental / Psychological; Government / Market Incentive; Social, and; Value.

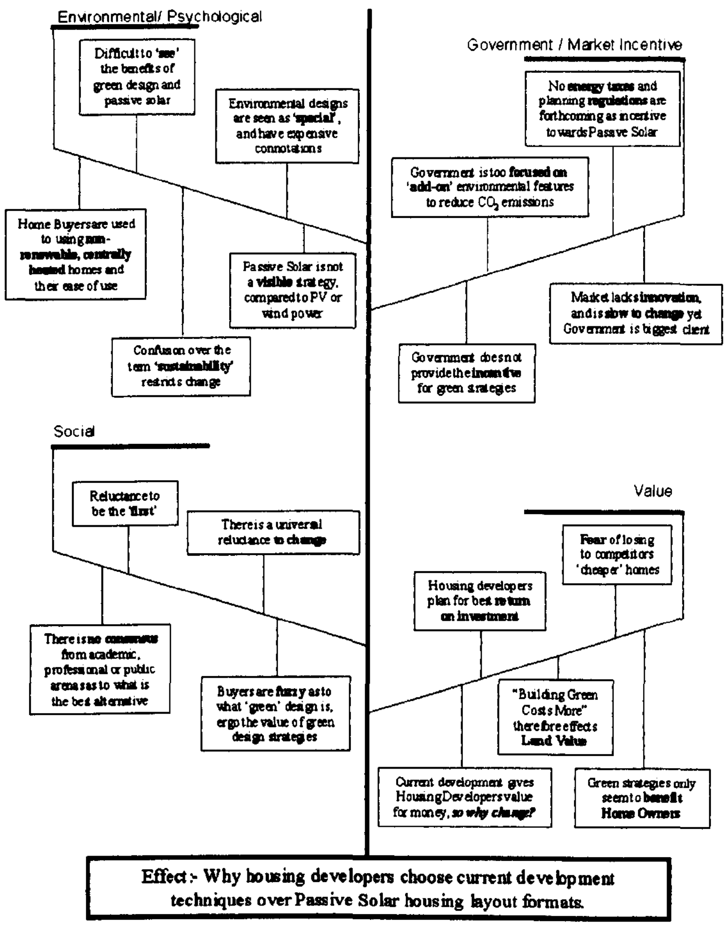


Figure 4.2.1.1: Cause and effect diagram on the reasons why passive solar as part of a wider environmental / sustainable development is not more readily adopted over current methods of development.

The tree structure in figure 4.2.1.1 aims to highlight the restrictions to passive solar housing layouts. The problems are listed on the branches and the major headings of the four main branches are 'Value', 'Social', 'Government' and 'Environmental'. In addition, the proximity to the effect (at the bottom of the figure) indicates the strength of the restriction upon the problem. For example, 'Value' is the closest in proximity to the problem therefore this research is looking to overcome this problem in particular.

Environmental and psychological restrictions on the adoption of environmental principles are the most obvious and stems from a reluctance to change from conventional, tried and tested methods of construction. This, arguably, is the easiest to overcome and requires time rather than any particular action. It took central heating two decades to become fully incorporated into housing (Turrent, *et al,* 1981).

Restriction to energy efficient forms of development can be overcome through market incentives (Pout, [2], 2000), which is a more direct approach to the adoption of environmental principles. Though the Government desires, however, not to be seen as 'pushing' something onto the industry, the current changes in policy in regards to tax reductions and grants for environmental and renewable technology has had little effect so far but it is a positive step forward (MacKenzie, 2001). In truth, the UK Government itself has been encouraged into providing incentives for all UK industries by Earth Summits in 1972 (Stockholm), 1992 (Rio) and 2002 (Johannesburg) whose general aim has been to set global sustainable and environmental targets and reducing emissions. The UK Government focuses on the very 'visual' environmental options such as wind energy, marine and photovoltaics. Rather than focusing on individual housing, which adopt a more holistic environmental approach.

The adoption of environmental principles changes, or is perceived to change, the social aspects of a home. There is no consensus in the building industry as to what constitutes a 'green' design and there is little that a housing developer can do to prove to the homebuyer that a house which adopts these principles actually works. The homebuyer is, therefore, cautious about owning an environmentally friendly design. A certification system is required similar to the NHER building rating scheme to determine the how environmentally friendly a development is, but how is this to be achieved without consensus from the relevant parties without any research and development.

The Value aspect relates to the perceived monetary advantages of current methods of construction over environmental methods. In this research, the tool is to be used by planners to ascertain if there are long term monetary advantages for passive solar, as an exemplar, over current methods of construction.

For a sustainable or environmental project to replace current methods of construction each issue listed in the *cause and effect* figure 4.2.1.1 needs to be overcome. Planning is crucial to every aspect of design - planning with quality results in designs with quality (Edwards, 2000). This section will suggest some changes that are needed in the planning process if environmental designs are to be encouraged.

For this research there is a need to clarify who is the 'planner'. An architect or a housing developer may plan a project, however, for the purposes of this research the planner in a development refers to planning officers in planning departments. It is this phase in a project that may benefit from an environmental site assessment tool that can ascertain how environmental a development is, adding to their current expertise.

4.2.2 HOUSING DEVELOPMENTS AND DENSITY

To ensure that housing developers adopt holistic environmental principles at the planning stage, they must be persuaded or given incentive. The preferred method of making the changes to include environmental considerations early in the planning process is through the local planning office. Planning officers have to deal with a number of pressures, however, and it easy for environmental or sustainable elements of a development to be low on the list of priorities. A key pressure, for example, is the Government drive to reduce time taken to gain planning consent. Planning officers also have to deal with environmental principles that are often ambiguous, making it difficult to recognise different principles of design. Bordass (2000) states that it is often difficult for environmental professionals to differentiate between an environmentally friendly dwelling and one which claims to be, so if environmental professionals find it difficult, without proper training how can planner officers know the difference?

Housing developers remain the driving force behind early planning decisions, however - decisions such as basic layout, quality, strategy, process, management, and, importantly density. Their main aim, as discussed, is economically driven, while ensuring it meets the stipulations of local planning authorities. Environmental professionals, and even designers, may not be involved at this stage, yet this is where the key decisions influencing passive solar are made - leading in some cases to increases in capital cost and the loss of the potential to save heating costs and emissions if added later in the design process.

Currently, the only stage where a change can be made to the developer's housing layout methods is at the planning consent stage; however the adoption of environmental designs at this point still relies on government incentives. For an environmental design to be adopted, one incentive that a housing developer may find attractive would be a rapid planning consent. **It is hoped that the tool developed will speed up the planning consent for the housing developer who opt for an environmentally friendly design, if adopted during the planning stage.**

Across the construction industry, housing developers plan, design and build on very similar principles and there is a fear of changing housing layout techniques as suggested by Bordass (2000). That is to say if most housing developers plan, design and build with similar principles, it is more difficult for the individual housing developer to change type (Brinkley, 2001; Levitt, 2000; Meikle and Connaughton, 1994). However, housing developers are solely responsible for many aspects of planning a project. It is usually they who have the first, and as importantly the final, say on how a development is laid out and specified, within broad guidelines. Smit (2001) notes that, "a lot of design in house building is done by marketing people. They look at what their competitors are doing and bring designers in too late". The housing developer, however, has a, "moral obligation [to the house buyer] to get it right" (Levitt, 2000) and this may be achieved through more sustainable approaches to housing.

Problems with housing layout design stem from the housing design after World War II, where the public aspiration was for a well equipped, detached home in the suburbs and this concept has remained the same since (Behling, 2000). Development of 'dream homes' has led to environmental problems such as the over demand and reliance on appliances in the home and also 'urban sprawl' Mitchell (2001). Urban sprawl is responsible for the unnecessary development of green field sites, increasing the dependence on the car (and exacerbating the neglect of public transport), and for the demand for single, detached family homes (Mitchell, 2001). More recently, the protection of greenfield sites, in the South East of England in particular, has increased the land value. This has, in turn, increased the sale value of housing making density targets an important aspect of Government planning policy in making housing more affordable.

The Bungalow is the most desired house type in the UK, the two-storey village home being a close second, claims a MORI poll (MORI, 2002; Dorrell, [1]. 2002). Set against Government objectives on high density housing, this poll highlights the difference in housing desires between government and homebuyer – an unsustainable approach to housing. The poll, generally, portrays the fact that low density, semi-urban, detached homes are the preferred housing type, exacerbating urban sprawl. To overcome problems of this nature, Mitchell (2001) introduces "smart growth", a planning technique that encourages, "pedestrian friendly communities, a mix of housing types, and less dependence on the car." Smart growth needs to be careful, however, and create a balance between perception and reality. PSD at high latitudes would find it difficult to achieve high density and achieve Government targets in these regards.

Density and Government set density targets are an issue of importance for planning, especially in more urban areas, and may affect the social cohesion of a community. Edwards & Turrent (2000) and Clarke (2000) promote high density as integral to a sustainable development, and indeed it is a critical area in achieving government density objectives, but high density housing does conflict with a number of other sustainable issues. The key reasoning for the argument is the amount of area used for the development of a project. That is too say the more compact environmental footprint, with higher densities, are more environmentally friendly. It is sound reasoning that high density sustains the environment, in a per hectare scale. Higher density does not mean heating costs and emissions are reduced, however, and it is this area that is of more immediate concern.

Probably the most sustainable housing type, which could adopt PSD principles, without detrimentally affecting density targets would be, terraced housing. O'Flynn (2000) highlights the fact that terraced housing is not popular with consumers, a point echoed by the MORI poll mentioned previously (Dorrel, [1], 2002), due to many problems created from recent designs coupled with the style of modern living. With the pressure for an 'urban renaissance', O'Flynn states that terraced development designs need to be vastly improved. CABE add that, "building at high densities demands good quality design" (Blackler, 2002). The 'Slim House' is the option proposed by O'Flynn (2000), which offers nothing aesthetically new, but creates a flexible, environmentally friendly and social space within, at an affordable cost. Like all projects of this nature, it is a showcase home, and it would take time for homebuyers to overcome their initial prejudices.

What smart growth, the Slim House and other developments such as BedZed, shortlisted for the Stirling Prize 2004, show is that there is a need for change in residential environments in and around our cities. What housing developers are starting to understand and incorporate into developments, is the need for a sense of community, rather than focusing on individual homes and this is essential for sustainable communities, villages, towns and cities. Levitt (2000) states that the, "quality of the home cannot be separated from the quality of the setting" and one of the main advantages of passive solar is the provision of an affordable home with a high quality interior environment.

Levitt (2000), however, notes that a PSD relies on orientation requiring significant alteration to street layout, which does not provide a secure community (that is it is not private). This is a common argument against passive solar, and to some extent the argument is sound, many critics claiming the benefits achieved in heating cannot be gained to the expense of losing the communities 'spirit'.

Critics, states Levitt (2000), often cite high density as the cause of failure in many projects but, Levitt adds, density is relative, a point echoed by Mitrany and Churchman, (1998). The setting also dictates the density of a development - a high density development in a semi-urban setting would separate the development from the surrounding, less dense setting, whereas the same development could be successful in an urban setting. Levitt (2000) believes creating a 'sense of place' and a strong, secure and stable community is more important than creating high density developments in areas not suited. Indeed there is evidence that high density residential communities will have a negative effect on social interaction and the value of place (Deshmukh, 1988), which could lead to a feeling of insecurity for residents (Astudillo, Much and Hermand, 2002). The opposite argument is equally valid where the planning of a development with spacious distances between homes can lead to a sense of seclusion and lack of security (Levitt, 2000).

In terms of this study, which is primarily concerned with looking at residential detached housing developments, the aim is to aid planners to determine how environmentally friendly a site is, given a site density above what is normal for a passive solar site. Levitt (2000) highlights that quality of life and spaces are intrinsically linked. Early planning of such homes with a PSD should not increase capital costs, yet should provide excellent space standards, and meet most Government housing objectives (Levitt, 2000). The tool developed in this research recognises that PSD is unlikely to meet existing density targets. It should also be noted that most sustainable housing developments would also find it difficult to meet densities of over 30dph, and certainly find it difficult to achieve 80dph in urban developments (Yanns, [1], 1994). The tool, therefore, will ascertain the effect of density upon a passive solar development by calculating the required spacing in order to meet the density of current methods of construction.

4.2.3 THE PLANNING SYSTEM

Passive solar design is dependent on the planning stage for maximum benefits to be accrued, so the approval of environmental designs during the planning process and the involvement of the local authority are fundamental. Developments will have some involvement from the local planning authority prior to approval. Local authorities rely on national building guidelines and also local area guidelines such as the Aberdeenshire local plan (extract is given in figure 4.2.3.1). All these guidelines are fairly broad (Cullingworth & Nadin, 2002).

Fig : 4.2.3.1; Extract from the Aberdeenshire Local Plan of proposed future housing developments at Inverurie

On receiving the application the local authority will begin notification, publicity and consultation procedures (Cullingworth & Nadin, 2002). It is here where an environmental decision making tool could be useful. The local plan in particular is devised by local authorities planning departments around the UK, and has recommended densities for various sites, amenities and general environmental changes proposed for an area, for example, around a town or village. The local plan for Aberdeenshire strictly dictates areas of development without going into any specific detail or specification, and development outwith these areas would require extensive consultation, and could lead to a protracted negotiation process. An extract from the Aberdeenshire Local Plan is given in figure 4.2.3.1, it has been used, prior to site visits, to establish the areas of future housing and also establish the specific housing density at these locations.

The process seems straightforward; the local authority has provided a plan for future housing growth in specified areas and a housing developer need only to meet these guidelines. After they are met, planning consent can quickly be given. The basic premise being that a planning application is made; a planning authority oversees and reports to the local committee (made up of local politicians) who exercise the planning judgement of the decision maker (Moor, 2001). If significant objections are made by local public representatives or groups with concerns about the proposed development the expertise of the decision maker (the planner) may not be used. Instead the process may turn into a political forum and although this is an essential democratic process it will cause delays in the planning process. A tool that could assure the public and local councillors of the possible environmental benefits of a development would aid the planning authority in fulfilling their initial recommendations.

Moor (2001) highlights two major factors causing delay in the planning process, ensuring that planning consent is usually slow.

- Firstly, the NIMBY (Not In My Back Yard) point of view has increasingly gained a powerful and essential voice in planning decision making.
- Secondly, the increased politicisation of the planning processes over the last two decades.

Local objections and the involvement of local politicians slow the planning process, but the problems with the system is not only at local levels. The politicisation of planning and departmental changes at state level is causing confusion, and makes changing the planning process more complex (Milne, 2001). A tool, therefore, could be used to make planning decisions more open, which could reduce the time taken to gain planning consent.

The Government is signalling that the planning procedure is about to change. CABE states that the government needs to promote, "quality thresholds" and supports the Government proposal for, "statutory statement of purpose" (Blackler, 2002). The Town and Country Planning Association states that the government is to increase funding to planning departments, which will aid in speeding up the planning process, and will be crucial in advancing affordable housing (Dorrell, [2], 2002).

The planning procedure may be difficult to change, and there have been many attempts to change it (Moor, 2001) but it may soon have to change. The effect climate change will have on the planning process, restricting areas of development, may ensure that planning procedures will change (Sampson, 2001). Sampson notes that climate change is now a fact of life and with this in mind, insurers are increasingly demanding to be heard when considering planning applications, stating "Insurability must become a key consideration in permitting land development." If this demand is ignored, insurance cover may become unaffordable or unavailable. In just a couple of decades, climate change alone could be forcing changes to the planning system.

The planning consent procedure is a highly contentious phase of a housing development and certainly requires change with the incorporation of more sustainable principles but this may add to delays in planning application. An environmental site assessment tool could identify how a site can be arranged, advising on appropriate density and determine the environmental impact construction will have on a site.

4.3 PLANNING A PASSIVE SOLAR DEVELOPMENT

There are many elements to consider when planning a housing development, and environmental designs require more consideration than current methods of construction. The following figures (4.3.1 and 4.3.2) illustrate the main elements as part of an integrated passive solar design, which illustrates the complexity of planning this type of development. The scope of passive solar design, all the elements that are directly and indirectly inter-linked need to be considered during the planning of a passive solar development are featured in figure 4.3.1. All aspects of passive solar are inter-linked, with varying degrees of inter-dependency and these aspects need to be balanced in a given climate for optimum performance. The central elements of a passive solar design are given in figure 4.3.2.

It may be claimed that the UK construction industry is about to change it objectives, because of Government forces. Yet passive solar is yet to be seen as a holistic measure to improve of environmental and sustainable concepts in housing developments. Therefore it is difficult for planners to determine the benefits of these developments.

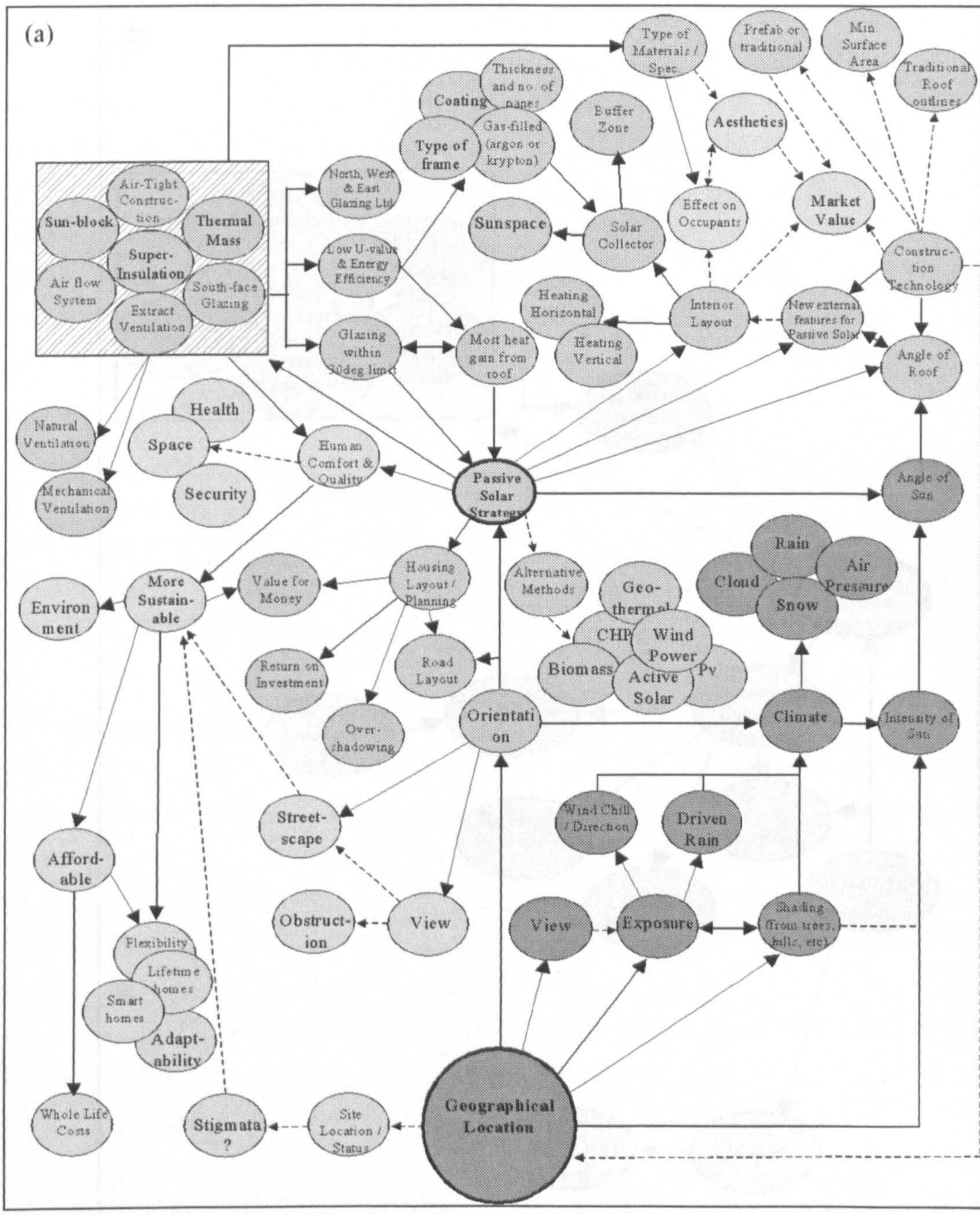


Figure 4.3.1 : The relationship between elements which may influence a Passive Solar Design and how PSD may affect various elements of housing

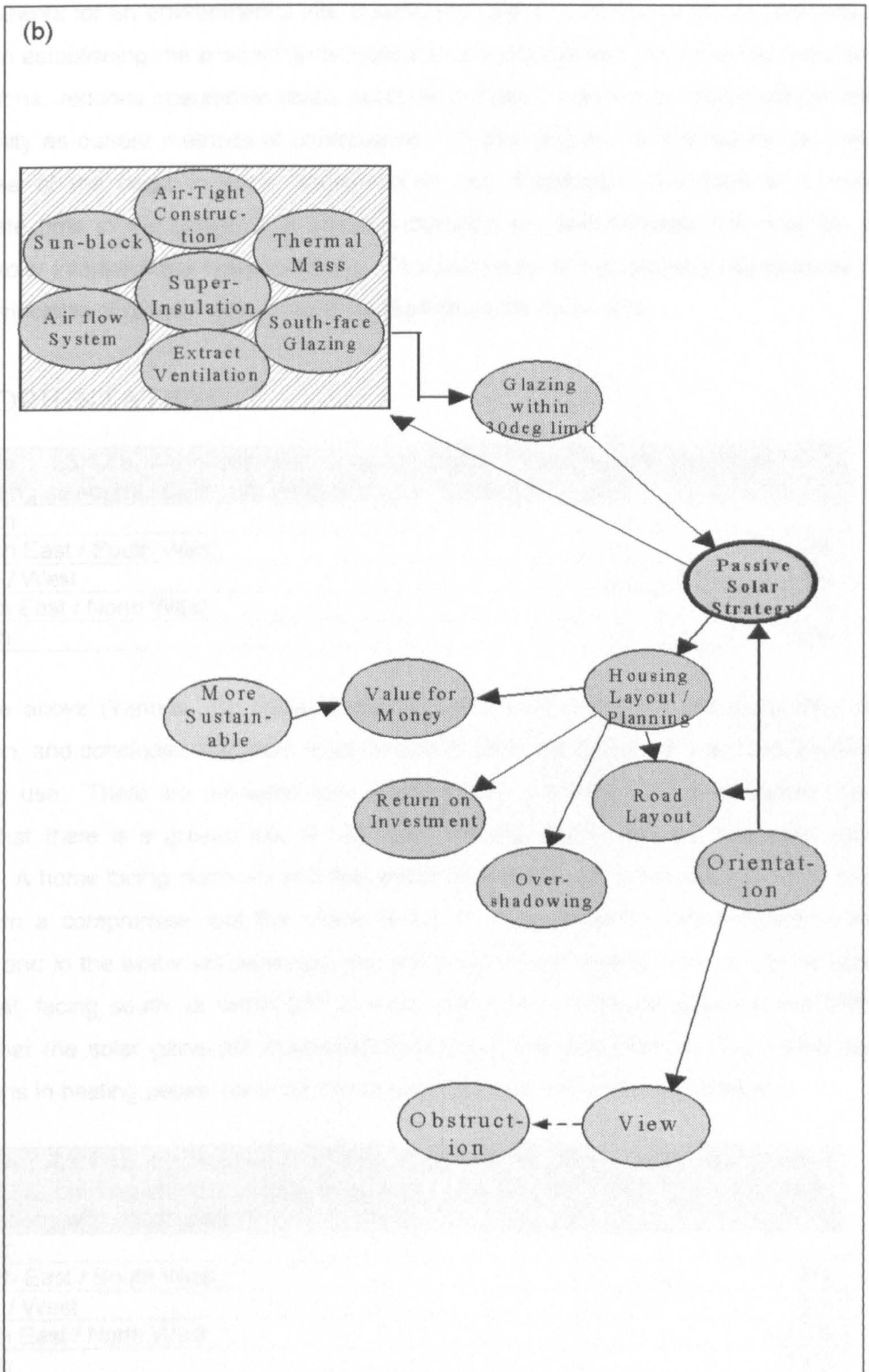


Figure 4.3.2 : The Elements of a PSD which are covered in this research

The framework for an environmental site assessment tool is a product that not only aids a planner in establishing the environmental potential of a site but also promotes the reduction of emissions, reduces operational costs, provides a healthy home at a similar capital cost and density as current methods of construction. A planning tool of this nature can raise awareness of the need to apply environmental and sustainable principles at a more appropriate time in the design of a housing development and stimulate the adoption of passive solar into the mass housing market. The remainder of this chapter outlines some of the key principles of passive solar in creating the framework for an ESA.

4.3.1 ORIENTATION

Table : 4.3.1.1a. Additional heating input for different orientations based on 1991 building standards. Data from Yannas ([1], p51, 1994)	
South	-
South East / South West	6%
East / West	15%
North East / North West	19%
North	22%

The table above (Yannas, [1], 1994) shows the difference in energy use depending on orientation, and concludes that, from south to east or west, the difference is a (15% increase in energy use. There are problems from facing in any orientation, however, facing north means that there is a greater risk of heat loss and the home does not maximise solar benefits. A home facing north will also feel perceptibly colder. A house facing west or east may seem a compromise, but the rooms facing in these directions will overheat in the summer and in the winter will barely get any direct light at all, relying more on diffuse light. In general, facing south, or within 25° of south, which is a recommendation of the BRE, means that the solar gains are maximised throughout the year (Yannas, [1], 1994) and fluctuations in heating peaks within the home are limited, or more easily controlled.

Table : 4.3.1.1b. Updated additional heating input for different orientations based on 2002 building standards (Scotland) (based on 70% south facing glazing, other elevations with equal glazing).	
South	-
South East / South West	3%
East / West	8%
North East / North West	10%
North	11%

The table above has been updated to include the recent changes to the thermal standards in Scotland (based on a 7x10 home with 70-30% glazing ratio). Using weather data for average Scotland (average overall) the deviations between south and west, for a similar sized house relating to the figure above, are less. BRE research would suggest that housing in the North-East of Scotland should not stray further than the BRE recommended limit of 25°, though with the modern thermal efficient standards the additional heating input is dramatically reduced. A house but with modern thermal efficiency standards (changed in 2002) offers an energy reduction of a maximum of 8%, as opposed to the 15% with the 1991 thermal standards. This illustrates the bridging gap between passive solar homes and thermal standards, the key change being insulation thickness and glazing. With this the case, currently a passive solar home can orientate within the 25° suggestion by BRE without increasing energy use significantly, research suggests that a 2-5% increase in energy use is not untypical, dependant on size of dwelling.

It may not be possible to provide a southern orientation on all the dwellings in a development and this is where a trade-off between passive solar and thermal standards may be possible. Yannas ([1], 1994) suggests that, "in all such cases a judgement will need to be made weighing the respective advantages and disadvantages of an off-south orientation."

4.3.2 OVERSHADOWING AND SITE CONDITIONS

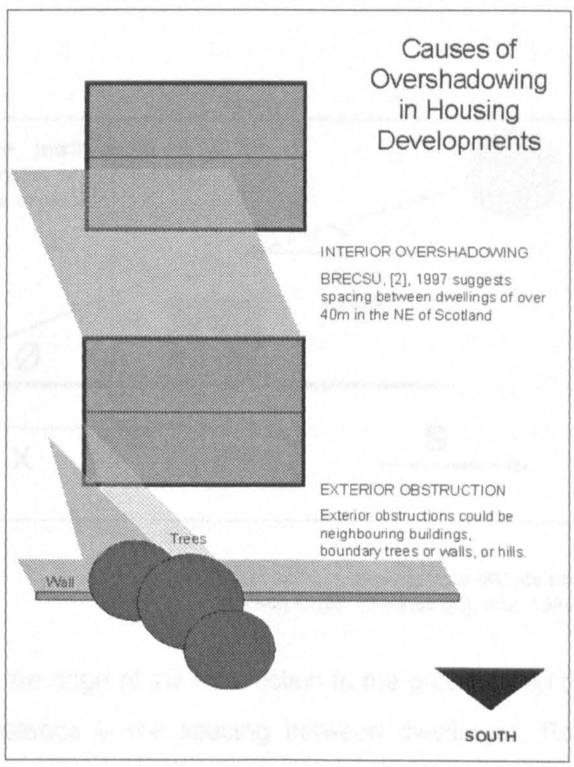


Fig : 4.3.2.1. Overshadowing in NE Scotland

Overshadowing is a term used to describe the shadow cast by an object by the sun, and in the case of year round solar access of all buildings on any site, it dictates the spacing (north-south) of buildings. Yannas ([1], 1994) suggests that spacing to avoid overshadowing of dwellings, for the Aberdeen latitude, is 40m. The UK average spacing for standard detached homes is between 15-20m, and less for dense sites over 40 dwellings per hectare (dph). Overshadowing is, therefore, a significant problem at northern latitudes, underestimating overshadowing will increase the heating requirement of homes (Yannas, [1], 1994).

Calculating the energy costs of individual buildings according to orientation is a relatively simple step, but this research is interested in applying these savings for groups of dwellings on sites. Minimising overshadowing, both for solar gain and density issues, requires careful forethought on site layout at high latitudes, and therefore overcoming the problem of overshadowing is the most important aim of site layout.

Since overshadowing is directly related to density, this forms the principal feature of the environmental site assessment. In the site assessment, the overshadowing at high latitudes above fifty degrees will determine the optimum density of the passive solar development. Once this has been achieved other aspects discussed in this chapter will ascertain the necessary trade-offs.

4.3.2.1 Obstruction Angle

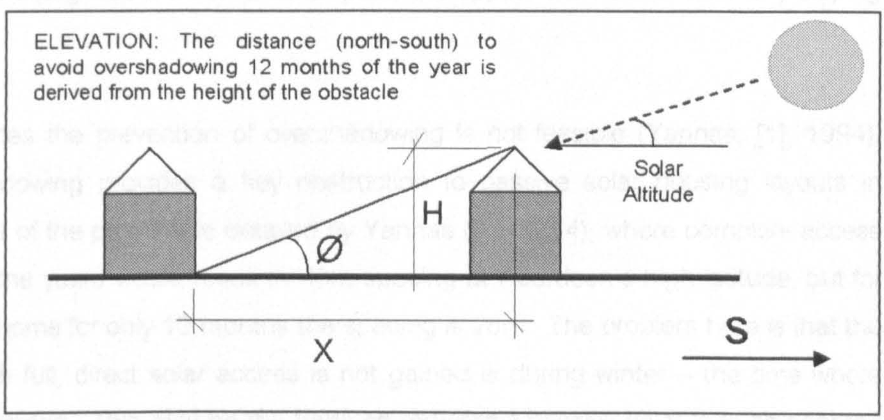


Fig : 4.3.2.2. Section showing solar altitude and obstruction angle. (Yannas ([1], p52, 1994)

The obstruction angle is the angle (θ) from the ridge of the obstruction to the ground level of the obstructed dwelling. The resultant distance is the spacing between dwellings. For Aberdeen the minimum solar altitude in winter is around 9° at 57° latitude. If the obstruction angle is greater than the solar altitude then the southernmost building is restricting solar access. From this the minimum spacing can be calculated, with the additional information of the height of the obstruction needed. The height may be determined from a collection of simple geometrical dimensions of basic housing forms in tabular format.

$$\tan \varnothing = \frac{H}{X}$$

$$X = \frac{H}{\tan \varnothing}$$

Ø = Obstruction angle (deg)
H = Height of obstruction (m)
X = Spacing (m)

Fig : 4.3.2.3. Equation for calculating overshadowing distances and obstruction angle (Yannas ([1], p52, 1994).

In terms of the environmental site assessment, the use of these formulae is further explained in chapter five.

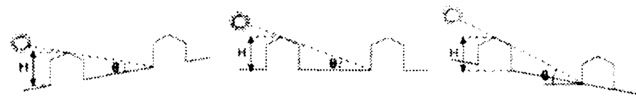
4.3.2.2 Causes and Effect of Overshadowing

In the case of southerly-orientated sites, obstructions may be caused by existing features, which may be dwellings, trees and topographical features, other causes of overshadowing may be internal site layout or grouping of proposed buildings, particularly in high density sites. Site slope also has a considerable effect, using Priene as an example, this passive solar development was situated on a southerly sloping hillside, resulting in the spacing between dwellings being less than on a flatter plan, the opposite is true for northerly sloping sites.

In northern latitudes the prevention of overshadowing is not feasible (Yannas, [1], 1994), therefore overshadowing provides a key obstruction to passive solar housing layouts in winter. The extent of the problem is detailed by Yannas ([1], 1994), where complete access for 12 months of the years would result in 40m spacing at Aberdeen's high latitude, but for solar access to a home for only 10 months the spacing is 28m. The problem here is that the 2 months in which full, direct solar access is not gained is during winter – the time where heating is most needed. This may be the trade-off required if passive solar is to be adopted at northern latitudes such as in the North East of Scotland, however. The passive solar design may need to rely on diffuse light and the consequence of increasing the demand on the heating source.

The direct result of any overshadowing is an increase in energy use, but also the feeling of warmth which direct solar access provides is an equally significant loss. Yannas ([1], 1994) illustrates graphically the proportion of loss, and from this it can found that if the spacing, at Aberdeen, was reduced to 20m, from the recommended 40m, energy use would increase by 12%.

Recommended spacing for dwelling rows



Latitude	Obstruction angle[1], θ	Spacing[2]	10% slope south	Flat site	10% slope north
50–52°N	13.5 (2%)	spacing (for H = 7m)	20m	29m	53m
		spacing factor (xH)	2.80H	4.17H	7.50H
	16.5 (5%)	spacing	17m	24m	38m
		spacing factor (xH)	2.40H	3.38H	5.35H
Above 52°N	10.0 (2%)	spacing	24m	40m	97m
		spacing factor (xH)	3.44H	5.67H	13.76H
	13.5 (5%)	spacing	20m	29m	53m
		spacing factor (xH)	2.80H	4.17H	7.50H

1 Obstruction angle as seen from a viewpoint at ground level; percentage values in parentheses show estimated increase in heating energy compared with totally unobstructed dwelling.
2 The values for spacing represent the distance from the external wall of the obstructed dwelling to the projection on the ground of the ridge of the obstructing row

Fig : 4.3.2.4. Recommended spacing for dwelling rows, Yannas ([1], 1994)

Yannas ([1], 1994) provides the above table of recommended guidelines for spacing between dwellings. Accurate spacing distances will be calculated for specific sites in Scotland in this research, but this table illustrates the differences latitude and obstruction angle causes. The spacing and obstruction angles have been determined from the point of the obstruction's ridge to the ground point of the obstructed building, the ridge height being anticipated as 7m. For spacing to be determined out-with the 7m used for this table, a simple mathematical equation is also given in this table expressed as the spacing factor x H, H being the height of the obstruction.

Figure 4.3.2.4 provides a simple example of typical distances caused by overshadowing, but cannot provide accurate data for the purposes of the environmental site assessment. In the ESA the site will be known therefore information will be available in regards to latitude and permitted solar altitude. In this case some basic information will be needed if the ESA is to find the overshadowing distance accurately.

The information required to find the overshadowing distance is still the same as detailed above, but information on house height may not be known at the time of analysis. The ESA has a method of overcoming this problem to portray accurately the overshadowing distance. The ESA uses databases of housing footprints and typical housing heights based on various roof pitches. The use of databases is important in this research in terms of future development of the product into GIS, but also the databases allow for the simplification of input data. The databases not only allow for the need for less input data but bypasses the need for detailed information at a such an early stage in the planning of a development. If necessary, various site scenarios may be determined for each site characteristic.

Yannas ([1], 1994) also highlights the fact that the calculations in figure 4.3.2.4 were determined using certain assumptions, and states that closer spacing can be achieved by, for example, creating breaks in dwelling rows, though this also has disadvantages. The main assumption is that the passive solar home requires solar gain throughout the year with glazing down to ground level. This may not be needed, and there may be some trade-offs applicable if certain passive solar design features are changed, such as in this case, sill levels. The drawback of this tool is that a decision is required early in the design process of the project development as to the sill height.

Commonly, a passive solar home is restricted, in high latitudes, by the solar altitude and the need for direct solar gain. This is not always absolutely the case, however. Passive solar can work efficiently without the need for direct solar gain and, if necessary, alternative (and environmentally friendly) means of achieving heating in the home can overcome periods where solar gain is unavailable. This trade-off between passive solar and a back-up heating system is used in the ESA, and assumes that there will be a period annually that will require the full use of a back-up heating system.

Passive solar design is also commonly assumed to have ground level to roof level glazing to maximise solar gain. The basic calculation assumes glazing on the ground level of the obstructed building, but if this is not the case, Yannas ([1], 1994) provides the means to calculate from any glazing point on the obstructed dwelling. In addition, if overshadowing is unavoidable, to meet density targets, Yannas ([1], 1994) also provides data to calculate the potential increase in energy use this will cause. The equations for calculating the spacing and obstruction angles in the framework tool are discussed more fully in chapter five.

4.3.2.3 Site conditions and layout planning

Site development density

Passive solar and other environmentally friendly planning layouts are not generally considered alongside density targets. For the housing developer every site, be it rural, semi-urban or city centre urban, has density targets either stipulated internally to maximise profit or a minimum, and occasionally a maximum, is stipulated by the local planning office. Yannas ([1], 1994) states that in England and Wales the average built density is about twenty four dwellings per hectare (dph). With the drive by Government for increased densities, as part of their commitment to the Kyoto Protocol, the DPH of recent sites has

usually been between 25-35dph, for detached homes. In principle, acceptable passive solar at densities between 25-35dph can be achieved with appropriate layout design and a fortuitous site.
Site investigation of semi-urban sites in the North-East of Scotland have densities between 20-45dph. In addition, sites, which are small, say less than half a hectare usually have between 5-15 homes upon them, and usually have a larger floor area, in some cases up to 500m^2. Whereas sites of around two hectares would usually have between 85-105 homes, which have a floor area around 120m^2 or less.

Semi-urban and rural sites in the North-East of Scotland have a high risk of overshadowing from adjacent buildings and obstructions, but natural obstructions can also be a main cause of overshadowing, be it within the site as trees or outwith the site. Exposed sites would require wind protection of some form. Aberdeen, being a coastal city, has many satellite towns along the coast and exposed sites in these localities need special consideration.

Urban sites generally do not have detached houses and are of a much higher density, and consequently the housing is predominantly taller. With these sites access to solar gain cannot be guaranteed and more innovative and active means of heating should be used. Though a percentage of dwellings, if buildings are orientated south, will get passive gains, not all are guaranteed this. This research does not cover urban sites which, because of their high density do not promote passive solar however, as Yannas ([1], 1994) states, "the milder urban microclimate is a form of compensation and there may be opportunities for further microclimatic enhancement through layout design." This may be of some compensation.

Site geometry and topography

A favourable site geometry and topography can make a significant difference between a successful passive solar site and one that is not. In particular, small sites have a greater risk of overshadowing from external obstructions and sites with irregular boundaries can restrict the orientation of a dwelling, more so with detached homes which operate as separate units. The orientation of the site itself can restrict the density and orientation of the dwellings within.

Other key points which influence orientation of homes are, listed by Yannas ([1], 1994);

- Access to site;
- Boundary conditions and gaps;
- Type and position of roads proposed and existing;
- Adjoining properties;
- Conservation orders and/or planning restrictions; and,

- Considerations of privacy will also influence orientation of a dwelling, and with large south facing windows this will become a significant issue.

Passive solar design is dependant on site topography if the design is to be used by housing developers; south-sloping sites favour passive solar and north facing slopes do not favour passive solar design. East-west sloping sites will favour passive solar in their respective orientations but will add to the heating input required in the home over the more favourable South orientation. In addition, east / west sloping sites will increase the spacing between dwellings due to over-shadowing if full, year round solar access is desired.

Roads and access

There are a variety of recommendations made by planning regarding roads and access to sites. Even on small sites, the car makes a significant impact on the site, with the road and paths on a site using up 7-15% of the area of a site. Coupled with the car usage area on plots encompassing driveways and garages, the result is that cars use a significant proportion of a residential site.

The most convenient arrangement for passive solar designs is where roads within the site run east-west, favouring access to plots and homes orientated north-south. A key strategy for the planning of internal roads and streets within residential areas is to reduce the risk of road traffic accident, and these strategies usually take the form of;

- Varying street direction;
- Signs at high risk areas; and,
- Reducing speed by the use of bollards, bumps and/or varying direction.

These safety measures are essential for residential streets, but increase the area requirements of roads on a site. The widths of roads are also limited to allow access for fire fighting.

Existing roads around the site boundary should be used, but careful consideration of privacy on the southern boundary is needed if PSD is to be used. Generally, a one-stop car park area / garage area for a sites needs is not considered by housing developers because it is perceived as unpopular to homebuyers, though it is a favourable option for PSD and other environmental layout strategies and limits the use of a car on a site. An external transport strategy is critical if limited parking is to be specified for a site. In the North East of Scotland, the preferred option for home developers is for a garage on the plot with access to an internal road. To create more privacy, specifically for more expensive homes, the home developer may provide less internal roads and longer private driveways, coupled with landscaping, to create privacy. Privacy is a commodity that is valued in some developments.

Advice for PSD sites varies, however the advice is to move the garage to the north side of dwellings, if possible (BRECSU, 1995). With careful consideration, the garage can provide a buffer zone to homes of the north facade, or even for streetscapes. The roads themselves need to be carefully considered in comparison to their traffic, residential developments restrict everyday traffic, so the usage of roads on site can be fairly accurately predicted. That being said, one-way systems on larger sites with paths separate from the roads, are advised; this has the added advantage of pedestrian safety and reducing the impact of roads on site (BRECSU, [2]. 1997).

The ESA compares housing sites, and it is possible to ascertain the effect of the spacing of dwellings by changing the road layout and size. The basic model will ascertain the effect of two way road systems and one way road systems, together with off-site parking (no roads).

Plot frontage and depth

The width and depth of a plot is an important consideration when designing a passive solar housing layout. A wider plot ultimately means more solar gain for a passive solar home. Currently, however, housing developers predominantly build narrowly fronted dwellings and consequently the plots reflect this. As Yannas ([1], 1994) highlights, spacing should be the first consideration, frontage should then be considered in relation to the rooms needed to face south.

Roads, parking, landscaping, play/recreation areas, boundary shape, if not already dictated by planning restrictions of dph, influence plot sizes, and site topography/orientation as discussed previously. This means plot sizes are often restricted before consideration of housing orientation and therefore passive solar.

In the ESA the plot sizes are calculated automatically according to a database of simple geometric housing footprints aimed at maximising solar gain. From this database, the width of a plot can be calculated and the depth is, of course, determined by the overshadowing of the home.

4.3.2.4 Wind protection, Green-space and Landscaping

With passive solar, heat gain is an important aspect of the design but once heat gain has been achieved through the provision of south orientated glazing, then preventing heat loss is essential. Internally this can be achieved through better thermal standards, however, sheltering a site from prevailing winds not only benefits the thermal comfort of the homes in the site by reducing risk of heat loss, but also provides shelter for the external spaces also.

As Yannas ([1], 1994) points out, "Layout and landscaping measures aimed at providing protection from wind can reduce air infiltration into buildings and thus draughts and heat loss. Compared with open ground, sheltering also helps maintain higher air and soil temperatures."

Predictably, open and coastal sites can be prone to high winds, making outdoor spaces unusable during these periods (the winds are strongest during the day) and this also means that these sites are most at risk for heat loss, if not protected (Yannas, [1], 1994). Prevention of heat loss through wind protection can compensate for less solar gain if high densities are required, so the benefits of tackling this problem should not be underestimated. This is especially true for the North-East of Scotland which is ideally placed for the cold winter winds from the north-east.

In short, the site layout measures for protection from the wind could include;

- The staggering of buildings or irregular use of groups of dwellings;
- Mixed-use development or ensuring taller dwellings on site are used as obstructions against the prevailing wind;
- Grouping of dwellings to mimic courtyards; and,
- The more traditionally use of embankments, bushes, shrubs and trees to create shelter belts.

Care must be taken, however, to ensure that these items do not become future obstructions. The current model for the environmental site assessment does not incorporate aspects of wind, but this would be included in future developments of the tool.

Apart from the obvious problems of having existing trees on a site, landscaping is a relatively blank canvas until after the dwellings on site have been built. Large trees and bushes on the south side, with the winter sun at 8 degrees at the Aberdeen latitude, can cause significant overshadowing. Yannas ([1], 1994) states that the crown of a tree will restrict 70-

90% of the radiation from the sun with the trunks and branches blocking 20-40%, more so with dense bushes of course. The type of tree or bush is important also, evergreen trees restricting solar gain more so than deciduous trees.

With careful planning and consideration of micro and macroclimate around the site, and with careful spacing of landscaping elements, these potential problems need not exist. Indeed, they can become a benefit in providing privacy for individual homes and the site itself, it can increase the aesthetic quality of site if placed thoughtfully and provide shelter from sun during summer and also provide wind protection.

Planning may insist on the provision of green spaces within developments and it is common practice to provide community spaces within a development for the sale of homes.

An investigation of the sites in the North East of Scotland highlighted that many sites have an element of green space. Green space is more prevalent where there is no adjacent park or public area amenities and is more commonly found round the boundary of sites. Some sites, however, have significant areas of green space, and therefore the proportion of green spaces for a site is included in the ESA. Though the total amount of green space may not be accurately known, a percentage area of a site should be detailed so that a comparison between alternatives can more readily be made.

To reiterate, green space may include:

- Public rights of way or paths within the boundary of the site.
- A greenbelt around the site.
- Internal Park or amenities for public play area.
- Any other space within the boundary of the site not immediately within the boundaries of building plots.

4.3.3 HOUSING LAYOUTS

Detached Individual houses and private developments

Individual detached homes are usually only considered in private developments. These types of building are more quirky or customised in design than housing in the mass market and often reflect the owners who built them. In these types of homes, architectural philosophy, design and planning for privacy are important considerations. It is these types of homes where environmental design is predominant, if the clients are willing, and it is here where the best environmental designs are found particularly as part of showcase projects. In many cases the site/plot itself is carefully chosen long before the design is formalised, and careful consideration of adjacent properties needs to be taken.

Developments which have predominantly detached homes are usually at the lower end of DPH statistics, Yannas ([1], 1994) states around 20-25dph, the homes being dispersed, sometimes seemingly randomly, around the site. Yannas ([1], 1994) states that plots tend to be over 360m^2, with average dwelling sizes of around 135m^2. An investigation of the sites around the city of Aberdeen highlight the fact that detached homes in medium to large scale developments have a higher dwellings per hectare rate of over twenty five.

In the North East of Scotland, the maximum density for a passive solar home is between 18-22dph (depending on latitude) and this is overcome in the tool so that passive solar homes can be adopted at any density. This passive solar density depends on there being flat sites with favourable aspects for passive solar designs therefore passive solar homes may be more restricted in real site scenarios. Yannas ([1], 1994; [2], 1994) and Borer and Harris (1998) highlight a number of case studies of passive solar design, which show that passive solar sites invariably have fewer homes per hectare. Appendix B covers an investigation of a passive solar design in the North East of Scotland (Deveci, *et al*, 2000).

Developments can combine several building types (mixed-use development) varying height, style and floor area, though most developments are predominantly 3-4 bedroom homes. Passive solar layout can benefit from mixed-use developments if smaller dwellings are sited to the south of the site, meaning less overshadowing and consequently less spacing between developments. This should mean that developments of this type are more comparable with common layout practice.

In addition to the detached, layout option, clusters of housing can be grouped into communal courtyards or similar. Some of these dwellings would be less successful in terms of solar gain because of poor orientation but should recoup some of the lost benefits through protection from heat loss and wind, a better 'micro climate' than more random layouts. Grouping dwellings often has the benefit of creating sense of place, improved access, privacy, security and security.

4.4 LIFE CYCLE COSTING: A MEANS TO FIND THE VALUE OF GREEN DESIGN

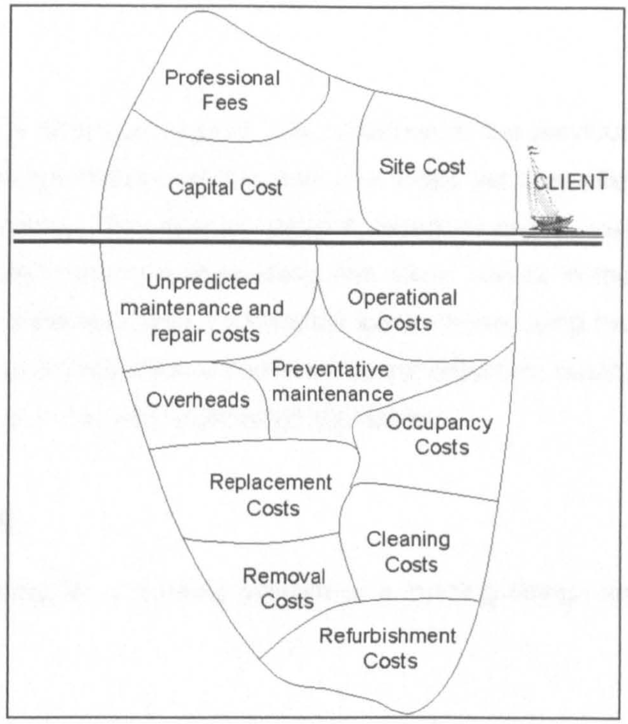


Fig : 4.4.1; whole life costs of a building / building element. *(adapted from Al-Hajj, 1991)*.

This section describes the costing features that have been used in the model in this research and what should be considered in the future development of the environmental site assessment tool. Life cycle costing monetarily compares between two or more alternatives, in this case between optimised PSD, passive solar design meeting any planning restrictions and conventional methods of construction (the standard house). LCC will be defined in this section in regards to this research. The disadvantages of using LCC will be discussed and some of the terminology will be explained.

Life cycle costing is not exclusive to the construction industry; its original use was promoted widely by varying US departments for assessing public and civil works and also in determining space utilisation. Life cycle costing is a relatively recent term for the UK construction industry for a variety of reasons, but mainly due to the reluctance to change (and the lack of relevant data) from the traditional costing system (relying solely on capital costs). Life cycle costing is particularly useful in the construction industry due to the fact that costs are not limited to the building of a home. A significant proportion of the cost of a home will be accrued in the operation and maintenance of a home through its life. Since this technique recognises benefits over the whole life of a home, it can, for example, recognise the increasing problem of limited economic resources and is designed in such a way as to provide the best design alternative from a range of options. In effect life cycle costing, if accurate data is available and utilised, can provide a designer and client with the consequences of various courses of action and enable more informed decision making within the design process.

In the case of energy conservation, it is particularly useful. As described in the previous chapter, the capital (initial) costs for environmental designs can vary widely yet they offer recognisable reduction in operational costs. Choosing an element based on capital cost alone, say double-glazed windows against triple glazed windows with low-e, results in the double-glazed window units being the preferred option. Basing the same choice using the life cycle costing method, taking into account reduction in heat loss, sound reduction, quality and durability, the triple-glazed window unit may be the preferred alternative.

Definitions of Life Cycle Costing

Flanagan (1984) defined life cycle costing for a building element or a building design as follows:

> *"Life cycle costing is a method of appraising quality and total cost of buildings whereby the economic consequences of available alternatives are analysed to arrive at the optimum cost solution. The technique is equally applicable to existing buildings or for consideration of an element of a building."*

A further definition of life cycle costing is given by Kirk and Dell'isola (1995):

> *"... LCC [Life Cycle Costing] is an economic assessment of an item, area, system, or facility that considers all the significant costs of ownership over its economic life, expressed in terms of equivalent dollars."*

The definition by the British Standard Glossary of Maintenance Management Terms in Terotechnology (Al'Hajj, 1991) is:

> *"... the technique of considering the total cost of ownership of an item of material, taking into account all the costs of acquisition, personnel training, operation, maintenance, modification and disposal, for the purpose of making decisions on new or changed requirements and as a control mechanism in service, for existing and future items".*

In this case the intention is to use life cycle costing for the analysis of different housing types in the environmental site assessment. Though the capital costs of the different housing types will not be calculated (there are too many specification variations to portray this accurately). For this reason the passive solar designs that have been chosen are affordable. That is to say, the capital costs will be similar to current construction as exhibited by Deveci, *et al*, (2000). The operational costs have been calculated through energy calculating software. The environmental site assessment software can be used to portray operational life cycle characteristics that are accurate enough to be used for comparative purposes.

Why use Life Cycle Costing?

Capital costs can vary widely as Ashworth (1988) describes, "It has long been recognised that to evaluate the costs of buildings on the basis of their initial costs alone is unsatisfactory." Logically there is no reason why the maintenance and operation/running costs are not similarly variable from element to element.

For the client who intends to pay for the capital costs and running costs of a building the initial cost is the most significant single payment. However Flanagan, et al (1989), stated that in all building case studies the initial costs were less than half of the whole life costs.

The main aim of life cycle costing is to provide value for money for the client and this is done by identifying "... the option with the lowest net cost", not only for the construction stage but also over a building's life. It should be noted that in the same way as monetary cost can be established over a life cycle, it is important to establish emissions over a life cycle, in order to achieve UK government objectives.

The Elements of Life Cycle Costs

Initial (Capital) costs. Initial or capital costs are those, which the client pays before the building is commissioned (Seeley, 1996; Kirk and Dell'isola, 1995, Morton and Jagger, 1995; Bull, 1993, Ashworth, 1991; Ferry and Brandon, 1991; Flanagan, et al, 1989 and Flanagan, 1987). In the environmental site assessment, without relevant data from housing developers, capital costs will be unknown. In future research, capital costs will need to be incorporated and anticipated through partnership with industry.

Costs-in-use or running costs. These are the costs associated with the client while in occupancy / ownership of the building (Seeley, 1996; Kirk and Dell'isola, 1995, Bull, 1993, Ashworth, 1991; Ferry and Brandon, 1991; Flanagan, et al, 1989 and Flanagan, 1987). Running costs can be classed into five different categories, explained as follows:

1. ***Maintenance Costs.*** These are the costs associated with every component in a building and involve planning, inspection, temporary or permanent repair, replacement of each individual building element and furnishing. Maintenance, if an element fails or it's 'life' ends, can be the most expensive single payment of the occupancy for a client.

Maintenance work is generated by a number of different causes identified by Seeley (1996 and 1987) as "... including weathering, corrosion, dirt, structural and thermal movement, wear, low initial expenditure, passage of time, incorrect specification, interior design, poor detailing and damage by users." Maintenance can be categorised under three different headings (BMI, 1995); Preventative Maintenance, Corrective Maintenance and Emergency Maintenance.

Preventative maintenance has the advantage of being predictable and can form part of a maintenance plan making data more reliable and accurate. In this research, all maintenance costs are determined to be similar and are therefore may not be included. This is because this research does not change the material specification of any of the designs, for example the passive solar home will not use timber cladding instead of a block and render cladding. Future evolutions of the environmental site assessment may include these costs, especially if more radical environmental principles are to be determined.

2. ***Energy (operational) costs.*** Ashworth (1988) explains these costs as being "... in the context of providing all the required fuel for heating, lighting, cooling and power requirements of a building." The nature of passive solar design, and indeed all environmental design features, gives it an advantage over current methods of construction built to building regulations minima (and potentially their greater advantage for homebuyers and the environment) is the potential for operational cost reduction. Though of course some environmental features do not offer significant cost reduction but are far better for the environment (in regards to reduced emissions or sustainable sources of fuel). This is the most important aspect as pertains to the environmental site assessment in overcoming issues of density restriction. Both the life cycle monetary and emission costs will be determined.

4. ***Cleaning costs.*** The Joint Centre for Land Development Studies at the College of Estate Management, University of Reading, in its draft design manual for "*Life cycle costs for Architects*", points out that there are two factors that will effect cleaning, both stemming from the clients choice/discretion. These are quality and frequency. For a large building, such as an office block or university, the staffing, equipment and operational costs of cleaning are quite large and often are a major component of a dedicated estate management programme. In the case of residential developments of homes of a similar

size, most cleaning is conducted by the homeowner, and assumed to be the same cost (same size = same cost), and therefore need not be included.

4. ***Rates, Tax and Insurance costs.*** Insurance costs for this study are deemed to be equal, if occupied by the same family. All these costs are important when determining the discount rate (which is explained more fully later in this section). Many items in a building can be claimed on tax exemption and some maintenance costs in particular can be claimed, though less so than in the past. However tax exemption is only specific to private building/owners and public owned buildings are only subject to small tax exemption. Taxes are calculated from 2001.

5. ***Estate Management or Staffing costs (Overheads).*** Not included in this assessment as this is predominantly associated with commercial premises.

The Life Cycle Costing Data Required for Model

The Time Value of Money. The time value of money is the most influential item of any Life Cycle Cost Analysis as any monetary item is affected by inflation or deflation. Any amount of guesswork will not determine what the value of money will be in the future. It is important to understand the following outlined by Flanagan, et al (1989):

> *"Any acceptable investment appraisal technique must exhibit two properties;*
> - *It should take account of all cash flows associated with the investment.*
> - *It must make proper allowance for the time value of money."*

Interest formulas. Kirk and Dell'Isola (1995) state that, "to quantify the impact of the interest rate in relating pounds spent today and pounds spent in the future," there are six commonly used interest tables that cover all predictable future payments and discounts them to the present date or baseline date. Three different types are used and they are:

Fig : 4.4.2a Single Present Worth** (PW) or **Net Present Value

The Net Present Worth represents the net value or ' worth' of a project given a prevailing rate of interest expressed as a single value. This factor may be used to determine the present amount (at the baseline date) of a future amount discounted at interest rate *i* for *n* periods. This is expressed in the formula:

$$PW = \frac{1}{(1 \quad i)^n} \ X F$$

Where i = interest rate per period
n = number of interest periods
F = future amount

***Fig : 4.4.2b Periodic Payment** (PP)*

This equation finds the periodic payment (annual) amount of a future amount. This may be used where a present amount at *i* percent interest rate is returned in *n* equal periodic instalments. This is expressed in the formula;

$$PP = \frac{i(1+i)^n}{(1+i)^n - 1} \ X P$$

Where P = present amount

***Fig : 4.4.2c Present Worth of Annuity** (PWA)*

The PWA factor is the reciprocal of PP. This is used where the periodic payment is known and the total amount is needed to be found at a future date. This is expressed in the formula;

$$PWA = \frac{(1+i)^n - 1}{i(1+i)^n} \ X A$$

Where A = uniform sum of money in each period

The Net Present Value method (4.4.2a) is used for the environmental site assessment. This type of LCC provides the information applicable to this type of analysis in the construction industry.

***Analysis Period and Life Expectancy**.* In this project an arbitrary life span of **60 years** is to be used as this is accepted by BMI (1999) sources and Ashworth, ([2], 1996; 1997) as the typical life span of a detached domestic dwelling. The durability of housing is dependant on various aspect including the physical aspects of a home (deterioration of materials, for example), economic and social factors. All these factors add to ensure that the typical obsolescence for a home is around 60 years, though there are examples of homes with a much shorter and longer life cycle.

The life expectancy of components in a building is difficult to determine and only an estimate of the most likely scenario is possible. Ashworth, ([1], 1996) explains that, "Obsolescence that eventually occurs both in the design and the technology are perhaps the main reasons why generally sound components are removed and replaced. In other situations components decay, are damaged or disused." Ashworth, ([1], 1996) goes on to remark that for most components, elements and such in a house there is still a lack of recorded evidence for life expectancy to be accurately portrayed. Meikle and Connaughton (1994) also discuss the "probable life" of housing to be difficult to determine and the life cycle of homes rely on a variety of complex criteria.

It must also be pointed out that estimating of life expectancies for each alternative is an important part of any life cycle study as Ashworth, ([1], 1996) states, "... life expectancies form an integral part of a life cycle costing calculation." Yet any estimation of the life expectancy will be a guesstimate.

Difficulties expected while conducting Life Cycle Cost Analysis

Seeley (1996) lists the difficulties that are prevalent when using LCC and to the construction industry in general as follows:

- The difficulty of accurately assessing the maintenance and running costs of different materials, processes and systems. There is a great scarcity of reliable historical data and predicting the lives of materials and components is often fraught with dangers.

- There are four types of payments - initial, annual, periodic and unexpected. These all have to be related to a common basis for comparison purposes.

- Tax has a bearing on maintenance costs and needs consideration, as it can reduce the impact of maintenance costs.

- The selection of suitable interest rates for calculation involving periods of up to sixty years is extremely difficult. This may be overcome by conducting a risk analysis, which looks at the effect of various different interest rates.

- Inflationary tendencies may not affect all costs in a uniform manner, thus distorting significantly the results of life cycle costing calculations, particularly as maintenance has a higher labour component that new work. Inflation will cause energy costs to fluctuate also especially for future use of non-renewable energy. For this research, which uses the same heating system for each alternative but in future the difficulty will need more investigation so that it may be overcome.

- Where projects are to be sold as an investment on completion the building client may show little interest in securing savings in maintenance and running costs.

- Where the initial funds available to the building client are severely restricted, or his interest in the project is of quite short-term duration, it is of little consequence to him to be told that he can save large sums of money in the future by spending more on the initial construction.

- Future costs can be affected by change in taste and fashion, changing statutory requirements for buildings and the replacement of worn out components by superior updated items.

- The lives of different types of buildings and materials are difficult to forecast with accuracy.

As shown above life cycle cost studies are notoriously difficult to predict for the reasons given above that are all valid for many types of life cycle cost analysis. Yet life cycle costing has also proven to be advantageous and that all types of costing calculations have historically relied on unreliable data and unforeseeable future problems. By excluding most of the ancillary costs associated with the life of the building, and basing costs on BRE accredited software and actual housing studies, accurate data can be used for this study.

4.5 DEVELOPMENT TOWARDS THE METHODOLOGY

In the development of the research towards a methodology to test the aims of the research, aspects of planning and the restrictions of modern day construction were detailed. In addition, the necessary sources of data for the analysis and consequent creation of the site assessment tool were addressed. The following are the key points of this phase of the research;

- To ensure that housing developers adopt holistic environmental principles at the planning stage, they must be persuaded or given incentive. The preferred method of making the changes to include environmental considerations early in the planning process is through the local planning office. Planning officers have to deal with a number of pressures, however, and it is easy for environmental or sustainable elements of a development to be low on the list of important issues to be addressed. A key pressure, for example, is the Government drive to reduce time taken to gain planning consent. Planning officers also have to deal with environmental principles that are often ambiguous, making it difficult to recognise different principles of design. It is often difficult for eco-friendly experts to differentiate between an environmentally friendly dwelling and one which claims to be, so if eco-friendly experts find it difficult, without proper training how can planner officers know the difference (Bordass, 2000). A tool is required during this stage which both utilises the inherent advantages of environmental principles with the assurance that these measures can and will be adopted, with the full knowledge of the benefits that will be accrued.

- Solar design requires changes to planning methods, requiring different orientation and shadowing distances over current methods of construction which require early planning decision making, making passive solar difficult to adopt throughout the UK as standard practice without changes to planning policy. The mathematical methods of determining solar principles are outlined.

- Careful consideration of environmental design, and in particular passive solar design, is required in order to create developments which can deliver policy objectives. The continued material and building element innovation in the construction industry is affecting environmental design significantly, bridging the divide between a typical home and an environmental home. It may be argued that innovation in building elements, for example glazing, could quickly make the monetary benefits of environmental design comparable to 'common' construction in the future. In defence of environmental design such as passive solar, these techniques provide many non-monetary benefits coupled with reducing operational costs, ensuring that homes built using these principles are healthier than their contemporaries.

- This chapter ends with a discussion of various calculating methods used in the planning tool developed in this research. Life cycle costing is the main method used for selecting environmental building materials and / or building elements. The life cycle costing analysis discussed will be used within the environmental site assessment to provide long term cost analysis. It is essential to predict the long-term benefits over current methods of construction to overcome the resistance to their adoption. In addition, it is important to determine the life cycle costs of non-monetary aspects such as emissions in environmental housing developments in achieving stated Government objectives.

5 Data Collection Methodology and Product Development

5.1 INTRODUCTION

There is a widespread perception in the construction industry that the cost of environmental designs is too great for the mass housing market (Bordass, 2000). Attempts have been made by governments to reduce the emissions from the industry and to change the planning process to place emphasis on environmental needs, but the increased politicisation has not been successful in aiding the environmental agenda, certainly in the short term. For many mainstream housing developers many types of environmentally friendly designs, which have been widely reported, such as straw bale housing, may seem extreme and not applicable to them. In addition, environmental designs for 'showcase' homes are often seen as overly complex and expensive and may not be the best medium for communicating what is available for mass housing. The complex issues surrounding environmentally friendly design make it difficult for planners to differentiate between developments – the difference between a sustainable design and current mainstream methods of construction is not black and white.

The current UK Government uses the reduction of monetary costs and emissions as an indicator of a sustainable design (SAP and the Carbon Index Method for example), but this does not cover every aspect of energy and material conservation. Most forms of grant aid aimed at reducing these emissions are for expensive, add-on features such as photovoltaics. This may be a reasonable approach, emphasising retro-fit solutions in a construction industry whose products have very long lives, but the design of new housing and its relationship to the site is not easily incorporated into such policy. It is an aim of this research to explore other mechanisms for encouraging better environmental design through the application of policy.

There is no decision-making tool designed for the planners of developments, which can determine the environmental credentials of a design for an overall site and help decision-makers to act appropriately. Currently, through the adoption of BRE accredited software that defines the 'SAP' (standard assessment procedure) for a home, or through hybrid manual/mathematical methods, the energy costs and emissions associated with a home can be determined. Most developments contain more than one individual home, however, and the grouping of dwellings, which is of greatest concern to planners, can have more impact than the design of an individual home.

The objective of this chapter is to detail the methodology for the development of a model of a software product which can determine the value of the site and advise the planners of developments as to the best case scenarios, for varying densities, on a site. The product aims to overcome perceived barriers to the introduction of environmental design and introduce the development of environmental concepts earlier in the design process. This product development is the foundation for the future development of an environmental site assessment tool for the planners of developments. Future development of the product is intended to include the introduction of a 3D software package, such as geographical information systems (GIS). GIS has the advantage of accuracy, visualisation and it is already partially used in most planning departments.

5.2 METHODS OF ENVIRONMENTAL ASSESSMENT

Most planners or designers of environmental projects rely on rules-of-thumb or past experience to determine if a building is environmentally friendly or not. Though valid and currently being the most representative way of creating an environmentally 'green' home, such methods are not appropriate for a non-experienced layperson to make judgements on the environmental credentials of designs.

Another variable of importance to this research is land value. In particular, how do you resolve one sustainable issue of density (that is the more houses on a site the more sustainable the site is) with passive solar design (in northern latitudes the density is significantly limited)? Both issues have major benefits. Firstly, the value of land is the key issue for a developer and the homebuyer in terms of affordability. That is to say, low land value is directly linked to the sale of low cost housing, which is an important for the UK government, especially in the South East of England. Passive solar design, however, will create fewer emissions (environment) and significantly reduced heating bills (economic), both issues of concern to the Government. A tool is needed that can determine the effect of density and land value on passive solar design, while still taking account of the benefits of PSD. The research is carried out in the premise that it is not possible simply to choose one option over the other.

A formal assessment procedure would aid in providing a decision making tool, enabling the consideration of trade-offs between environmental advantages and land value. Chamber, Simmons and Wackernagel (2000) describe various techniques to create an ecological footprint that can aid in the decision making process, if used appropriately. They highlight the fact that sustainability indicators should be used in creating a more sustainable environment and offer some key methods in creating these indicators. This research aims to use passive solar design as an exemplar of more sustainable design and assess the life cycle benefits of emissions and costs.

5.3 HOUSE DATA REQUIREMENTS

The previous chapter noted that across the construction industry, housing developers plan, design and build on very similar principles, creating semi-urban environments with narrow, closely spaced detached or semi-detached, dwellings. This immediately creates problems for innovation at planning level since one housing developer will not adapt different principles, such as environmental design, if the rest of the industry does not also change (Blackler, [2], 2002). Chapter three highlighted the fact that issues such as sustainability, green design and brown-field sites can be, as Cullingworth and Nadin (2002) describe, 'extraneous' - meaning they have additional cost risk to the homebuyer. On the other hand these concerns are central to the objectives of the planning office (Cullingworth & Nadin, 2002). In short, the principal housing form of densely packed, detached homes built to minimum building regulation standard is the result of economic imperatives coupled to risk aversion.

Housing developers remain the driving force behind early planning decisions, however - decisions such as basic layout, quality, strategy, process, management, and, importantly density. Their main aim, as discussed in previous chapters, is economically driven, while ensuring it meets the stipulations of local planning authorities. Eco-friendly experts, and even designers, are not involved at this stage, yet this is where the key decisions influencing passive solar are made - leading in some cases to increases in capital cost and the loss of the potential to save heating costs and emissions if added later in the design process. Currently, the key time when changes can be made to the developer's overall plan is at the planning consent stage; however the adoption of environmental designs at this stage still relies on government incentives. For an environmental design to be adopted, one incentive that a housing developer may find attractive would be rapid planning.

The information required to produce the software product comparing passive solar developments with current housing projects requires the investigation of key characteristics of current mass housing and advanced passive solar designs. The housing form chosen for this analysis is the detached home, in suburban development – this has been established as the most likely place for passive solar design and also detached homes create more emissions per unit (Edwards, 2000). An analysis of housing density in suburban mass housing in the test area, the North East of Scotland, has been conducted, to investigate whether there is are additional physical limitations on the number of houses in a development imposed by the adoption of passive solar design, in particular.

5.3.1 STANDARD HOUSE INVESTIGATION

This research aims to compare current housing against passive solar to anticipate the benefits the latter can accrue, in real site scenarios. The sample of sites used was drawn from the population of sites for major speculative housing developments in the North East of Scotland, of between 10 and 200 homes, built between 1998 and 2001. To do this, an investigation of current housing needs to be undertaken to establish if there are any differences. This analysis will be used in the environmental site assessment to compare a standard home to a passive solar home. A standard home may be defined as a home which meets the thermal (Scottish) standards set out in 2002, constructed as per the typical form in the North East of Scotland. Standard housing represents current methods of construction to the desired density, for a site.

Data on current new housing forms is readily available from housing developers in Scotland. The research chose seven different developers from major national companies such as Wimpey and more localised developers such as Robertson timber frame. The designs conformed to Building Standards Regulations in force in 2000. In particular information was gathered on simple, predominantly detached housing types in the North East of Scotland, though many of these housing types may be used throughout Scotland. The North East of Scotland offers a particularly challenging location since the solar altitude is low during the winter months when heating is needed. Therefore, if savings may be made at this location using detached housing forms, then there is an argument for claiming that PSD can be used for mass housing in most climatic areas.

Houses were chosen on the basis that they had been built or were intended to be built in housing developments on sites in the North East of Scotland. The data gathered from these houses included basic type (list follows), size, main orientation to street and proportion of glazing of each facade. Houses from these developments were divided into the following types, which reflect the types built on the sites targeted in the North East of Scotland (excluding Aberdeen City):

1. two-storey detached
2. bungalow
3. detached with habitable roof-space
4. semi-detached and,
5. terraced

The first three categories are of particular interest since they are all detached and the tool has been developed to encompass these three housing forms.

The aim of the database of housing types is twofold, firstly to ascertain the **average home** in terms of floor area, wall area, total glazing area and the proportion of glazing on each orientated façade. The relationship of glazing area to façade (north, south, east and, west) is of interest since there may be a perception that the total area of passive solar glazing is significantly greater than typical housing. This is a key aesthetic and economic feature that differentiates a green design from current designs.

To investigate this and room layouts the façades were categorised. The designation of 'main elevation' was given to the façade, which faced onto the street or was the elevation with the main access to the dwelling. The naming of the remaining facades followed respective of the designation of the 'main elevation'. The back elevation was opposite the main elevation with side A always being on the right and side B on the left.

5.3.2 SITE DENSITY INVESTIGATION

The literature review suggests that passive solar projects cannot compete with current projects in regards to density (see figure 5.4.2.1 which covers the restrictions upon passive solar housing layouts). This makes passive solar homes potentially less feasible for mass suburban housing, reducing return on investment and the value of the land. The Aberdeenshire Local Plan was used to select sites and to investigate the housing built in the last five years, housing currently under construction and future housing. The density of housing achieved on these sites was investigated.

Only housing developments with predominantly detached housing built within the past five years, or sites with a proposal for future housing development, throughout the North East of Scotland were chosen. The number of passive solar homes which can be placed on these sites was investigated. This can be easily determined by a simple mathematical analysis using data on optimising PSD from the Building Research Establishment.

Using a single passive solar house, one can determine the over-shading distance at a particular latitude by determining the solar altitude. This will give you the distance from the apex of one house to the window level of the house to the north. By determining the footprint of the home, you can determine the area of a single passive solar plot, which would provide solar access to a dwelling throughout the year. The figure 5.3.2.1 illustrates this method. From this, the number of passive solar homes on a site can be determined and compared to the number of houses actually achieved or planned and the number of narrow frontage houses which could potentially fit on the site. This gives a quantitative measure of the potential difference between solutions using the different housing types.

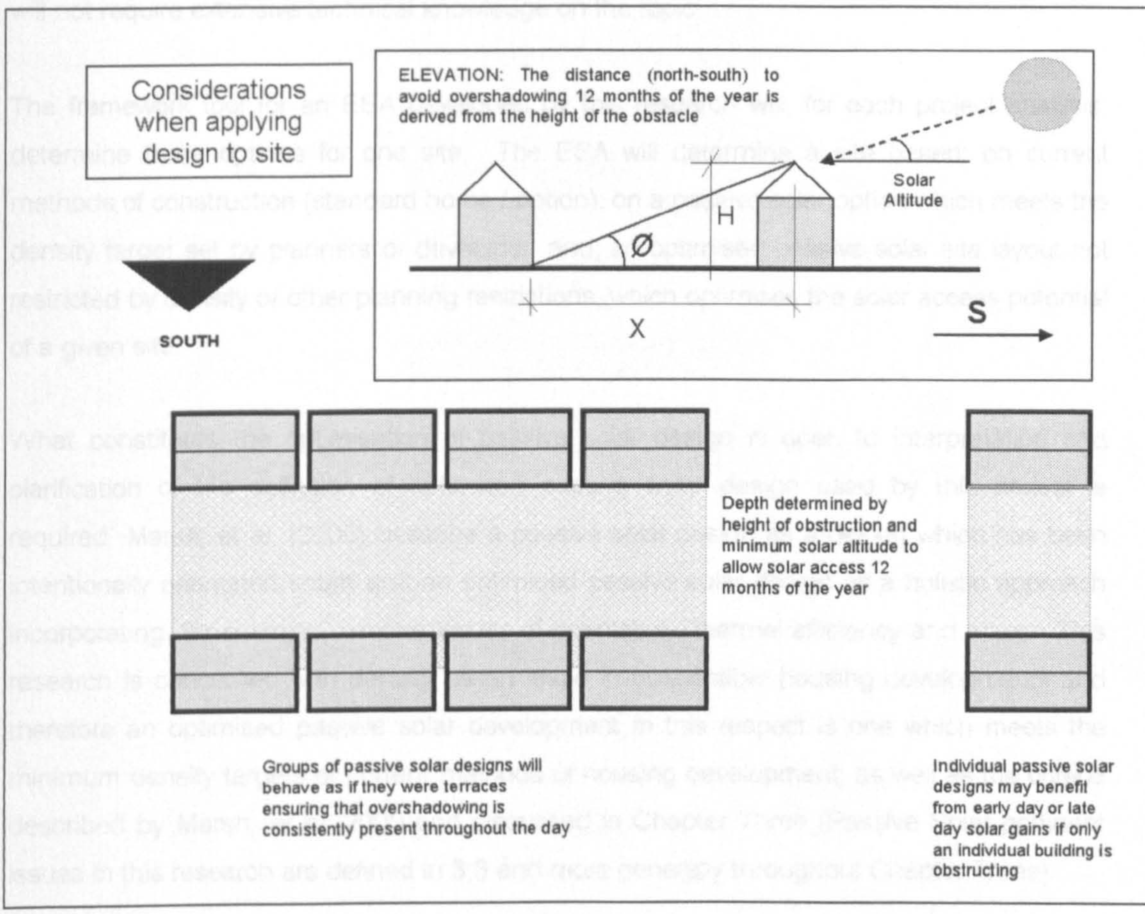


Figure 5.3.2.1: Anticipated restrictions on Groups of Passive Solar Designs

5.4 PASSIVE SOLAR DATA REQUIREMENTS

Passive solar design principles, and how to calculate them, are readily available from a variety of sources. Basic information from literature is available from Borer and Harris (1997) but there are also a number of techniques to calculate passive solar and its benefits. Tools have been produced which use simple mathematical calculations, by Yannas ([1], 1994) and Kachadorian (1997) amongst others. In addition BRE accredited software is available to determine heating power, costs and emissions. Life cycle costing data, used to ascertain the long term costs of housing is readily available from literature such as Kirk and Dell'Isola 1995 and more recent work at this University by Kishk (2001). The environmental site assessment produced by this research collates this information to determine the best alternative for a given site.

The environmental site assessment required an appropriate user interface, where calculation of housing operation costs has been completed. The user has a range of alternative passive solar designs to choose from, from optimised passive solar design to a standard house which is orientated with the main façade to the south. By offering this choice, the planner of developments can see the possible benefits of each version of a passive solar design and will not require extensive technical knowledge on the topic.

The framework tool for an ESA developed by this research will, for each project analysis, determine three options for one site. The ESA will determine a site based; on current methods of construction (standard home / option); on a passive solar option which meets the density target set by planners or developer, and; an optimised passive solar site layout not restricted by density or other planning restrictions, which optimises the solar access potential of a given site.

What constitutes the optimisation of passive solar design is open to interpretation and clarification of the definition of optimised passive solar design used by this project is required. Marsh, et al, (2000) describe a passive solar design as a design which has been intentionally orientated south and an optimised passive solar design as a holistic approach incorporating, for example, various issues of orientation, thermal efficiency and mass. This research is concerned with density as an issue in sustainable housing developments and therefore an optimised passive solar development in this respect is one which meets the minimum density targets of current methods of housing development, as well as the criteria described by Marsh, *et al*, 2000 and discussed in Chapter Three (Passive Solar pertinent issues in this research are defined in 3.3 and more generally throughout Chapter Three).

This research, as alluded to in Chapter One, has a number of restrictions necessarily placed upon it. The following figure outlines what these restrictions are. The wider sustainability issues on the outer ring in the figure highlight the varying and complex issues (Cox, *et al*, 2002), which sustainable housing must tackle. These issues, it should be noted, can be conflicting and it takes a great amount of knowledge and experience to balance the risks involved. To take an example from another field, in sustainable transport, though car use may be considered to be fundamentally un-sustainable in that it uses fossil fuels and emits noxious gases, car pooling or car sharing, allowing the use of cars yet reducing the number of cars on the road, may be considered to be a **more** sustainable option. The key, and the approach taken in this research, is to encourage more sustainable practices than we currently have, as opposed to seeking absolute sustainability.

Concentrating on passive solar issues (the middle ring) there are pertinent issues relating to the research that are not directly tackled. For example, this research uses whole life costing but there is potential to go much further in exploring wider life cycle issues than has not been possible given the constraints of the current research. The middle ring also has a wide range of subjective issues which, without a multi-disciplinary approach, are difficult to overcome. The inner ring, therefore, highlights the key variables which are used and determined in this research. These variables focus on the quantitative issues of passive solar design and on detached housing forms, to determine the costs and emissions of housing development if density becomes a sustainability issue.

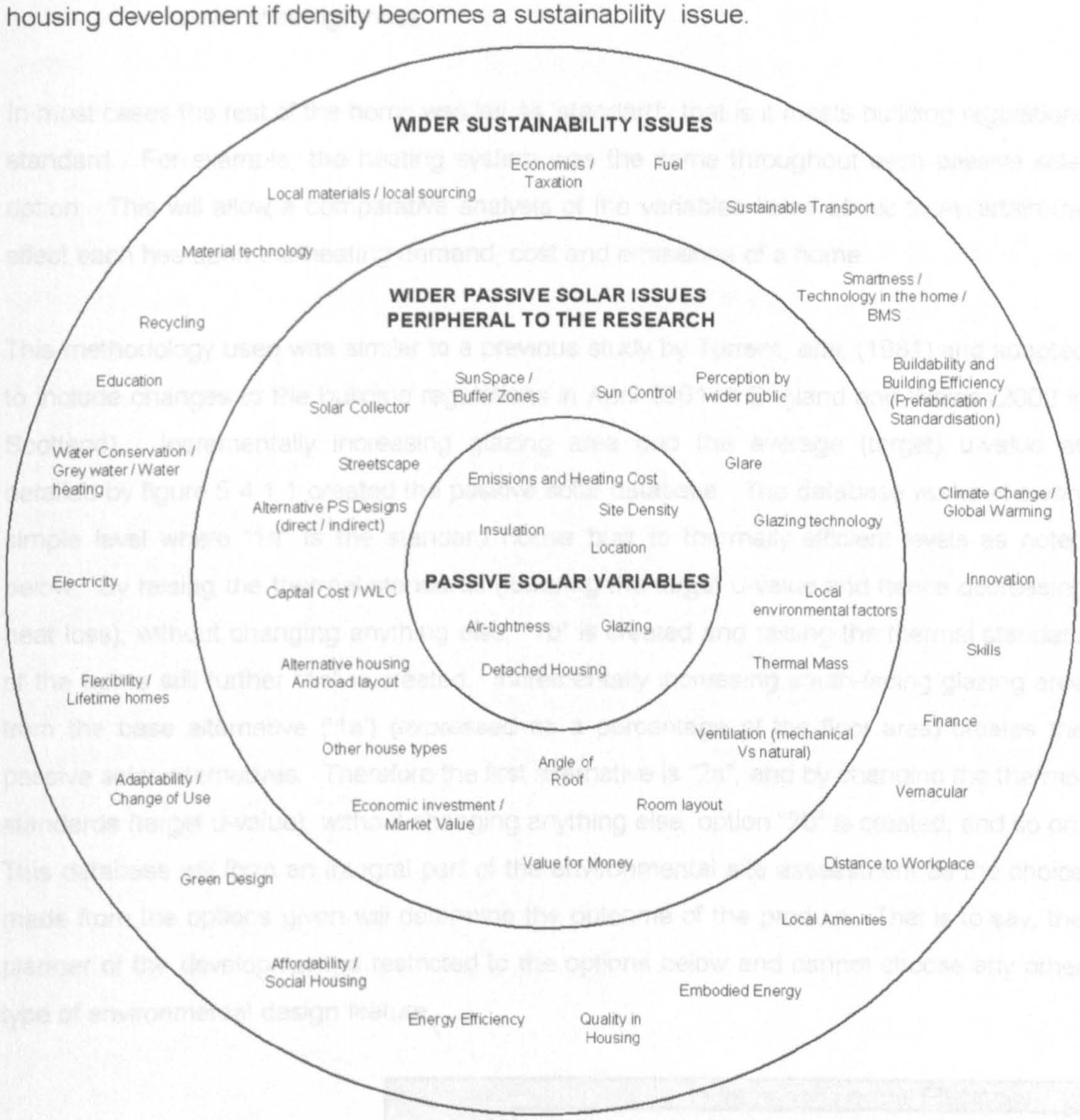


Figure 5.4.1: Restrictions placed on research.

5.4.1 PASSIVE SOLAR DATABASE

A database of passive solar options was created for use in the ESA. To find the basic operational costs of each of these options BRE accredited software was used, named JPA Designer. The basic principle for including a database of different passive solar type is to make the tool as simple to use as possible. The following list introduces the key variables used to find the various passive solar types. The features of a passive solar listed below were incrementally changed to create a variety of passive solar options. The options with the most notable differences were included as part of the passive solar database. The design basis for each passive solar home was developed after analysis of Deveci, et al, (2000) and Yannas ([2], 1994).

- Insulation standard (Target U-Value method used)
- Amount and orientation of glazing
- Level of air-tightness

In most cases the rest of the home was left as 'standard', that is it meets building regulations standard. For example, the heating system was the same throughout each passive solar option. This will allow a comparative analysis of the variables listed above to ascertain the effect each has upon the heating demand, cost and emissions of a home.

This methodology used was similar to a previous study by Turrent, *etal*, (1981) and adapted to include changes to the building regulations in April 2001 in England and Wales (2002 in Scotland). Incrementally increasing glazing area and the average (target) u-value as detailed by figure 5.4.1.1 created the passive solar database. The database works at a very simple level where "1a" is the standard house built to thermally efficient levels as noted below. By raising the thermal standards (lowering the target u-value and hence decreasing heat loss), without changing anything else, "1b" is created and raising the thermal standard of the home still further "1c" is created. Incrementally increasing south-facing glazing area from the base alternative ('1a') (expressed as a percentage of the floor area) creates the passive solar alternatives. Therefore the first alternative is "2a", and by changing the thermal standards (target u-value), without changing anything else, option "2b" is created, and so on.

This database will form an integral part of the environmental site assessment as the choice made from the options given will determine the outcome of the product. That is to say, the planner of the development is restricted to the options below and cannot choose any other type of environmental design feature.

Increasing Thermal Efficiency

Incremental Changes from the Basic Housing Type (Option 1)

	a	b	c
Option 1	1a	1b	1c
Option 2	2a	2b	2c
Option 3	3a	3b	3c
Option 4	4a	4b	4c
Option 5	5a	5b	5c
Option 6	6a	6b	6c
Option 7	7a	7b	7c
Option 8	8a	8b	8c
Option 9	9a	9b	9c
Option 10	10a	10b	10c
Option 11	11a	11b	11c

Fig : 5.4.1.1. Layout of passive solar database

Future development of the environmental site assessment will include a much larger database giving further variations on different environmental features.

It should also be highlighted that another restriction placed on this research is the focus of the costs and emissions onto one house type. The fact that all costs are drawn from the one house type may lead to problems with the use of the data in a predictive tool for all house types. The tool, however, is not for the prediction of future costs. This research is a comparative analysis so small inaccuracies in costs, etc are forgivable if the same methodology is used throughout and comparison is of like with like. It should however be recognised that in any future development of this tool this area would need to be developed so that the costs and emissions from a housing development may be more accurately portrayed. This work is included as part of the recommendations in Chapter Eight.

5.4.2 ENVIRONMENTAL SITE ASSESSMENT

To create the framework for the tool, the following input menus (figures 5.4.2.1-8 on the following pages) list the information which is required. The information needed to be general and simple due to the nature of the information available at this stage of a design. Using the simple geometrical shapes and basic values in databases and by using simple menus the ESA only requires basic knowledge of the technical and cost issues involved in a housing project, most of the calculation being hidden from the user. The current research uses Microsoft Excel for its noted usability and easy computation functions, but future adaptability of the software needs to be explored fully.

The following section details each key input menu, which the user will use. Explanation of the function of each menu is provided, along with the key mathematical calculations. The framework tool for the ESA is covered in Appendix A.

INPUT MENU 1 : General Data on Site

- Total Area of Site (TA)
- Latitude of site
- No of Plots/Houses (H)
- Road Data
  - Two way road (x)
  - Single way road (y)
  - General (Public) parking (excludes private driveways) (z)
- Green-space (estimated percentage of site) (G)
- Any area given to site other than domestic housing (a)

Figure 5.4.2.1

The tool is specifically designed to be used prior to any major design decision or construction of the project, therefore information on the site will be limited. However the information listed above should be readily available, and for risk analysis, investigation of variations in the information should be analysed. Mathematically, the information above is needed to find the actual area of the site to be used for housing, excluding the areas for roads and green-space, in particular. The number of houses (or plots) anticipated for the site is needed so that any passive solar project meets this target density. The latitude of the site will also be a known and used to find the minimum solar angle so that an optimised passive solar design may be determined that will benefit from full, year round solar access.

The density may be found, therefore, by the following equation:

Density (dph) = Total Area of Site / Number of Plots

The solar altitude is determined using software created from a known mathematical formula. Chapter six will outline how the solar altitude is calculated in more depth (also see Appendix A).

INPUT MENU 2 : Specific Data on Site

- Average area of plot (AvP)
- Average area of house
- Storey height (H)
  - One
  - Two
  - Other
- Sill height from ground level (*sh*)
- Slope angle (s)

Fig 5.4.2.2

The information listed above is more site specific, and is mostly determined by the adoption of databases listing simple geometric dimensions of a home, the footprint and height. It is assumed that each project will have different plot sizes, and this is information needs to be simplified to determine the average area of a plot. The average area of plot is first determined from the following equation:

$$AvP = \frac{TA - ((x+y+z)+(G * TA) + a)}{H}$$

Fig 5.4.2.3. Average area of plot

Having the area of a plot, the area of a home may be determined. Investigation of sites in the North East of Scotland can determine the average area of a house by finding the relationship between plot size and house size. The average area of a home on this site may also be determined by calculating the total floor area on a site and dividing by the number of houses (See data on sample plots in Appendix E). The information for this calculation, however, will not be available (or truly accurate) at this stage of a project. Once the floor area is known, the value is used to select simple housing footprints from a database.

To determine the spacing between dwellings (**X**), the storey height needs to be known. By knowing whether the building is one storey, two storey or another type, and using the floor area (the average for the site has been determined) a selection process is initiated to calculate the approximate true height. This selection process uses a database IF function. That is to say, IF a simple house has a floor area (x) and the form (one, two, other) of the house is (y) then the true height is found (H). This framework tool assumes that all the houses are the same height, but for sites with various heights (one or two storey) then product development of this tool would incorporate this aspect.

Using the simple geometric values for the site, an estimated spacing between dwellings (on a north-south axis) is determined. This information provides data for determining the obstruction angle (expressed in figure 4.3.2.3) as:

$$\text{Tan } \Theta = \frac{H}{X}$$

The equation above (Yannas, [1], 1994, p52) gives an obstruction angle (tan □) for the site, this equation does not consider other factors such as slope angle (an important consideration as most sites are not flat) and the sill height (the above equation assumes a sill height of 0m, ground level). Therefore a more accurate obstruction angle is determined by the following equation:

$$\text{Tan } \Theta = \frac{H - sh - (\text{Tan } s * X)}{X}$$

Fig: 5.4.2.4. Calculation of obstruction angle in the environmental site assessment

The reduction or increase in spacing caused by the slope angle (s), which could be a positive or negative value, is calculated by multiplying slope angle by estimated spacing (a re-arranged form of the previous equation where 'H' is found). The value for the sill height (sh) is determined from a chart sourced from Yannas ([1], 1994), which calculates the reduction in spacing for various sill levels from 0 to 2 metres above ground level or by using the mathematical formula also in Yannas ([1], 1994, p52).

INPUT MENU 3 : Orientation

- Number of houses facing which direction
    - North, North East, East, South East, South, South West, West, North West
- Number of homes on southern boundary

Fig 5.4.2.5

Yannas ([1], 1994); Kachadorian (1997) and Borer & Harris (1998) are only three of the many sources which highlight the fact that PSD may not need to directly face south. Therefore this software can determine the effect on heating demand if a typical passive solar home does not face directly south. The values have been calculated to incorporate the changes to the Scottish thermal regulations in 2002, and are displayed in tabular format in the framework tool (see Appendix A for all tables in the tool). The user needs only to select the main orientation, and the additional heating demand in calculated.

The orientation and total of houses on the southern boundary of the site also needs to be known. In these homes, the effect of overshadowing is not from within the site, but from the exterior of the site. These homes, therefore, are excluded from previous calculations under the headings general and specific site data.

INPUT MENU 4 : Exterior Obstruction

- Is there an exterior obstruction?
  - Yes, No
- Height of obstruction
- Distance from obstruction
- Approximate number of houses affected by obstruction

Fig 5.4.2.6

The ESA tool will also determine the effect of exterior obstructions, if there are any. Similar to finding the obstruction angle between housing, the height and distance of an exterior obstruction are needed to determine the obstruction angle. This in turn will determine if there will be an increase in the heating demand if the exterior obstruction prevents full, year round solar access. The distance and height of the exterior obstruction, unlike for the overshadowing calculations for the main body of the site, should be a known. The exterior obstruction is an existing obstruction, such as a mature tree, hill, house, or similar. Anticipated future obstructions cannot be included if their height and distance to buildings are unknown but should always be a consideration. The number of houses affected by the obstruction may be a estimated total as it depends on the type of obstruction. Simple plotting of the shadow of the obstruction, however, can determine, fairly accurately, the area affected and hence the anticipated total of houses which the obstruction will effect.

INPUT MENU 5 : Passive Solar Alternatives

- Selection process from passive solar database
  - 1 - Type of insulation (*Standard, Energy-efficient or Super-insulation)*
  - 2 - Level of air-tightness (*Standard, Intermediate or Super*)
  - 3 - Amount of glazing (*Standard – range of glass to floor area ratios*)
  - 4 - Boiler type (*Standard, Biomass, energy-efficient*)
- Selected output from passive solar database

Fig 5.4.2.7

See 5.3.1 on how the passive solar alternatives were devised. The tool needs to select an appropriate passive solar option from the passive solar database. The selection process has been made as simple as possible, using simple recognisable linguistic options, but does require a level of technical expertise. This may be overcome by running a risk analysis by looking at each option individually to find the benefit or cost of each alternative. The user is given four menu choices, with a further range of options (typically three options minimum). Given these selections, a passive solar option is selected from the database. It should be noted that boiler type is included as a menu choice, but the demonstration tool created only a limited amount of options using either Biomass or energy-efficient boiler types.

INPUT MENU 6 : Life Cycle Costing Information
- Discount Rate (i)
- Period of Analysis
- Cost Data and Period for passive solar option
  - Survey and inspection, period
  - Maintenance/repair, period
  - Replacement, period
  - Residual costs, period

Fig 5.4.2.8

Life cycle costing is an ideal decision making tool to determine the best scenario of a product, element or house over the whole life cycle. The framework tool includes a simple analysis of LCC between the alternatives and asks the user to include costs for the items above. It should be noted that the operational costs are included in the life cycle cost analysis, and the cost is determined dependant on the passive solar option chosen. The values above require some level of expertise on behalf of the user, but Government sources may find the discount rate (which is an amalgamation of various taxes). A risk assessment of the life cycle costs may be conducted (by the user of the tool) by varying the discount rate of future costs to get an accurate portrait of the variations of future costs. Others sources for life cycle costs and information include prices books, Kishk (2001), Seeley (1996), BMI (1999) and Ashworth (1996). The main mathematical tool used in the ESA to find the present worth of costs can be expressed (see figure 4.4.2a) as follows:

$$PW = \frac{1}{(1+i)^n} \times F$$

Where i = interest rate per period
n = number of interest periods
F = future amount

5.4.3 CASE STUDY

This project has benefited from previous research of a case study in the North East of Scotland (Deveci, et al, 2000). The research, discussed in Chapter Six and more fully in Appendix B), investigates an affordable passive solar design using LCC, performance evaluation and POE techniques. The case study is included in this research as an information source on important specification criteria, such as glazing, orientation, insulation, etc. The project selected for study is a home in Peterculter, Aberdeen designed to reduce the dependence on non-renewable fuels. One of the passive solar options is based on this case study. This enables an option in the database to benefit from the practical information provided by the case study so as to ensure that the passive solar options are both realistic and will work in most locations in the North East of Scotland.

Analysis of the home after construction is essential in determining the *real* performance of a passive solar home. By using hardware which can log the temperature and humidity for months at a time at various locations in the home, a realistic analysis of the case study home was undertaken. The use of thermographic technology to determine both the extent and location of heat loss can also offer vast improvements in future homes.

An energy analysis also provides information on energy patterns in a home, ensuring that every space in a home is heated appropriately. The case study allows a look at a passive solar design in practice, to determine the amount of heat used on the coldest winter day and the possibility of overheating in summer.

5.5 SOURCES AND DATA COLLECTION

Standard Housing and the North East of Scotland

In creating the database of standard housing types, the internet was initially used to establish new projects in the area and the type of housing currently being built in the North East of Scotland. The sites chosen had detached housing as the main housing type and exhibited high density, characterised by their proximity to their neighbours. The local council (Aberdeenshire) was used to get more accurate data on sites in the North East of Scotland such as the density of these sites. Where possible, this was backed by site investigation of various projects built in the past ten years, projects recently built or under construction and sites for future construction. Sites visited included Portlethen, Westhill (Elrick) and Peterhead. The housing developers in the database, chosen because they regularly build in this area, are listed below;

- Bett Homes (http://www.betthomes.co.uk/)
- Cala Homes (http://www.cala.co.uk/)
- Wimpey Homes/McLean Homes (http://www.georgewimpey.co.uk/)
- Stewart Milne Homes (http://www.stewartmilne.com/)
- Robertson Homes (http://www.timberkit.co.uk/)
- Scotia Homes (http://www.scotia-homes.co.uk/)

All the development sites used in the study were obtained from the Aberdeenshire Local Plan. This does not however detail the specifics of site design (such as the number of detached, semi-detached or terraced houses).

Passive Solar Design

Sources of information for passive solar design also stemmed from the internet, however, literature sources were predominantly used for the investigation into passive solar design. Published data from the Building Research Establishment offers more relevant data on passive solar homes in the UK (BRECSU, 1995 & 1997; Yannas, [1], 1994). Case studies are the most useful source of information on passive solar design, but there are few recent examples of this type of housing (Deveci, et al, 2000; Borer and Harris, 1998; Yannas, [2], 1994). Investigation into passive solar in the seventies in the US is covered Balcomb (1992) and more recently by Kachadorian (1997).

Software and models

Yannas ([1], 1994), Borer and Harris (1998) and Kachadorian (1997) provide mathematical tools for the calculation of solar gain and whole house operational costs. These tools were referred to in this research but the standard assessment procedure (SAP) software, BRE accredited, called *'JPA Designer'*, was mainly used to find operational costs of standard and passive solar house options.

In order to incorporate the data in the environmental site assessment, the information needed to have the following characteristics:

- Can be incorporated into software which calculates energy cost and emissions
- To be comparable, simply and efficiently
- Costs needed to be on a rate per floor area (m^2) basis
- Easily entered into a computer package as part of the environmental site assessment
- Use simple input data for complex calculation
- Have ability to be used as a whole life cost, if applicable
- Available to be part of a GIS mapping system in future developments

The environmental site assessment was manually created from various government accredited data sources and transferred into a spreadsheet. Mathematical models for the computation of alternatives were readily available but are indeed complex, though the input data needed to create an analysis of alternatives needs to be kept simple.

5.6 DATA PRESENTATION

A visual display of the data represented in the framework tool for an environmental site assessment offers various advantages over other mathematical based data representation techniques. Tufte (2001) notes that the visual display of complex ideas communicates with, "clarity, precision ,and efficiency" and this is important to illustrate cost and emission benefits of passive solar designs over current methods of construction.

In addition, visual data representation can graphically portray more clearly each comparative option. There is a minimum of three options to be portrayed in the analyses, which are listed below (see figure 5.6.1). With three options being used to compare costs and emissions, the visual representation technique seems the most appropriate way of portraying the data from the tool.

- Standard Housing (site layouts, which adhere to current methods of construction)
- Optimised Passive Solar Housing (Passive layout to benefit fully from passive gains)
- Selected Option by User (Option A, Option B, ..., Option Z)

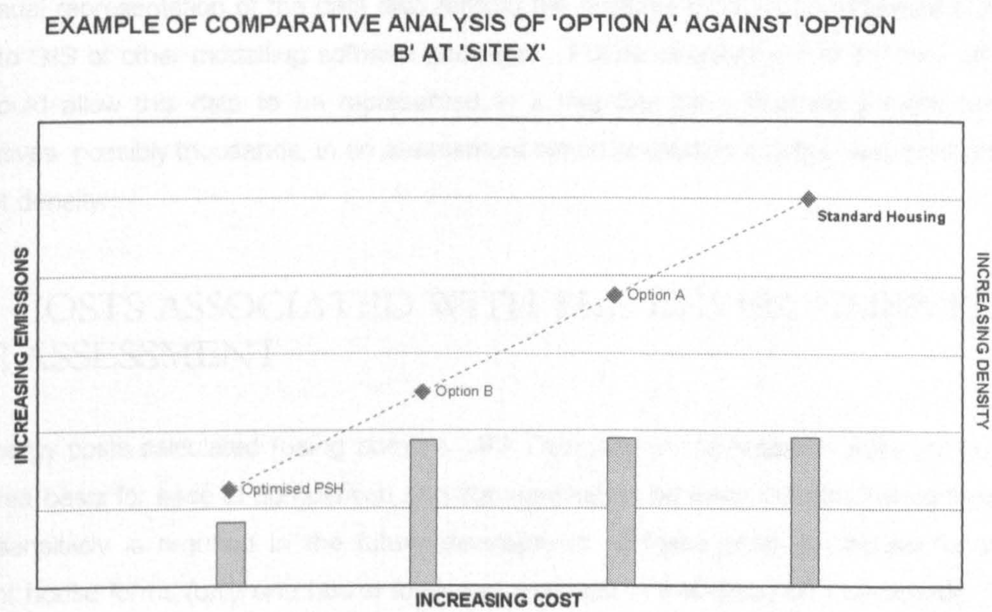


Fig 5.6.1 : Example of proposed visual data representation for ESA

From this visual representation of the data from the environmental site assessment there is some key information which can be derived:

- The graph represents the emissions, cost (points) and density (bars) of each option.

- Option A and option B are midway between optimised and standard housing in this example. This tells the user that there are trade-offs are needed to achieve an environmentally friendly design on this site over an optimised passive solar design;
- Comparing option A and B with standard housing on this example also tells the user that some savings are possible without requiring loss of density on the site, and;
- The dotted line connecting each alternative is in relation to the heating system type and efficiency. This was a restriction on the research. In future research, this relationship would not be present if different heating systems were used.
- The density of each site is displayed using a bar graph (values read from the right axis). This research looks at density as an issue of a more sustainable housing development therefore the densities of Standard, Option A and Option B are identical. The optimised passive solar heating alternative saves on cost and emissions primarily by having fewer homes on Site 'X'.
- Future development of this presentation technique may include further data to incorporate more qualitative information.

This presentation technique is used to illustrate the test site provided in Chapter Seven.

The visual representation of the data also reflects the possible product development of the tool into GIS or other modelling software packages. Future development of the tool using GIS could allow this data to be represented in a map-like form, illustrating many more alternatives, possibly thousands, in an assessment aimed at establishing the best alternative at a set density.

5.7 COSTS ASSOCIATED WITH THE ENVIRONMENTAL SITE ASSESSMENT

The energy costs calculated (using primarily JPA Designer) in the research were on a unit floor area basis for ease of comparison and standardisation between different house types. More sensitivity is required in the future development of these costs to include for the different house forms (only one house form was analysed in this research - detached). To clarify, all costs are derived as follows, for a 100m^2 home with heating costs of approximately £250/year the basic rate is £2.50/m^2/year. From this other homes of the same technical design and geometrical proportions, but of different floor area, can be assumed to have the same energy consumption per m2, on average. As stated earlier, this research is a comparative analysis and future research will be developed that will incorporate data on alternative house types and house sizes can predict future costs more accurately.

Energy costs are based on data from software relevant to the 2001 changes to the thermal efficiency standards and are already out of date – the product therefore requires continuous development with regard to updates. Due to environmental sustainability initiatives, limitations of fossil fuel and global warming the cost per unit of different energy sources will fluctuate. Electricity costs in future will reduce when more sustainable sources of electricity will be used, and gas / oil cost per unit are set to increase due to the limitations of fossil fuels. These costs are set to change radically in the next decade.

5.8 SUMMARY

- The restrictions on the research are discussed and highlighted (figure 5.4.1). As necessary, the research has focused on the quantitative aspects of passive solar design and though other aspects are not included in this research that is not to say they are not recognised as being important.

- Data was collated on detached standard housing on sites around the North East of Scotland and passive solar housing. These housing types are represented in a tabular / database format in view of future research using GIS.

- Standard, commercially available (BRE accredited) software for calculating operational energy use was used, though in future costs may change and this would require regular updating of this information (by post or downloaded). This information forms part of a combined database of standard and passive solar housing.

- Sources of data are readily available to calculate all aspects of housing and passive solar, though they require collating into a single product. The environmental site assessment aims to do this without requiring the planner to be experienced or to have much knowledge of environmental design.

- A visual method of representing the data is preferred as it is more easily understood and representative of the data output when expressing complex data. In addition, it is more representative of the future method of data representation through GIS.

6 Initial Investigation of Sites and Collation of Data for Environmental Site Assessment

6.1 INTRODUCTION

This section will establish the optimum density for a group of passive solar homes in the North East of Scotland. If groups of passive solar homes do not meet the density set by current methods of development in the North East of Scotland, methods of overcoming this shortfall will be investigated. This chapter will first introduce a case study of an optimised passive solar design in North East of Scotland.

This section will also describe the creation of a database of standard homes. A simple standard home has been used so that a database of passive solar homes can be derived from this basic home and the spacing of current methods of development can be established.

Putting the data on standard and passive solar homes into database format is essential. Databases will overcome the need for the user of this product to be technically proficient in this area by making the calculation process more automated. In addition, databases of housing types make it simpler to develop the method and to incorporate into GIS. The use of databases is not new, Turrent, *et al*, (1981) used a database format incrementally to increase insulation, change orientation and add glazing to a standard home type, and this study clearly illustrates the benefits of doing so. Modern building simulation software often uses databases to automate the calculation process so that non-professional personnel can use the software (this broadens the market they can sell the product to).

As discussed in chapter 3, passive solar is a holistic approach which incorporates various aspects of building design and technology. This section also investigates the critical elements of construction that constitutes a PSD. Insulation, air-tightness and glazing offer significant input into a passive solar design, and their influences will be briefly discussed. The creation of a passive solar database is important for the tool and the construction of this is detailed in this chapter. The costs and emissions of each passive solar alternative will be given and discussed.

6.2 INTRODUCING THE ZERO HEATING HOME

The 'zero heating' home was a building developed by architect Gokay Deveci assisted by a team of researchers from the Robert Gordon University including the author. Located in Peterculter, Aberdeen and built in 1999-2000 it is a working example of a passive solar design in the North East of Scotland. It is used in this research as both an example and a reference point for the development of a passive solar database. It is a home that simply tries to reduce the heating demand by using passive solar design, utilising internal heat gains, having a thermally efficient building envelope (super-insulation in floor, walls and roof) and using thermal mass (in the floor). The extra cost of these features was not to be at the expense of the client, therefore the construction method was efficient to reduce structural costs and there was no dedicated heating system. The only heating feature in the home is a wood burning stove. The following sections describe the case study more fully.

6.2.1 THE BACKGROUND AND AIM OF THE ZERO HEATING HOME

One of the aims of the 'Zero Heating' home was to move away from environmental designs as showcase projects or the use 'cutting edge' technology. The reason for showcase projects, such as the Integer house, is straightforward – they are used to highlight and encourage the use of renewable and innovative technologies that may not be understood by the wider construction industry. The technologies are expensive, however, and rarely are they used in mass market, housing developments and they, arguably, encourage the perception that environmental design is expensive. The design principles in this case study are simple and basic environmental and vernacular architecture to ensure that the design is acceptable to the general public. The design is an evolution of previous projects and therefore brings together these design principles through practical experience and life cycle analysis.

In order to achieve reduced energy use, improved life cycle criteria and/or enhanced sustainability, there is assumed to be an inevitable capital cost increase, however modest. The 'Zero Heating' home is a practical demonstration that this need not be the case. It has delivered savings in energy use, adopts broader sustainable criteria, at an initial capital cost less than the most basic specification private sector housing by the volume builders. This has been achieved by adopting affordable and basic environmental design principles and taking advantage of the inherent environment properties of a construction system developed to reduce material use and capital cost.

The specific aim of the design and construction project, built for a private client and completed in November 1999, was to reduce the need for dedicated heating plant to be as close as possible to zero in a simple, replicable design which could be applied, perhaps in modified form, to a mass market for affordable housing.

6.2.2 THE DESIGN

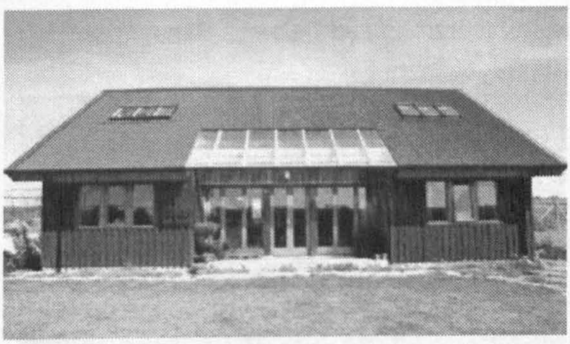
The basic ethos of the research at The Robert Gordon University is to exert maximum pressure to ensure that new homes realise the highest standards of sustainability affordably. There is no argument that with the predicted growth in the house building sector over the next decade (DETR, 1996) it is important that designers realise that a more sustainable house building industry is needed. At the core of the increasingly complex concept of sustainability (Cox, *et al*, 2002), lies the need for greater energy conserving designs.

The 'Zero Heating' home is the latest, it should be highlighted, in a series of built designs, which are the result of an iterative research and design process.

Plc 6.2.1 & 6.2.2 : Affordable Rural Housing Project, Kincardine O'Neill, Aberdeenshire

The Affordable Rural Housing Project primarily tackled the issues of affordable homes in rural locations but as a key secondary criterion tackled broader sustainability issues. Using timber throughout and utilising the concept of lifetime homes through flexibility (movable partitions) and adaptability (prepared un-utilised loft-spaces) these buildings exhibit affordable quality homes.

This project, however, failed to tackle basic energy efficient issues (though insulation was slightly greater than standard at the time of construction) and the only energy conservation, arguably, is through the utilisation of timber (as compared to more common alternatives). Future projects would incorporate aspects of PSD, thermal efficiency, etc. This would be achieved without significantly increasing capital expenditure.



Pic 6.2.3 & 6.2.4 : The Van Midden House, Netherley, Aberdeenshire

The Van Midden House was an intermediate variation along the same theme. This home was orientated south to benefit from passive solar gain, was open plan and had increased levels of insulation and thermally efficient windows. This home is similar to some passive solar designed buildings south of the border in basic geometric shape (Yannas, [2], 1994) but the form is also a reflection of local architecture. This home had a wood burning stove as the main method of heating but did require prolonged periods of heating. The capital saving was made by using recognised building techniques (timber frame) and ensuring that waste from the construction process was reduced to a minimum. It was hypothesized after the construction of this home that the heating in a subsequent home using the same construction technique could be reduced to almost zero therefore not needing any heating at all without adding to the capital expenditure.

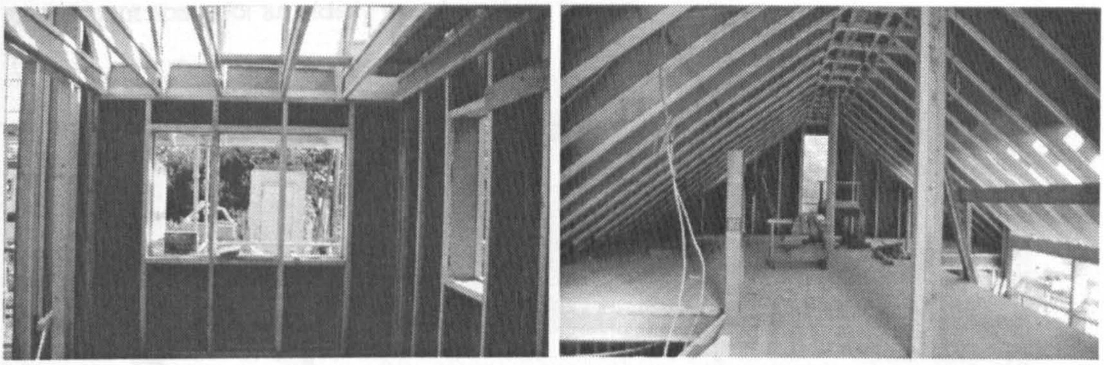
The 'Zero-Heating' house is the latest evolution of this design philosophy. The 'Zero Heating' home is a timber (I beam) framed, timber clad, detached house, using standardised components and incorporating a number of relatively simple technological approaches. The principal aim of this design was to ensure that, as far as possible, all the heating needs of the house can be derived from internal gains such as lighting, cooking, human body heat etc, thus eliminating the need for a central heating system. The energy efficient specification therefore includes;

- Super-insulation within the depth of structural timber "I" beams using recycled, newspaper insulation
- Passive solar design employing some thermal mass to smooth out diurnal temperature fluctuations
- Low E triple glazing to optimise heat loss to heat gain ratio
- Closely controlled mechanical ventilation with heat recovery through extractor units
- Quality control of the construction process to guarantee optimum air-tightness
- Solar water heating through roof-mounted panels
- The use of sustainable materials, including locally produced, recycled and 'waste' materials selected by LCC and a weighted evaluation.

Pic 6.2.5 & 6.2.6 : The 'Zero Heating' Home, Peterculter, Aberdeen

Most aspects of the design are not conceptually new. Rather its originality lies in bringing together reliable, simple energy conserving technologies holistically and in an affordable manner. The main thrust of the idea for this building was the elimination of dedicated heating plant through the use of insulation 400mm thick in the roof, 350mm thick in the walls and 200mm thick in the concrete floor acting as the thermal mass.

The 'Zero Heating' family home is built using timber 'I' beams, which are simultaneously quick to install and designed to be less expensive than traditional construction by spanning clear lengths without the secondary supports needed in trusses. This allows for a large upper storey open space in the roof (6.2.8 below). Except for the main glazed facade facing south, all windows were placed between timber studs to reduce waste. There are a number of additional advantage of the structural system used in that the timber was from a sustainable source, the glue used by the timber 'I' beams is environmentally friendly and the construction uses a third less timber than the solid timber alternative. The crucial advantage of these 'I' beams, however, lies in their increased depth, which allows extremely deep insulation to be incorporated into the structure without any significant cost penalty in terms of additional structure. The reduction in cost of the structure of this building was also aided by the fact that it is similar in form to the Van Midden home. The same builder is also used for the 'Zero Heating' home. The design also incorporates an air tight envelope and heat recovery in a mechanical ventilation system.



Pic 6.2.7 & 6.2.8 : Structure of the 'Zero Heating' Home

Externally, the building is clad in locally purchased Scottish larch cladding with clay tiles, both of which have expected life spans of around 60 years (Component Life Manual, 1992). The glazing is mostly south facing, with most of the north, east and west glazing restricted. This allows daylight to enter on the south facade while reducing heat loss on the remaining facades. The windows are triple glazed, krypton filled units, roof lights are double glazed and 'low E' glass is used throughout. Ventilation is controlled using mechanical units with heat recovery, which were tested in laboratory conditions.

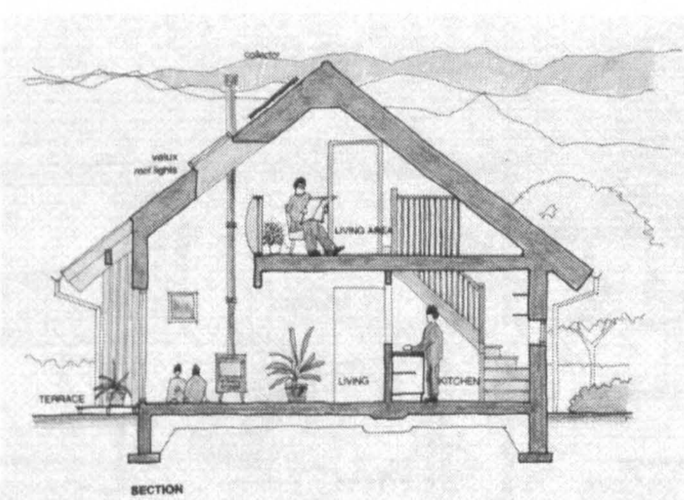


Fig 6.2.9 : Section through home

The interior of the building is more open than conventional, 'cellular' homes, which allows heat to circulate more effectively, employing the concept of 'buffer zones' or 'comfort zones' (Borer & Harris, 1998; Case, 1983). Another innovation is the near elimination of dedicated circulation space by allowing all rooms to open off the central living space and balcony. As a consequence most of the interior space is two storey, which allows light to flood in for long periods of the day.

The following figures illustrate this concept. Please note that the master bedroom on the ground differs from the opposing side due to the client's requirement for a separate apartment space for an elderly member of the family.

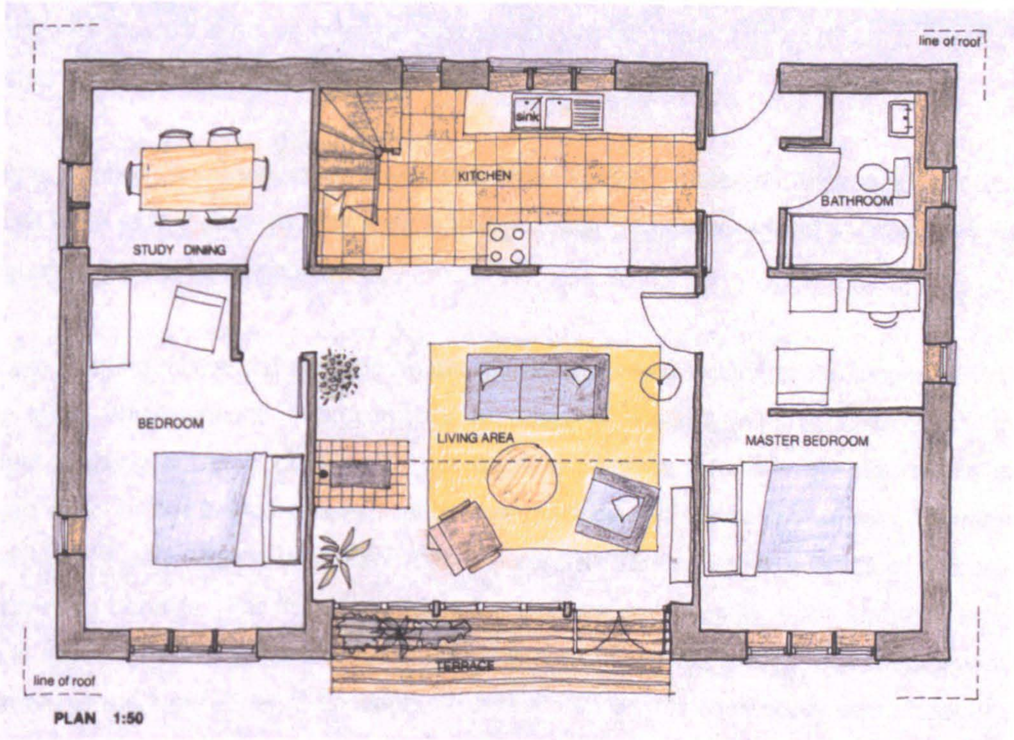


Fig 6.2.10 : Ground Floor Plan

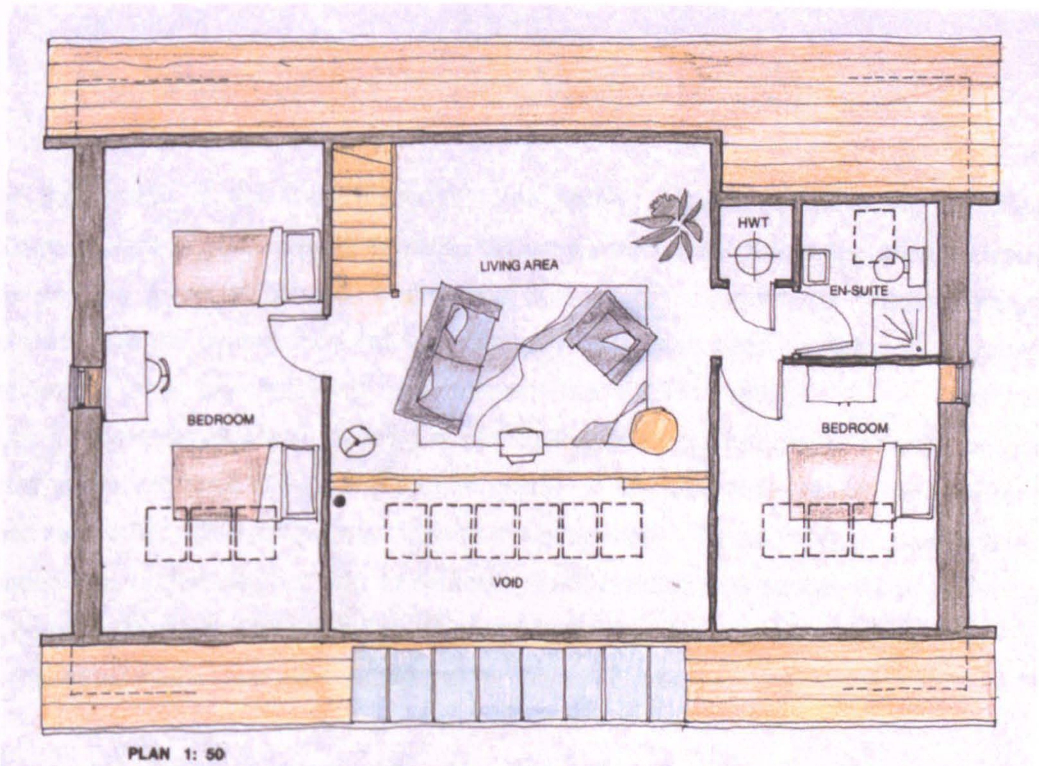


Fig 6.2.11 : Upper Floor Plan

In addition to the added insulation, passive solar design, thermal mass, mechanical heat recovery fans and triple glazing, solar panels were installed to aid the water heating of the house. A wood stove is also included in the central living space as a back-up during winter, though preliminary studies by the Robert Gordon University suggested that internal temperatures inside the house over the year should not fall below 14°C, without the use of a dedicated heating plant (Deveci, *et al*, 2000).

The specification also included environmentally friendly materials wherever possible. Materials were locally sourced whenever possible, leading to lower embodied energy as well as, arguably, greater sustainability.

The 'Zero Heating' home claims to be an affordable, replicable model for housing which can deliver large environmental improvements at costs consistent with, or lower than, the cheapest housing currently on offer by our builders of mass housing. These results are achieved even for the one-off prototypical development carried out so far. Moving to greater standardisation and volume production offers potentially much higher savings and greater environmental benefits. Far from compromising architectural integrity, such standardisation can, it is argued, help to improve many aspects of our built environment. This is achieved in the climate of the North East of Scotland. The research on this case study was undertaken during 2000-01 was used to establish if these claims were accurate, a brief summary of the research undertaken is given in the following sections.

6.3 THE RESEARCH ON THE 'ZERO HEATING' HOME

Whilst the design of the 'Zero Heating' home applied a series of generally accepted principles of good, environmentally sensitive design it would have been inappropriate merely to assume the levels of benefits arising from this design. Indeed the building design professions and the construction industry generally have often been criticised for a lack of measurement and 'benchmarking' of achievements (DETR, 1999). A key factor in producing innovative affordable housing in particular is ensuring that capital savings are not secured at the expense of higher life cycle costs. A life cycle analysis of the home set against two other alternatives was therefore undertaken. In addition, a performance evaluation was undertaken not only to establish if the building was successful in achieving basic comfort targets but also to inform so that future variations may be improved upon. A performance evaluation was also undertaken for the same reasons.

6.3.1 THE LIFE CYCLE COST ANALYSIS

There are obvious life cycle advantages to the 'Zero Heating' home in terms of energy use, but these need to be set against the capital expenditure and the maintenance profile. The Research Team therefore carried out a desk study of the life cycle costs of the design, using computer based techniques developed by a team of researchers at Robert Gordon and Salford Universities (Kishk, 2001).

The life cycle cost study assessed the capital, maintenance, running, operation and eventual disposal costs of the house through its life cycle, as well as modelling theoretical energy running costs. The study was carried out using the best available, industry standard information. A sensitivity analysis was carried out to ensure its robustness in the face of a wide range of possible future scenarios (Kirk & Dell'Isola, 1995; Bull, 1993). Life cycle costing was used for two separate purposes, these were:

- As a tool for the selection and specification of building elements and materials prior and during construction. Importantly, the study was carried out iteratively with the design process with, for example, conclusions about the maintenance profile of materials informing design decisions.

- As a tool to ascertain recommendations for future evolutions of the design concept. After completion, a further life cycle study was undertaken to analyse three alternatives: the 'Zero Heating' home; a design of the same form as the 'Zero Heating' home but with conventional materials for Aberdeenshire and insulation to building regulation standards and an 'off the shelf' standard design of approximately the same size by a local developer.

The Team was anxious to ensure that the life-cycle study helped to optimise the design. For example, whole life costs are minimised for an insulation thickness of between 300 and 450 mm. Consequently the 'Zero Heating' family home has 350mm of insulation in the walls and 400mm of insulation in the roof. Life-cycle information is thereby used intelligently in the design process, rather than merely in a post-facto justification process.

The building life cycle was assumed to be sixty years, a conventional assumption for this kind of study (Ashworth, 1997, Ashworth, 1996). A variety of cladding materials, including Scottish larch, softwood, concrete block and render, brick and metal cladding were assessed over the stipulated life cycle. These results challenge conventional thinking about the 'temporary' nature of timber as a cladding material and are confirmed by many examples in the north of Scotland. Environmentally friendliness, local sourcing, affordability and LCC analysis were the key components in the selection of these materials to ensure short and long term benefits.

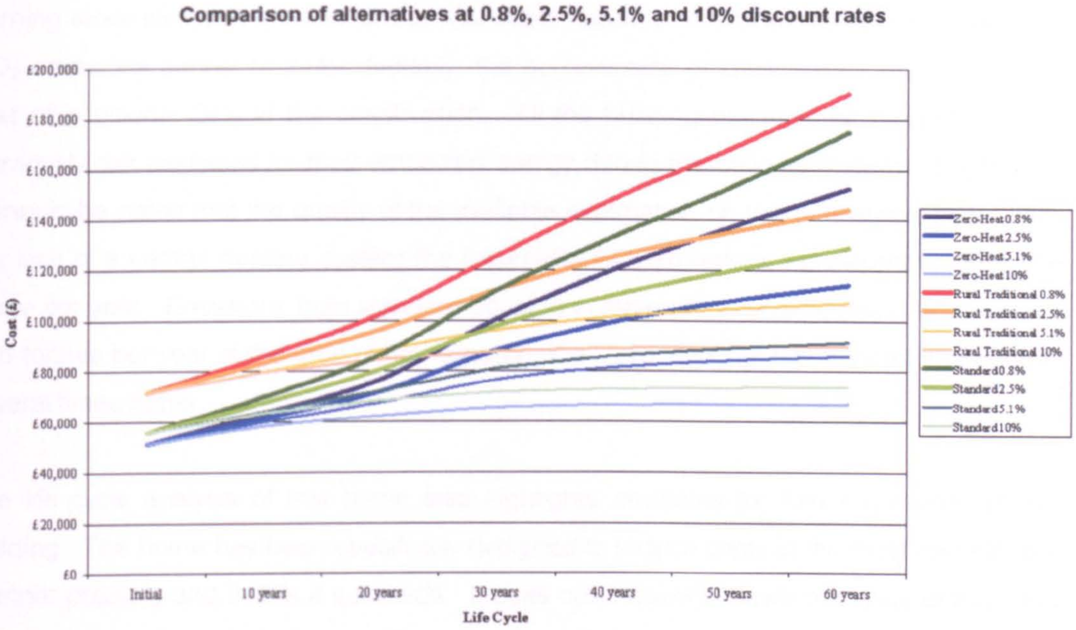


Fig 6.3.1.1 : Comparison of alternatives at four various discount rates(The Zero-Heat home, The Rural Traditional (based on average costs from technical literature) and The Standard house (based on tender costs for an off-the-shelf timber frame developer)

In its primary aim of reducing heating costs the 'Zero Heating' home succeeds in reducing annual heating costs by 74% over current 'standard' housing designed in accordance with modern building regulations at all discount rates (see figure 6.3.1.1). The most striking feature of the design is its ability to save on heating bills, with a SAP (standard assessment procedure) rating of +120 (at the time of construction). A summary of the total life cycle costs at 2.5% discount rate is given in figure 6.3.1.2 detailing where the primary benefits of the 'Zero Heating' houses are. Investigation of various discount rates were conducted but the 'Zero Heating' home remained the preferred alternative.

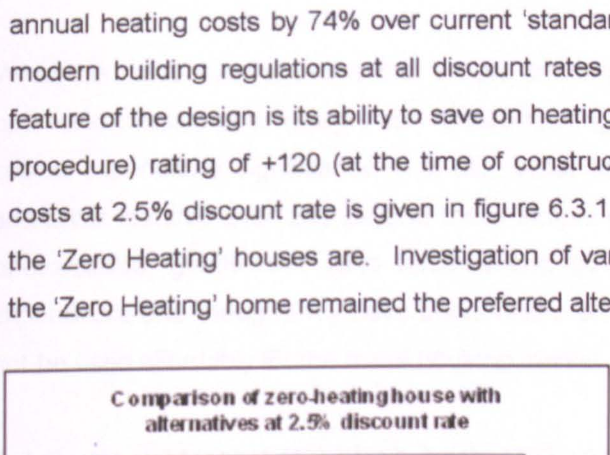


Fig 6.3.1.2 : Summary of Life Cycle Costs between Alternatives

Over the life cycle of a building, the CO_2 emissions are also an important consideration for any design. The 'Zero Heating' home exhausts considerably less CO_2 emissions every year than its nearest alternative through the lack of fossil fuelled heating. The use of a wood burning stove was also chosen for the renewable nature of the biomass fuel, thus reducing CO_2 emissions almost to zero. Notably, the achievement of lower emissions is not at the cost of additional CO_2 in the construction. All the building materials for the project were previously risk assessed for their embodied energy during the building materials life, though it should be noted that the quality of the available information on this is relatively poor. With the lack of a central heating system the theoretical CO_2 emissions were approximately one tonne per year. Emissions from standard housing in the north east of Scotland is between 4 to 6 tonnes per year at the time of the research, the 'Zero Heating' home therefore performs several times better.

The life cycle analysis of this home also highlights problems for future variations of this building. The home has been specifically designed to reduce costs in the most cost efficient manner possible and in this it succeeds. It does not, however, tackle the issue of electricity and water heating sufficiently. The problem of these issues is highlighted by the specification of $4m^2$ of solar panels to aid the water heating in the home. The solar panels have obvious environmental benefits yet the payback for just $4m^2$ of solar panels is just under 60 years with a best case discount rate (Scott, *et al*, 2000). This is the case for many 'add-on' environmental features of this manner.

What this case study shows is that simple environmental designs features, in this case an optimised passive solar design, can reduce heating costs significantly without adding to the capital expenditure significantly, if at all. What the life cycle analysis also shows is that additional features over and beyond these simple design measures such as solar panels, photovoltaics, geothermal, wind turbines and so on will add significantly to the capital expenditure and though they have undoubtable environmental benefits, these features can not be used affordably for the mass housing market.

6.3.2 ENVIRONMENTAL MONITORING AND EVALUATION

A crucial aspect of the research on the case study, the 'zero heating' house, was the confirmation, as far as possible, of theoretical performance with the reality of the building's use. This is important for the three following reasons

- To confirm the quality of the design
- To compare with the validity of the desk study assessment methods
- To provide recommendations for future evolutions of the design concept

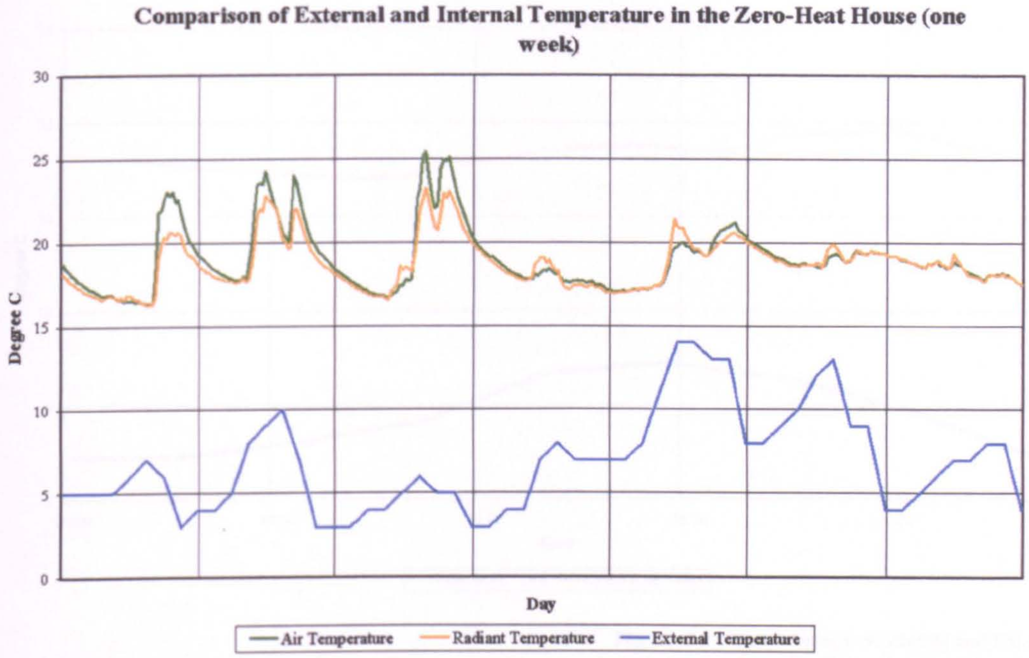


Figure 6.3.2.1 : logged temperature in main living space (proximity to the stove highlights periods when stove is heating home and when external temperature is such that the stove is not needed)

The environmental monitoring took place over a period of 24 months and included both the coldest part of an Aberdeen winter and some of the warmest periods in the summer (the figure above details one week in March). Temperature and humidity sensors were placed in various locations throughout the home and external temperature readings were also taken. Sensors were linked to 'Squirrel' data loggers and the longitudinal data downloaded periodically. Energy use was also monitored over the period. An initial assessment of the quality of insulation was also carried out using a thermal imaging camera.

The results confirm the desk studies and the precepts of the design. The internal climate during the period of analysis fulfils the entire requirements for creating a healthy home. Areas where the 'Zero Heating' family home succeeds are as follows;

- Provide good daylight and sunlight
- Insulate well to provide thermal comfort
- Air-tight construction which avoids draughts
- Uses well-insulated, air-tight construction to avoid condensation
- Vents pollutants & excess moisture at source
- Has plenty of open-able windows
- Easily understood secondary heating element, which is radiant, and uses bio-mass fuel

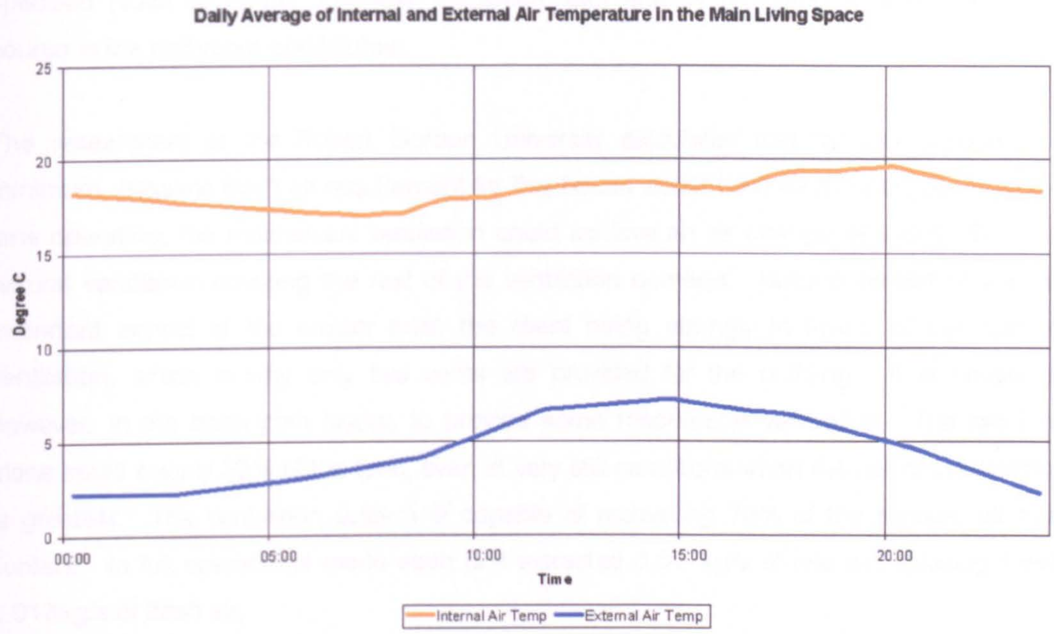


Fig 6.3.2.2 : Daily average of Internal and External air temperatures in the 'Zero Heating' taken during 2000 Winter (Dec-Feb)

For external daily temperatures above 5°C (please note that the external temperatures do not take into account Wind-chill), the secondary heating element (wood stove) is not required to heat the building. The 'Zero Heating' family home maintains temperatures for each day at an average of between 17 to 18°C through passive solar heating, internal gains and a well-insulated structure. When the external daily temperature averages below 5°C the secondary heating element is required to burn for 2-3 hours which will then heat the house for around 24 hours. The daily average temperature for the 'Zero Heating' home is given in figure 6.3.2.2 which shows a consistent and comfortable temperature. During the period the desk studies were confirmed as accurate in predicting the potential savings of around 70% over standard housing in Scotland. When the heating is needed, however, the wood burning stove proves to be ineffective, heating the area slowly at first before heating the space to quite a high level. The heat ensures that the landing space above the main living space is too warm throughout the day when the stove is used and the occupants then open a window to compensate. The area above the stove is now being used, as a consequence of the overheating, as a space for drying clothes.

The average temperature at night is 16.5°C and the average temperature during the day is 17.75°C for the living areas. In the evenings, when the building is fully occupied, the average temperature (until midnight) was between 18.5°C and 20°C.

Internal humidity falls within the recommended comfort zones. All rooms range between 41 and 49%. It is hypothesised that humidity is controlled by the highly hygroscopic materials specified (such as timber, cellulose insulation, etc) and by removing excess moisture at source in the bathroom and kitchen.

The researchers at the Robert Gordon University calculated that for four occupants a minimum, baseline fresh air requirement for this house would be 0.49 air changes. With two fans operating, the mechanical ventilation could achieve an air change rate of 0.15/hr with natural ventilation covering the rest of the ventilation demand. Natural ventilation was an important aspect of the project brief, the client being strongly in favour of this form of ventilation, which is why only two vents are provided for the building. It is necessary however, in the open plan layout, to provide some mechanical ventilation. The two fans alone could supply 30% of the total, even in very still conditions when the risk of overheating is greatest. The ventilation system is capable of recovering 70% of the exhaust air heat content. In full operational mode each unit extracted 0.017kg/s of tale air replacing it with 0.013kg/s of fresh air.

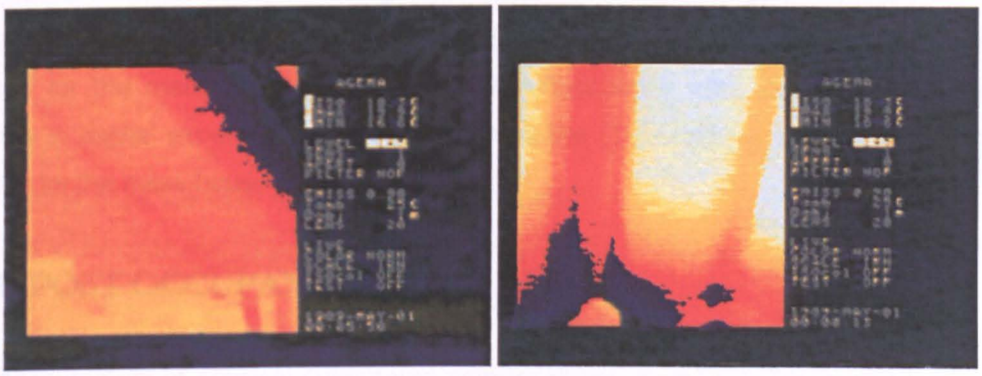


Figure 6.3.2.3 : Internal views of Thermographic Scanning

Thermographic scanning was used to establish the performance of the construction of the 'Zero Heating' project. Thermographic scanning enables analysis of the building to assess the detailing and variables such as the quality of the installation of insulation and in this case established the temperature of the internal and external surfaces. With the information this provided it is possible to establish which areas require improvement or slightly better detailing to provide more air tight or better insulated joints and construction.

The thermographic scans confirm that the building has been well built in that it is correctly insulated, the windows and doors are air tight and that there is little evidence of cold bridging. At high sensitivity settings the scans also suggested areas of design improvement around the foot of the south facing glazing (figure above, right) and service points through the structure of the building.

The performance evaluation highlights that the building functions as per recommended standards for most of the spaces in the home, the exception being in the bathroom (the internal walls of this space is insulated and therefore is 'separate' from the rest of the building). The heating element proves to be in-efficient. A preferred method of heating would be under-floor radiant heating but this would add capital expenditure to the life cycle costs previously undertaken. The payback for such a scheme would be 12 years (costs on top of those described for the life cycle cost analysis). A further area of concern would be the abundance of heat at the apex of the main living space. The heat here is wasted and could be re-circulated though this would require a mechanical process which the clients were keen to avoid.

Overall the heating proved to be a success for the project clients. It would be doubtful that this would be the case for every client. For young family and older couple demographics the preferred internal temperature is often above 20 degree centigrade and the heating in this home is not flexible or efficient enough to ensure this average temperature in winter. The heating system, it should therefore be noted, would certainly require changing before being adopted for the mass housing market. This consequently may mean that there is an increase in capital expenditure to be expected for the 'Zero Heating' home if it were to be adopted for the mass housing market.

6.3.3 POST OCCUPANCY EVALUATION

The measurement of physical criteria was complemented by a Post-Occupancy Evaluation and periodic interviews with the occupants to establish both their satisfaction with the finished product and their patterns of use of the building (Preiser, et al 1988).

Three aspects of note arose with the Post Occupancy Evaluation

Firstly and following points previously made in 6.3.2, the overheating of the landing space above the main living space caused a small problem for the family at times. The space itself has proved useful and popular. Since the space does prove to be warm throughout the day (especially above the stove when it is on) the clothes are often dried here. It is also utilised as an additional living space that feels more secure than the main living space (which has a large proportion of the window area in the building) and also proves to be popular for the children and their friends.

Secondly, the open planning was a problem at times with regard to noise. This will always be a problem in family homes that have open internal spaces and it not a preferred housing types for some people. Therefore care should be made when applying open planned homes in the mass housing market and a small but separate space additional 'living' room may be required.

Thirdly, the performance evaluation found that the building kept a consistent temperature throughout the year. That is to say, there are no under-heating problems in winter and no over-heating problems in summer. The family, as an addition to this, noted that in summer after external activities in the sun, noted that the inside of the home felt cool and comfortable when re-entered.

Other than these comfort and physical issues with the home, the POE established that the home is both healthy and provides comfortable spaces for a large family. The client was satisfied with the home.

6.3.4 THE WAY FORWARD

The direct lessons for the design which have been drawn from the 'Zero Heating' home project and the attendant research are of two basic types which might be called 'refinement' and 'progression'. That is, there are aspects of the established design which might be refined to perform better in future variations, as well as ways in which the iterative research and design process can progress to new types of innovation in future projects.

Whilst the completed building performed well overall, the following aspects would benefit from refinement.

- The recording of temperatures shows an increase between the lower level and the ceiling level in the double height space. Consideration needs to be given to the layout design of two-storey houses. It might be appropriate, for example, to locate bedrooms downstairs and the living spaces upstairs under certain circumstances, in so far as Part M of the Building Standards allows. Alternatively, the stove may be repositioned so that it has a ledge above it, much like a window cill above a radiator. This would ensure that heating is appropriately distributed. Environmentally friendly ways of circulating warm air towards the lower, cooler levels in the house is also an option. The lack of control or flexibility of the heating system, though appropriate for this home, will ensure that a wood burning stove is not an appropriate heating system for the mass housing market. Wood burning community heating schemes, however, may be more appropriate for housing developments.

- The perception of the environmental appropriateness of mechanical ventilation proved problematic. The Client's presumption was that fresh air intake is most appropriate by opening the windows and that the mechanical heat recovery system should be left switched off. Although aware of energy efficient principles and environmentally sound design strategies, the Clients are unsure how to achieve them within this building. Future projects will involve more comprehensive user manuals, but the issue of how to ensure the correct use of the building throughout its life cycle remains a difficult one. The inclination of the client was to open the windows, yet in an open plan, air-tight structure this will undermine the performance of the building. In housing it is difficult to balance the optimum performance of a building with the home-owners lifestyle. For the mass housing market this may ultimately come down to the individual need of the home-owner and it would be risky to suggest, therefore, that the 'Zero Heating' home is the model used for all homes.

- In terms of its physical performance the mechanical ventilation with heat recovery has confirmed the manufacturer claims. In future designs the introduction of a full ventilation system with heat recovery in the upper storey of the living space will be considered to reduce vertical temperature gradients.

- Analysis with the thermographic camera has shown that there is some cold bridging at the service points and around the sole plate. As regards the service points, greater quality of workmanship could provide less cold bridging, but some cold bridging at this point is inevitable. The sole plate, around the glazing on the south facade requires more insulation or a raised step of concrete (for the glazed area only), as condensation becomes a risk at low temperatures. Careful insulation of the lintel above the glazed area on the south facade needs further consideration also, though U values in this area still exceed current standards. The home as a whole has benefited from the same builder who built the similar 'Van Midden' house being chosen to build the 'Zero Heating' home.

- The bathroom was unable to benefit from the heat distributed from the passive solar design as much as the rest of the building, due to the insulation of the surrounding walls. Currently the Clients are using an electric towel dryer to heat the bathroom. Further consideration will be given to the way in which the bathroom can benefit from passive aspects of the design or possibly by the direct use of warm air from ventilation system. The solution may be in using materials, which provide sound reduction but at the some time allow heat transfer.

Future variants of the design are now being considered which will extend the environmental agenda and allow further progression of design and research activities. This will include consideration of the following areas.

- The more comprehensive use of locally sourced materials, particularly timber and investigation of supply of environmental friendly materials.
- Greater autonomy of resource use through, for example, consideration of the minimising and recycling of water waste, both sewage and grey water.
- The more extensive use and intensive investigation of hygroscopic materials, such as timber, in controlling humidity and air quality.
- The development of other forms of the design, to progress towards a more mass housing market. For example, the design of terraced and semi detached forms and medium rise, urban developments.
- The development of alternative heating systems, to progress towards a more mass housing market. For example, renewably fuelled community heating schemes.
- The adoption of this home into housing developments and housing site layouts will need to be investigated. This may include investigation of financial purchase, market trends, re-sale to establish if sustainable housing design is sustainable economically.
- The wider investigation of the impact of environmental designs over their life cycles from extraction to demolishment.

It is by no means suggested that the 'Zero-Heating' home is a model to be used throughout the North-East of Scotland or Scotland as it is an evolutionary housing model tackling the specific need to reduce the dependence on non-renewable sources of heating energy. The 'Zero Heating' home is also a home specifically designed for a private family. There are a number of general conclusions from the research on this case study which are applicable.

The basic environmental features used holistically in this building ensured that the Capital expenditure of this home was comparable with standard housing to minimum building regulations (at the time). PSD can therefore be an affordable housing approach.

The capital savings were not at the expense of poor running costs. Heating costs were significantly lower than a standard house comparison (approximately 75%). It should be noted that this is only for the **space heating** of the home. The issues of water heating and alternative forms of electricity production were not tackled in this home. If these issues had been tackled, in an effort to reduce running costs of electricity and water heating, then this would significantly increase the capital costs, which was not an aim of this project. It would be difficult to adopt features such as solar panels and photovoltaics in the mass market as they currently stand.

Glazing was placed between structural features in the house to cut down on waste. In addition, the total amount of glazing is comparable to that of a standard home (17% of the floor area in the 'Zero Heating' home compared to around 15% in a Standard home). The main emphasis was on re-orientating the glazing to face south and ensure that the glazing has a low U-value. The glazing in this home is similar in unit area to that of a standard home. This means that the cost of glazing is also similar. The glazing used in this home was triple glazed, argon-filled, low-e windows, which due to the increasing thermal standards is becoming more economically viable.

The effect of the thermally efficient envelope in the summer suggests that it is the insulation more than the passive solar gain that ensures that this building works. It is the retention of heat more than the solar gain that is has created a working home. Although an optimised passive solar design is a design that incorporates various aspects including super-insulation, it is predominantly the insulation in this home that ensures that it is successful. There is the question, therefore, that with a thermally efficient building such as this one, whether the orientation is important at all. That is an important question when it comes to groups of dwellings built to these standards where orientating a building south is significantly more difficult. With better insulation materials and methods available and with better glazing and heating technology for the home, it will be an ongoing question for the construction industry for the next decade.

6.4 DENSITY OF SITES IN THE NORTH EAST OF SCOTLAND

Currently, land value and density control the supply of housing and the affordability of a house for the average homeowner. In this research, density is an issue of sustainability and passive solar design is used as the exemplar. Therefore, if passive solar homes cannot match current methods of development in terms of density, then there is potential that passive solar homes may never be used in the mass housing market. The need for low density in many environmental designs conflicts with a housing developer's need to maximise land value and also government driven objectives, especially surrounding our major cities. The question, therefore, is whether passive solar designs are restricted by low density?

An analysis of sites in the North East of Scotland has been undertaken with the main aim being to distinguish if fewer homes per site are built if full-access passive solar gain is provided for each home. A number of assumptions have been made to establish this and these are as follows:

- The locations of the sites have been taken from the Aberdeenshire local plan, which covers all the Grampian region but not Aberdeen city. The belief is that if an effective passive solar development can be built at this high latitude, it should be at least equally effective on more southerly sites, once site specific environmental factors are accounted for. A number of towns in the North East of Scotland are satellite towns that have been or are growing around Aberdeen city and have been chosen for the fact that major developments of detached homes are built at these locations. Most of the developments are centred on the border of these towns and are classified as 'semi-urban' (SU on the following table). There are a few sites that are closer to the town centres of a number of places, and these are classified as Urban (U), the third classification is for Rural sites (R) but rural sites have not been included in the following table. Rural sites are a significantly different set of house development that encompass a wide range of issues not wholly pertinent to this research (such as travel distance, affordability, etc).

- The sites chosen are from the Aberdeenshire local plan, though not all the sites highlighted by the local plan are included in the investigation. The sites chosen had to be over ten homes in size and also be detached. The Aberdeenshire local plan has a reference for each site in relevance to their state of building development. These can be classified as follows,
    - **eh0** – Sites where housing is in the process of being built / in the process of planning application
    - **fh0** – Areas of future housing but is in the process of application
    - **ch0** – Sites where housing has been constructed / housing constructed as part of a phase in construction
    - **A,B,C** – Sites that have not been developed but has been designated for housing

- The sites chosen from the Aberdeenshire local plan are listed in the following table. These sites have been visited to investigate topography, the neighbouring housing and generally collate information not otherwise available from the local plan. The vast majority of the housing on these sites is detached housing. In some cases the sites include semi-detached as part of the site. Though not all sites are 100% detached homes they are predominantly detached, in most cases 90% or more of the dwellings are detached. In the Urban developments this may not be the case, however.

- The approximate floor area of each home is included in the following table, and these are the approximate internal dimensions. It is important to keep the total floor area the same between each alternative for this tool. Investigation of the significant difference between the floor size of PSD and standard housing, which admittedly will be different, are not covered in this research and perhaps should be covered in future research. In general, comparison between internal dimensions would mean that passive solar homes have a larger plan area since they have a greater wall depth. The significance of this problem is unknown in this research. In the following table, the indicated floor areas of each home are typical of homes from that area, after visiting the site.

- The area has been found using scaled maps though small errors may arise on more complicated sites. The total area of each site has been determined by the indicated boundaries in the Aberdeenshire local plan (though this may be different from actual sites to incorporate road access and green boundaries) and is inclusive of green-spaces (paths, play areas) and roads.

- The number of houses on each site is advised by the Aberdeenshire local plan (see column heading 'advised' in table 6.4.2.1) or can be taken for housing developers. The local plan details the desired number of houses for a site. This is often significantly lower than what is built, however. To determine the likely density of a site for future housing (as in column five in table 6.4.3.1) the site boundary was overlaid on existing neighbouring developments to find the typical number of houses for that area. The neighbouring sites were also used to calculate the density of future developments. By using a series of hectare sized grids overlaying the site plan of neighbouring developments (figure 6.4.1) the average density (dph) may be found.

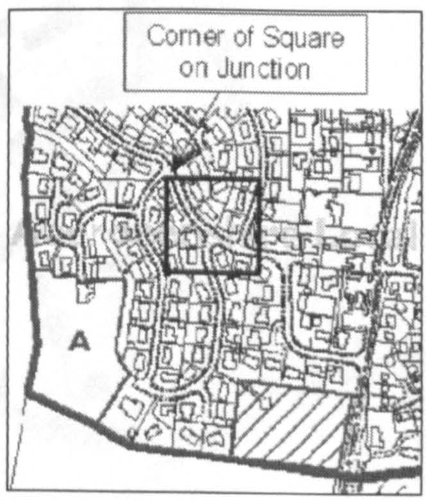


Fig : 6.4.1. Calculation of actual density on sites in the NE of Scotland by creating a series of hectare grids and calculating the average number of houses to find the typical dph for an area.

6.4.1 EXAMPLES OF SITES AROUND THE NORTH EAST OF SCOTLAND

Figures 6.4.1.1 is a site in Westhill (local plan designation eh1), a previously small village which has dramatically increased in size since the early 1980's. It is also an area zoned for many more housing developments in the next decade. On this site, which has only recently been completed (2002), the layout of modern housing developments is demonstrated. Dominated by circular roads and random, closely spaced, detached housing this housing scheme does not adhere to any environmental agenda. Many of the streets are in fact behaving, if they were orientated south, as if they were terraces. This site also shows elements of green-space, which is common on many suburban housing developments. Arguably, this relatively square site is suitably shaped for a passive solar development and this development is predominantly detached, two-storey homes. For this reason it has been included in table 6.4.3.1.

Fig 6.4.1.1 : (Above) Site in Westhill (eh1), Aberdeenshire, 129 homes (North to top of page)

Fig 6.4.1.2 : (Below) Site in Newmacher (eh3), Aberdeenshire (North to top of page)

Although figure 6.4.1.2 was not included in table 6.4.3.1 it does show the problems of modern housing development in the North East of Scotland. In this case the site fitted within the existing shape of the town resulting in an irregular boundary 'shape' (not square or rectangular) and unsuitable for passive solar designs. It also shows the clear proximity of each home (note the line of houses on the northern boundary). This site also exhibits elements of mixed-use, which is a more common housing arrangement as the distance from Aberdeen increases. Within this development are a range of house types including semi-detached, habitable roof-space homes as well as single storey housing. For this reason it is not included in table 6.4.3.1 but in future research mixed-use development as part of a sustainable agenda will need to be incorporated into any tool utilised.

Fig 6.4.1.3 : Site in Turriff (eh2), Aberdeenshire, (North to top of page)

Smaller sites such as this site (fig 6.4.1.3) are more suitable of becoming passive solar developments without losing any number of houses. This site in Turriff (too small to be included in table 6.4.3.1) exhibits many characteristics of larger developments with random housing arrangements and the close proximity of each home. This site is a gap site (housing developments are surrounding it) and the site also has a variety of housing types (single-storey and some semi detached housing types). In the future development of the tool more urban and small sites will be investigated. It is probable that they will be unsuitable in the context of the existing townscape for the adoption of passive solar design, but this needs to be investigated.

6.4.2 CALCULATING PASSIVE SOLAR PLOTS

The minimum plot area for a single passive solar home is formed by calculating the over-shadowing area. BRECSU, 1995 & 1997; Yannas, [1], 1994 state that a typical over-shadowing distance in Aberdeen is approximately 40m, a software system has been developed to calculate more accurately the over-shadowing distance for each site specified in the following table dependant on their latitude. Figure 6.4.2.1 illustrates how this distance is calculated (Yannas, [1], 1994) and figure 6.4.2.2 details the solar altitude throughout the year in Aberdeen. Note the low solar angles in the months of Dec, Jan and Nov. It is at these angles that it will be difficult for homes to gain full solar access. It is arguable that to gain full solar access in a passive solar development in northern climates such as in the NE of Scotland, housing requires to be more focused directly South than within the 25 degree limit suggested by BRECSU ([2], 1997).

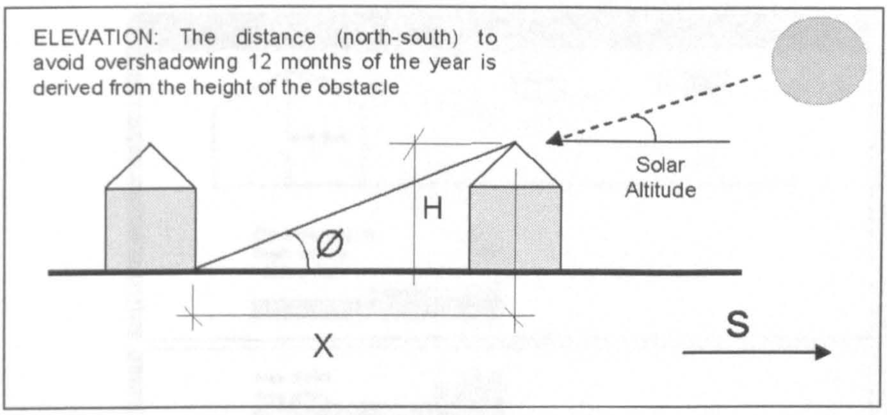


Fig 6.4.2.1 : Diagram of the overshadowing distance of passive solar designs (Yannas, [1], 1994)

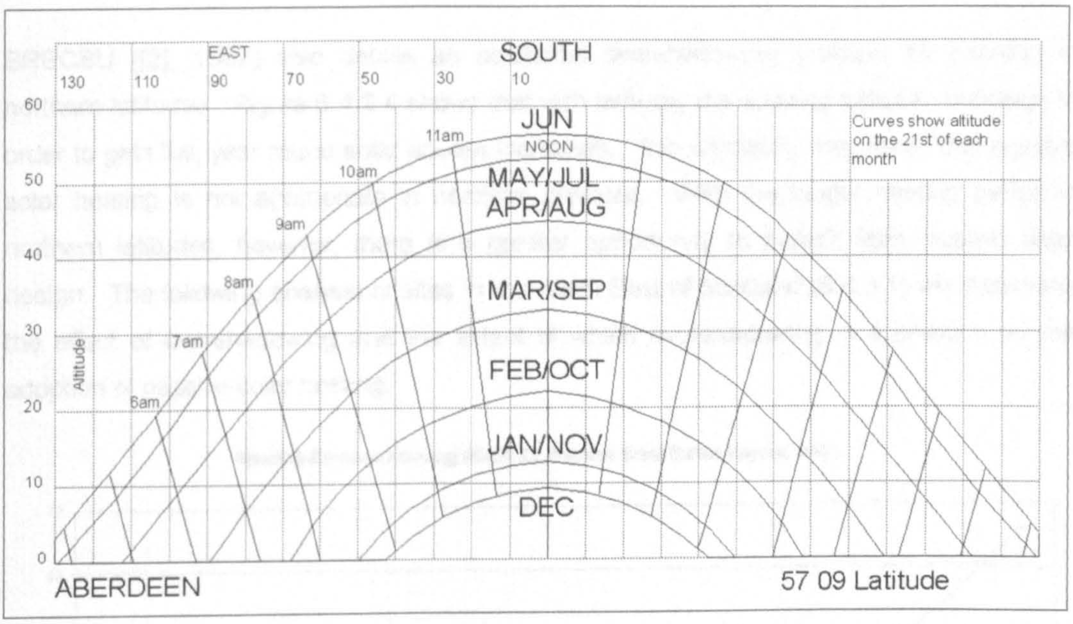


Fig 6.4.2.2 : Solar Angle throughout the year in the North East of Scotland (latitude Aberdeen)

Figure 6.4.2.1 illustrates how the overshadowing and minimum plot area is calculated for a passive solar design. The solar altitude was dependant on the latitude of each site, which enabled the overshadow distance to be calculated. The height of the passive solar dwelling was assumed to be for a two storey dwelling with typical roof pitch and floor height. The footprint of a passive solar home is based on case studies by Deveci, et al, (2000) and Yannas ([2], 1994) From these dimensions a minimum area of plot may be approximately determined, and consequently the total number of passive solar homes in a site can be calculated if the area of the plot is known.

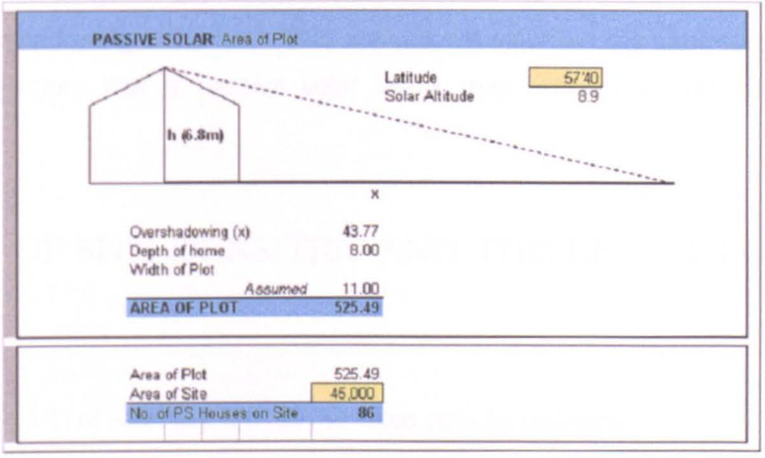


Fig 6.4.2.3 : Calculation of passive solar homes on a site

BRECSU ([2], 1997) also details an additional overshadowing problem for housing in northern latitudes. Figure 6.4.2.4 shows that with latitude, the spacing between buildings in order to gain full, year round solar access increases. This ultimately may mean that passive solar heating is not appropriate in northern climates. With the longer heating period in northern latitudes, however, there is a greater opportunity to benefit from passive solar design. The following analysis of sites in the North East of Scotland (6.4.3.1) will determine the effect of overshadowing and the extent of which overshadowing is a problem for the adoption of passive solar heating.

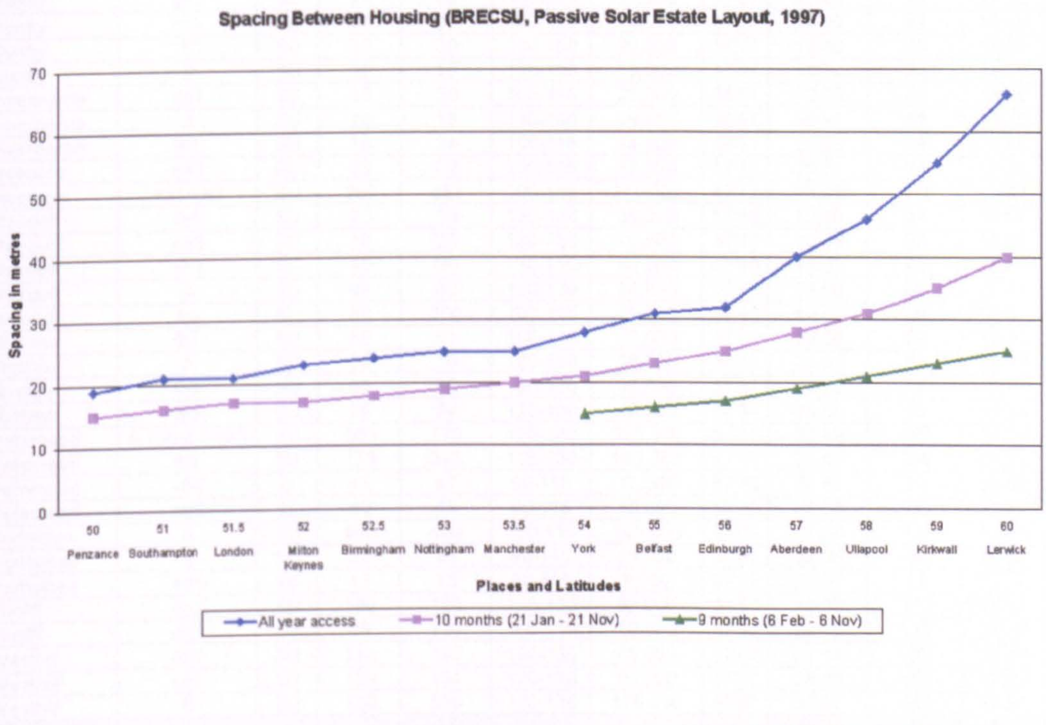


Figure 6.4.2.4 : The effect of solar altitude (expressed as spacing between housing) in northern latitudes (BRECSU, [2], 1997)

The main aim of this analysis, as stated previously, is to establish if the density of passive solar sites is limited by overshadowing distances. This analysis will establish the maximum number of dwellings per hectare that a passive solar layout may achieve at different latitudes.

6.4.3 COMPARISON OF SITE DENSITIES AND THE EFFECT OF OVERSHADOWING

The following is the table (6.4.3.1) of each site with all the listed data for analysis:-

TABLE 6.4.3.1 : INVESTIGATION OF DENSITY IN SITES AROUND THE NORTH EAST OF SCOTLAND

Location	Ref*		Number of Houses	Typical Number of houses for that area	Approx floor size	Area	Latitude	DPH of Housing Scheme	Number of Passive Solar Houses possible	Max DPH of Passive Solar
Banff	eh1	SU	60	128	100-115	45,000	57'40	28.44	**86**	**19.11**
Banff	fh2	SU	60	77	100-115	30,000	57'40	25.67	**58**	**19.33**
Banff	ch1	U	9	9	100-115	4,500	57'40	20.00	**9**	**20.00**
Banff	eh6	SU	24	24	120-130	12,500	57'40	19.20	**25**	**20.00**
Banff	eh7	SU	22	25	120-130	13,000	57'40	19.23	**27**	**20.77**
Blackburn	A	SU	130	140	100-115	64,000	57'13	21.88	**131**	**20.47**
Blackburn	B	SU	124	134	100-115	61,000	57'13	21.97	**122**	**20.00**
Blackburn	eh1	SU	143	165	100-115	75,000	57'13	22.00	**151**	**20.13**
Blackburn	C	SU	10	20	100-115	9,500	57'13	21.05	**19**	**20.00**
Blackburn	D	SU	36	36	100-115	15,000	57'13	24.00	**30**	**20.00**
Cruden Bay	ch1	SU	102	175	120-130	90,000	57'25	19.44	**175**	**19.44**
Ellon	eh1/ch1	SU	137	137	120-130	80,000	57'24	17.13	**144**	**18.00**
Ellon	eh2	SU	18	18	130-150	12,500	57'22	14.40	**20**	**16.00**
Huntly	eh2	SU	24	32	100-115	11,500	57'27	27.83	**22**	**19.13**
Huntly	ch1	SU	24	37	100-115	14,000	57'27	26.43	**27**	**19.29**
Huntly	C	SU	30	30	130-150	20,500	57'27	14.63	**36**	**17.56**
Huntly	D	SU	15	15	130-150	13,000	57'27	11.54	**23**	**17.69**
Inverbervie	eh1	SU	30	30	100-115	25,000	56'51	12.00	**47**	**18.80**
Inverbervie	A	SU	10	18	130-150	16,500	56'51	10.91	**31**	**18.79**
Inverbervie	fh1	SU	18	34	100-115	14,500	56'51	23.45	**30**	**20.69**
Inverurie	eh2	SU	35	52	100-115	17,500	57'17	29.71	**34**	**19.43**
Inverurie	eh1/ch3	SU	250	651	100-115	210,000	57'17	31.00	**410**	**19.52**
Macduff	fh1	SU	20	39	130-150	30,000	57'40	13.00	**44**	**14.67**
Macduff	eh3	SU	10	23	130-150	18,000	57'40	12.78	**25**	**13.89**
Macduff	eh1	SU	40	90	130-150	60,000	57'40	15.00	**96**	**16.00**
Macduff	A	SU	85	85	120-130	34,000	57'40	25.00	**66**	**19.41**
Macduff	fh2	SU	80	300	100-115	75,000	57'40	40.00	**146**	**19.47**
Mintlaw	fh1	SU	50	81	100-115	27,000	57'31	30.00	**52**	**19.26**
Mintlaw	A	SU	50	78	100-115	26,000	57'31	30.00	**50**	**19.23**
Mintlaw	fh2	SU	50	60	120-130	38,000	57'31	15.79	**67**	**17.63**
Mintlaw	fh3	SU	50	64	120-130	40,000	57'31	16.00	**70**	**17.50**
Peterhead	fh1/A/eh3/ch3	SU	560	770	120-130	325,000	57'30	23.69	**691**	**21.26**
Peterhead	fh2	SU	170	341	120-130	145,000	57'30	23.52	**306**	**21.10**
Peterhead	eh4	U	47	47	90-115	17,500	57'30	26.86	**35**	**20.00**
Peterhead	eh6	U	49	49	90-115	10,000	57'30	49.00	**20**	**20.00**
Portlethen	A	SU	400	400	100-115	145,000	57'04	27.59	**325**	**22.41**
Portlethen	B	SU	25	33	90-115	15,000	57'04	22.00	**30**	**20.00**
Portlethen	eh1	SU	13	13	90-115	6,000	57'04	21.67	**12**	**20.00**
Turriff	eh1	SU	100	100	120-130	65,000	57'33	15.38	**118**	**18.15**
Turriff	eh3	SU	98	110	100-115	50,000	57'33	22.00	**112**	**22.40**
Westhill	eh2	SU	114	140	120-130	45,000	57'07	31.11	**90**	**20.00**
Westhill	eh1	SU	129	154	120-130	55,000	57'07	28.00	**109**	**19.82**
Westhill	B	SU	330	570	120-130	175,000	57'07	32.57	**347**	**19.83**
Totals				**5534**				22.86	**4468**	**19.21**

* References are those taken from the Local Plan

The investigation of site density results in less housing for passive solar sites. If all housing in the North East of Scotland that was to be built on the sites investigated were passive solar only 4,468 of the 5,534 anticipated would be built. This is a 17% reduction, almost a fifth. Passive solar homes average around 20 dwellings per hectare, varying between 18 and 22 dwellings per hectare depending on latitude. This analysis shows, given the assumptions made, that optimised passive solar homes, to benefit from full, year round solar access, would not meet developer and local government targets for density.

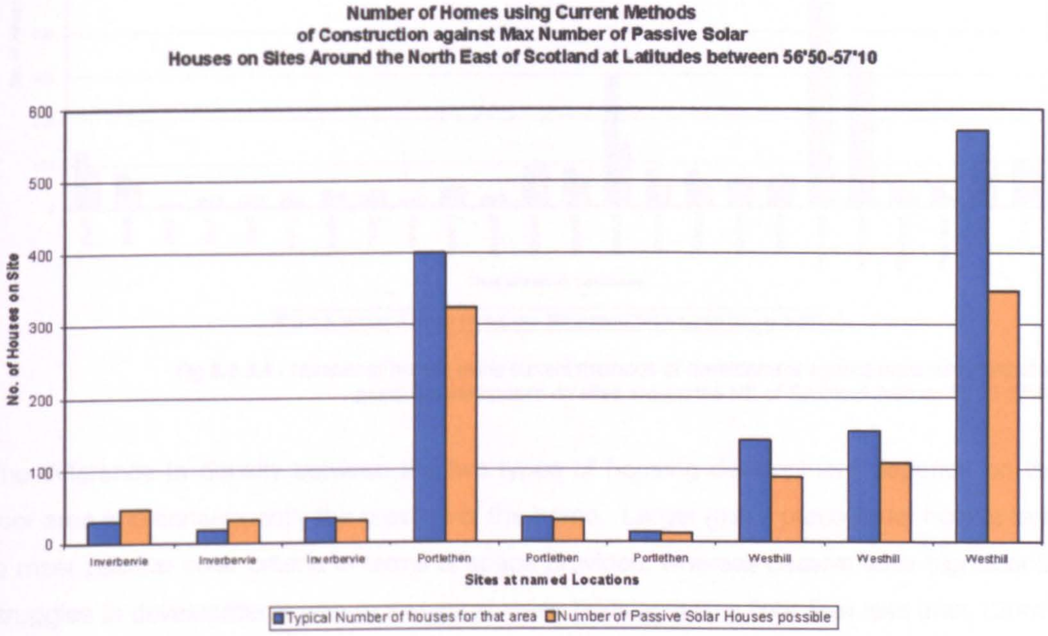


Fig 6.4.3.2 : Number of homes using current methods of development against maximum number of passive solar houses on sites around the NE of Scotland (latitude 56'50-57'10)

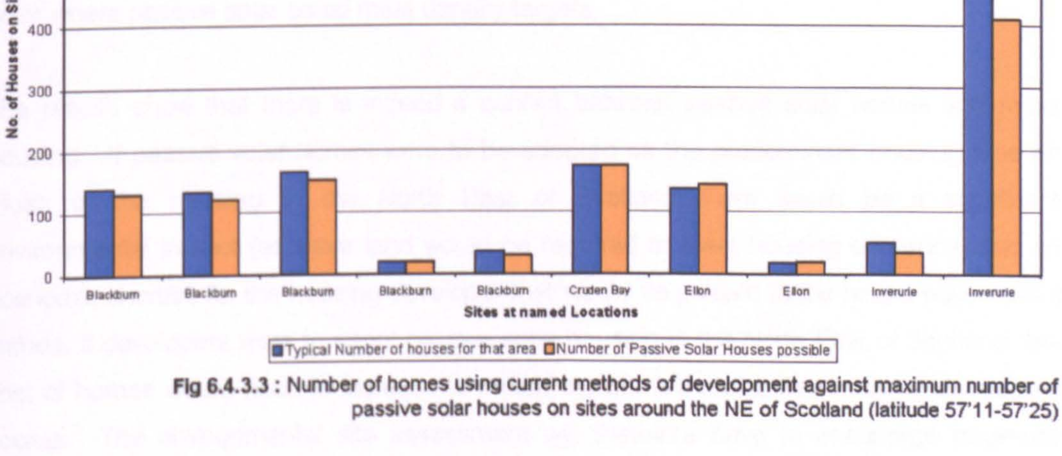


Fig 6.4.3.3 : Number of homes using current methods of development against maximum number of passive solar houses on sites around the NE of Scotland (latitude 57'11-57'25)

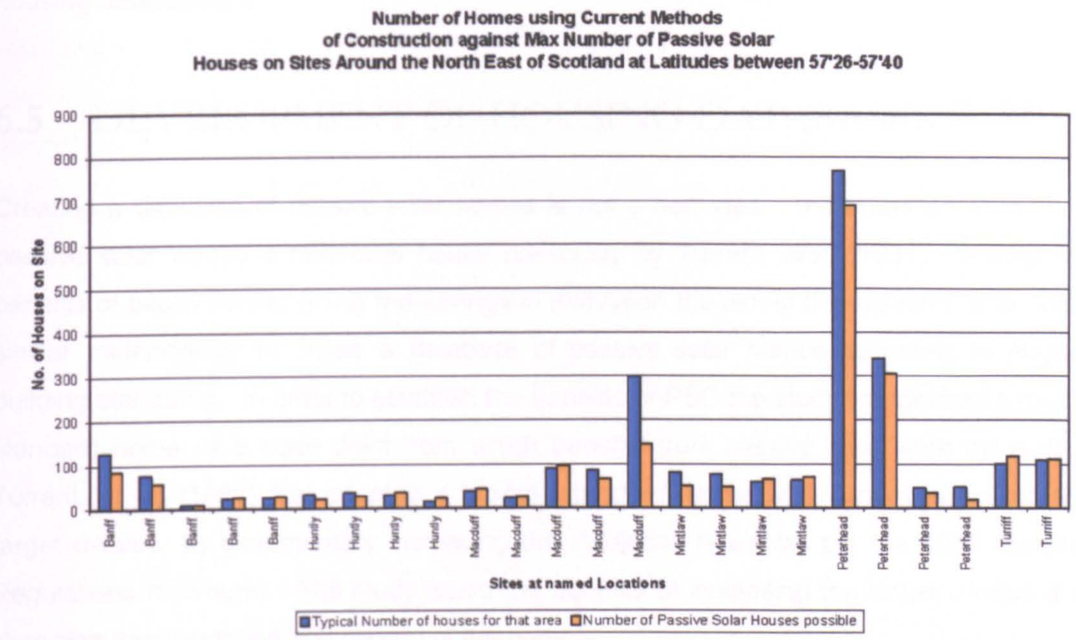


Fig 6.4.3.4 : Number of homes using current methods of development against maximum number of passive solar houses on sites around the NE of Scotland (latitude 57'26-57'40)

The difference in density between the two types of housing development depends on the floor area and consequently the prestige of the home. Larger (more prestigious) homes tend to meet passive solar criteria in terms of space provided, whereas passive solar significantly struggles in developments with more typical mass housing with a floor area less than $120m^2$. This is a trend throughout the sites investigated. It seems that more affordable home types will be restricted into crowded developments that lack the required spacing distances that encourage passive solar full, year round access the year round. It should be noted that using mixed-use housing developments, and also using low rise and high rise at appropriate zones around the site, might ensure that this problem could be overcome. Sites are investigated that had a mixed-use of single and two storey housing were not, however, arranged in such a fashion as to benefit from the adoption of passive solar. As such, sites investigated with some mix in housing form still did not reduce shading distances to the point where passive solar could meet density targets.

The results show that there is indeed a conflict between passive solar homes and mass housing. If passive solar homes were to be adopted as the predominant housing type for much of the housing in the North East of Scotland there would be a significant environmental impact (as more land would be required to meet housing demands) and an economic shortfall for the housing developer that would be passed to the house buyer. As it stands, if developers were to adopt passive solar housing in the North East of Scotland, the cost of homes would need to increase to match the current profits that housing developers accrue. The environmental site assessment will therefore have to encourage trade-offs between optimised passive solar design and a more basic, standard house in a conventional housing development.

6.5 DEVELOPMENT OF HOUSING DATABASES

Creating a database of passive solar homes is not a new idea. There was an analysis of passive solar versus a traditional house previously by Turrent, *etal*, (1981) covering the benefits of passive solar, giving the savings in Kwh/year: the aim of this research is to use a similar methodology to create a database of passive solar homes according to current building standards. In order to establish the benefits of PSD the study first devised a model standard home as a base point from which benefits from passive solar were measured. Turrent, et al, (1981) first adopted a typical (standard) home and Turrent increased the target u-value, by incrementally increasing the insulation levels (as per the 1981 Building Regulations minimum). The study found the benefits of increasing the target u-value and changing the orientation and glazing of the home.

It is important that any modern analysis of the benefits of passive solar takes account of increasing thermal standards. The study by Turrent, *etal*, (1981) did not, however, ascertain the benefits of a house being made airtight and this research has investigated this. Although most super-insulated houses are by nature 'air-tight' it is possible in the modern scenario to create a home that is air-tight, but not totally super-insulated, by creating an impervious barrier around the home. This type of home relies on filtered (heat recovery) air ventilation and is particularly useful for, for example, hay fever sufferers.

Turrent, as a comparison, found the annual kWh and cost / benefits of applying various passive solar options. The houses were assumed to be of the same shape and form as the base model. This was a simple yet robust way of ascertaining benefits and of comparing different housing types, which is otherwise a complex process.

This analysis has taken a similar methodological approach to create a passive solar database, starting from a base model akin to the 1981 study. The base model, as in the 1981 study, will have a set floor area, window size, footprint, orientation, etc in order to make the comparison between what is termed 'traditional' and 'passive solar' as straightforward as possible with such a complex scenario. The benefits of keeping it simple cannot be underestimated at this stage, as adding increasingly complex issues will increase the output information at the end of the study beyond what is needed to make the tool usable. The base model is a simple geometric housing form and dimensions will be reduced to a series of unit rates.

To ascertain the information required for the base model the existing design criteria obtained from building developers was used. In addition, the existing minimum building regulations (updated to 2002) forms the u-value target for the base model. Developers/Home builders have specific designs in their portfolio, which they use throughout their area. The research has identified and included in a database over **two hundred** applicable designs in over **twenty** sites throughout Scotland from nine major developers and builders (Appendix E).

House designs are readily available from housing developers and they are standard throughout Scotland and are similar to what is actually built on site. Keeping standard designs reduces design cost. The only reasons for changing designs in their portfolio is changing demand for a particular building type, site specific restrictions and/or specification changes.

The developments included in the database cover a range of building types, including terraced, semi-detached, bungalow and habitable roof-space homes but the analysis focuses upon the single family detached home. The floor areas for these dwellings range from 80m^2 up to 900m^2, but the study analysed homes below 500m^2. The study is specifically looking at typical mass housing not at the one-off, private homes. It was found that the typical total floor area for standard homes for housing developers in the North East of Scotland is between 100m^2 and 200m^2.

The analysis of standard homes from some of Scotland's premier home builders will be used to ascertain what the common **room layout** is, what proportion of **glazing is on each elevation** and the ratio of **glazing to floor area**.

6.5.1 BUILDING TYPE

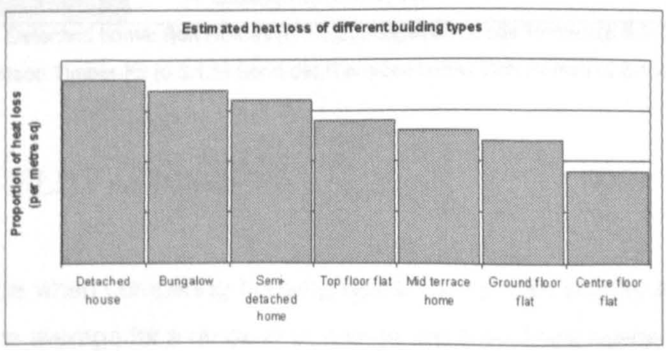


Fig 6.5.1.1 : Estimated heat loss from different building types (Edwards, 2000)

The database includes five house types; two-storey, detached homes; bungalows; two-storey, roof-space homes; semi-detached and terraced homes. In the database the detached housing type is the preferred house type, as this is predominantly the housing type which homebuyers aspire to. This house type also is the most popular, say building developers, for young families. It also provides an example of the worst housing type for heat losses, due to the greater external surface area per housing unit. Figure 6.3.1.1 illustrates this principle, the detached house also creating the most emissions by the same principle (adapted from Edwards, 2000).

The following shows typical pictorial examples of the housing types included in the database, taken from building developers hard copy and online brochures:

Detached home: Bett Homes (6.5.1.2) Bungalow: Scotia Homes (6.5.1.3)
Roof-space home: Robertson Timber-Kit (6.5.1.5) Semi-det./Terraced home: Bett Homes (6.5.1.4)

6.5.2 ORIENTATION OF ELEVATIONS

Some assumptions need to be made when comparing housing types, as the plan shapes of homes vary widely. So as to find the average for a range of buildings, the elevations needed to be given a designation, the following method was chosen for two different types of building footprint. Assumptions need to be made to ascertain a common orientation, especially for buildings with footprint other than rectangular, in order to compare buildings equally. For example, with buildings that are square, what is the main elevation? Is it the one with the main access? Or is it based on their interior room layout of the building with the main (living) room dictating the main elevation? Or is it simply the elevation that faces the street? If the database, which is to be created from these homes, can be fully utilised the correct orientation of the elevations need to be ascertained.

For a rectangular footprint, the main access to a home was assumed to be the 'main elevation', the main elevation being the side with access to the street. The main elevation was the pivotal elevation from which the other elevations were designated titles, on the right 'Side A'; on the left 'Side B' and on the opposing side of the main elevation; 'back elevation' (fig 6.5.2.1).

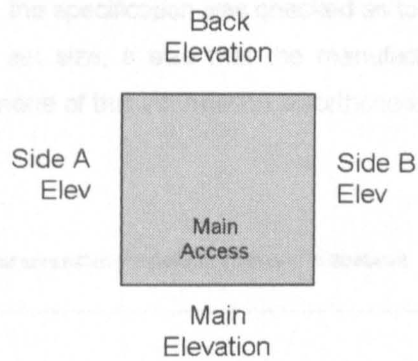


Fig 6.5.2.1 : The naming of elevations for the housing database

For those footprints which were not similar to square or rectangular shapes, for example 'L' shaped, the designation of elevations depended on either the main access (main access = main elevation). Alternatively, the orientation/layout of the **main room of the building**, commonly the lounge (Lounge = Main elevation) which is the biggest room of the house, and the focus of most activities, was designated 'main elevation' if the main access faced away from the street. Another alternative, if both the lounge and the main access, like the illustration below, faced away from the street (The lounge faces the back elevation, the main access is on Side B) was to name the elevation that faced the street as the main elevation.

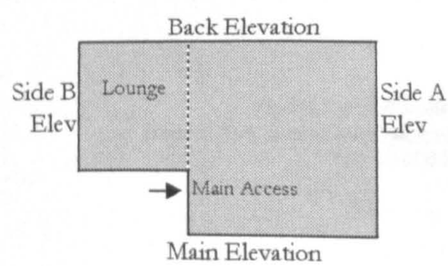


Fig 6.5.2.2 : The naming of elevations for the housing database (non-rectangular footprint)

6.5.3 INFORMATION COLLECTED FOR DATABASE

To create a base model, the minimum building regulation standards were adhered to in terms of heating, ventilation and thermal efficiency. The information that the database was created to find was simple dimensions, sizes and proportions of common building types.

Two key areas of information were the floor areas and glazing areas (here expressed as glass to floor area). The Floor area was important, as it is an indication of the plan size of the dwelling, and also it is a value that is used to create the base unit of measure. The Glazing area was derived from window schedules if it was available in building developer portfolios. If no window schedule is available, the specification was checked as to the type of windows used. Windows are commonly a set size, a size that the manufacturer mass produces (site specific windows are rare). If none of this information is forthcoming, window sizes can be scaled from drawn information.

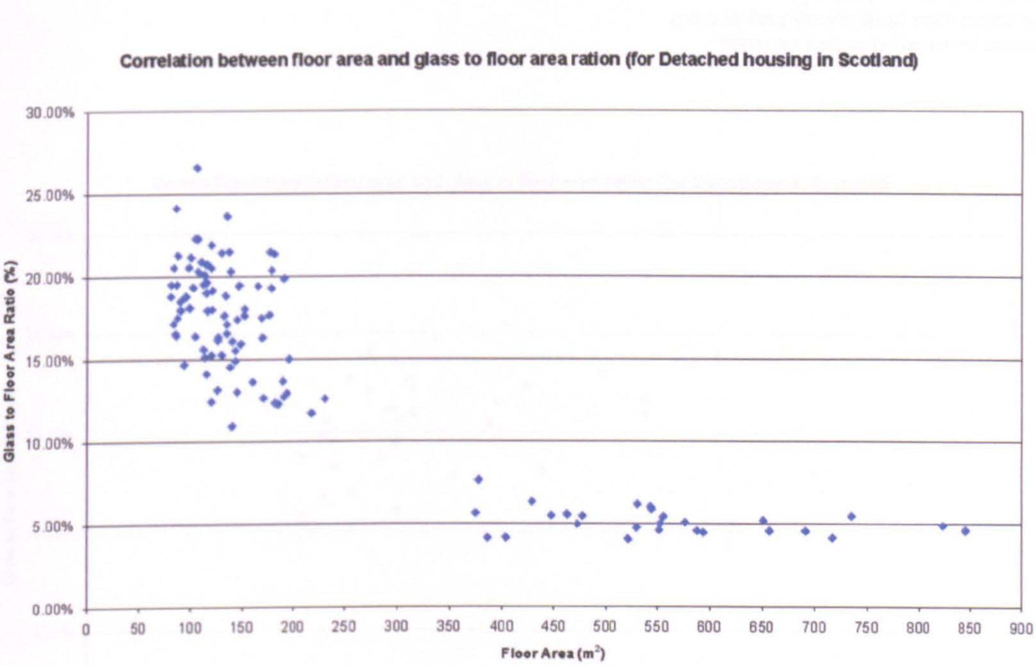


Fig 6.5.3.1 : Floor area against glass to floor area ratio of each house type (detached housing only)

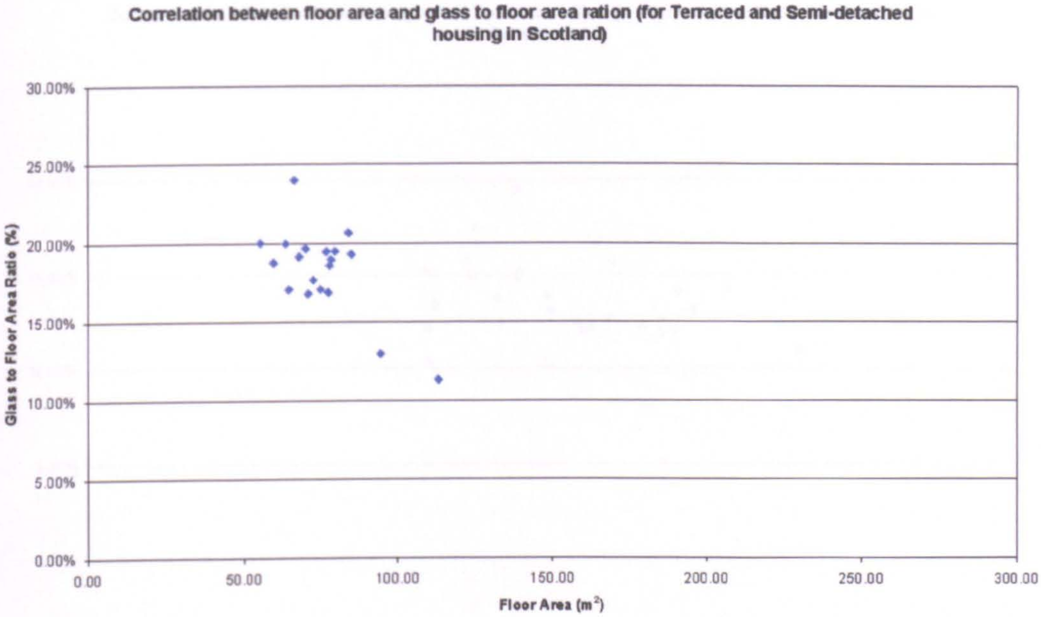


Fig 6.5.3.2 : Floor area against glass to floor area ratio of each house type (terraced and semi-detached housing)

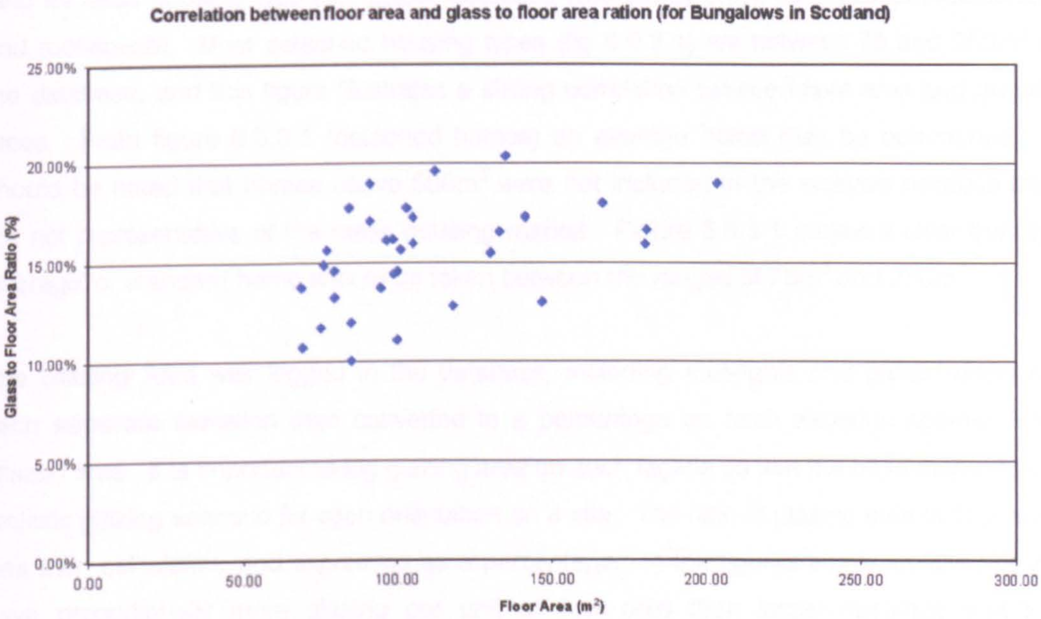


Fig 6.5.3.3 : Floor area against glass to floor area ratio of each house type (Bungalows only)

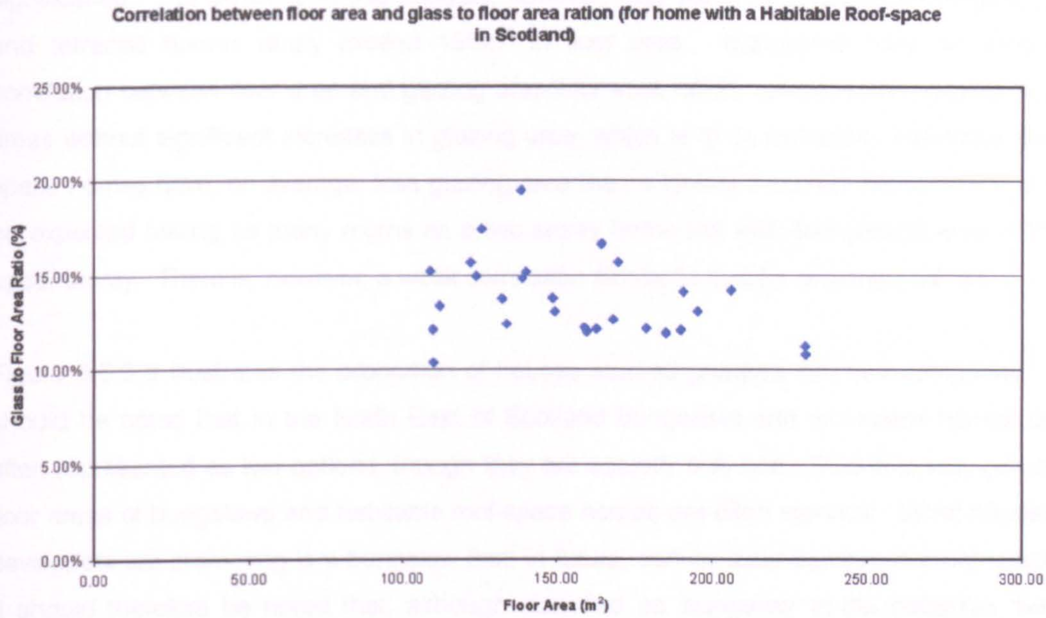


Fig 6.5.3.4 : Floor area against glass to floor area ratio of each house type (Roof-space homes only)

The four figures above illustrate the correlation between floor area and the glass to floor area ratio for each housing type (bungalow, detached (two-storey only), terraced/semi-detached, and roof-space). Most detached housing types (fig 6.5.3.1) are between 75 and 250m^2 in the database, and this figure illustrates a strong correlation between floor area and glazing areas. From figure 6.5.3.1 (detached homes) an average home may be determined. It should be noted that homes above 500m^2 were not included in the analysis because they are not representative of the mass housing market. Figure 6.5.3.1 makes it clear that the 'average' or standard home should be taken between the ranges of 75m^2 and 250m^2.

The Glazing Area was logged in the database, including roof-lights and glazed doors on each **separate** elevation then converted to a percentage on each elevation against Total Glazed area. It is important to log glazing area on each façade so that the base model has a realistic glazing scenario for each orientation on a site. The ratio of glazing area to floor area was then calculated, and expressed as a percentage. In the figures above smaller homes have proportionally more glazing per unit of floor area than larger dwellings and the difference can be quite significant. This statistic could be beneficial for these homes if they were re-orientated south. Consequently, this suggests that house types with larger floor areas are more dependent on conventional heating methods through central heating.

The other house types included (figures 6.5.3.2, 6.5.3.3 and 6.5.3.4) do not show such a strong correlation between floor area and glazing area/floor area ratio as in figure 6.5.3.1 (detached homes). Semi-detached and terraced homes showed broadly the same correlation, though there were insufficient homes in the database to demonstrate statistical significance. The similarity in this analysis, however, may partly be because semi-detached and terraced homes rarely exceed 125m^2 in floor area. Bungalows have an inverse correlation between floor area and glazing area/floor area ration, resulting from greater floor areas without significant increases in glazing area, which is to be expected. Habitable roof-space homes have, on average, less glazing area than a typical detached home, which is to be expected having as many rooms as a two storey home but with less glazing area in the upper storey. There is, however, a weak correlation similar to that for detached homes.

Figure 6.5.3.5 illustrates the proportion of houses studied grouped into four categories. It should be noted that in the North East of Scotland bungalows and roof-space homes are often represented as two options, though they are actually only one. That is to say, ground floor areas of bungalows and habitable roof-space homes are often identical. What housing developers are promoting is a bungalow that, in future, can be extended into the roof-space. It should therefore be noted that, although classified as 'bungalow' in the database, two-thirds of these homes could also be classified (in future or theoretically now) as roof-space homes. If this principle were applied to the database, the roof-space category would encompass approximately 25% of the database, whereas the bungalows would have a similar proportion to the semi-detached/terraced category.

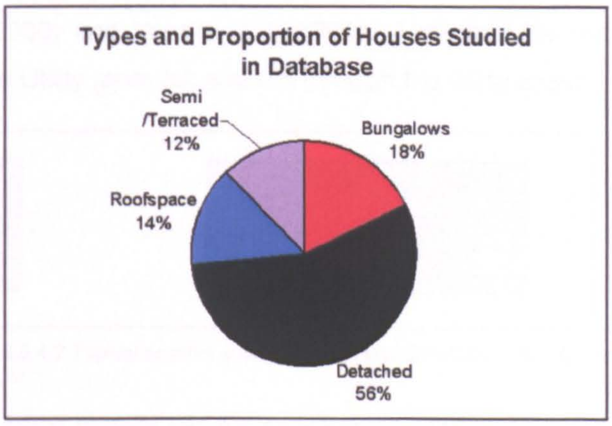


Fig 6.5.3.5 : The percentage of each house types studied

6.5.4 THE ROOM LAYOUTS

The database also catalogues the position of each individual room of a house type (ground floor only). Ascertaining the common room layout of standard homes is important for this research as passive solar designed homes rely upon a derivative of the open-plan room layout. Using the elevations (as designated earlier) a room is classified dependant on the location on each elevation. The database assumes a theoretical square footprint for this analysis for ease of interpretation splitting each elevation into three parts. The location of, say, the living room may therefore be; main elevation right; Side A bottom and; Side A Mid.

The following illustration shows the grid proportions. The centre of the grid, termed 'Interior' is for those rooms without access to an elevation.

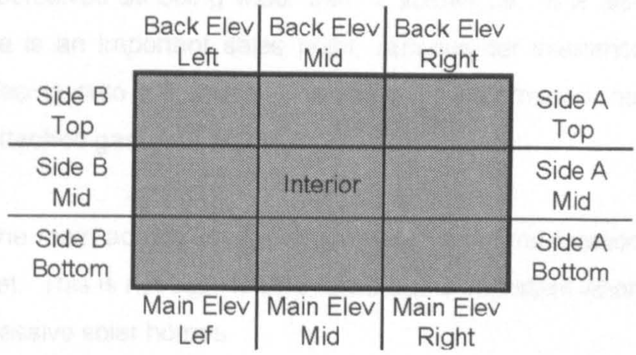


Fig 6.5.4.1 : Grid of room layouts

The room layout is important in passive solar design because of the method of heating and the distribution throughout a home. The central hub for the creation of heat is commonly the lounge/living space in a direct gain system (see case study 6.2 and also Borer & Harris, 1997; Yannas, [1], 1994), which is located on the south elevation, the heat created in this space is then distributed to other rooms.

Figure 6.5.4.2 show two passive solar variations using direct gain solar access, taken from BRESCU ([2], 1997), Deveci, et al, (2000) and Yannas ([2], 1994). Note that the main access of both footprints are through the Utility room (U) and not through the living space.

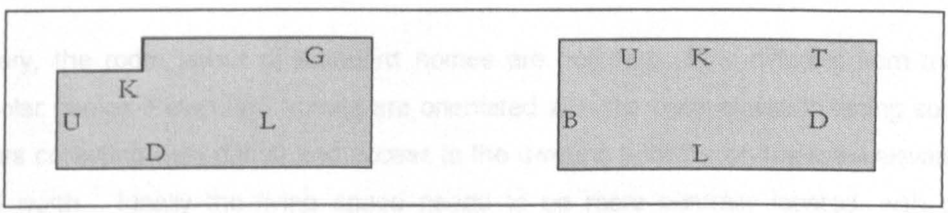


Fig : 6.5.4.2 Typical passive solar room layouts (BRECSU, 1997 & 1995)

From the database the most common room layouts for standard housing for each housing type was investigated. The database highlights the fact that most two-storey detached homes were rectangular in shape with the garage utilising much of one side of the rectangular footprint. Without the garage, the main body of the home is deeper or almost a square. The following sections describe more fully the different room layouts typical for each house type.

From the analysis of the database, a number of room layout variables can be outlined:

- The positions in the footprint of the dining and living spaces are interchangeable, meaning that the dining space and living space can change elevations.

- The garage often takes up a large proportion of the main elevation making the main elevation appear wider than the building actually is. It could be suggested that, from the outside, the building frontage is perceived as being wider than it actually is. It is also important to note that the garage is an important sales point, reduces car insurance premiums and is most practical facing onto the street. The database determined that 75% of detached homes had an attached garage.

- For many of the same reasons, the main access is almost always in a central location along the elevation facing the street. This is not significant in itself but is important when comparing the main access with passive solar homes.

- The toilet, the utility room and the kitchen are the three spaces aside from storage space that need the least window area and are usually grouped together (because of the need to reduce plumbing). The stairs are most commonly located in a central position (interior), but occasionally may be abutted onto the main or back elevations.

- A common feature of the back elevation on most new homes, mostly in the dining/living space or the breakfast/kitchen area, is patio doors. This, presumably, is for access to the exterior space of the back garden. It should be noted that a feature such as this if it faced south could collect a large proportion of the solar energy required to heat a home, at no additional cost, with only little specification change.

In summary, the room layout of standard homes are not particularly different from most passive solar homes if standard homes are orientated with the back elevation facing south (patio doors collecting heat gains) and access to the dwelling from the on the main elevation orientated north. Ideally the living space needs to be more centrally located, with the kitchen, utility and toilet on the north side (main elevation). If a standard home is orientated with the back elevation facing south, then the garage can offer shelter of the north side of the dwelling. The major obstacle is the creation of the open-plan space needed to circulate warm solar heated air around the home.

Detached House

	Int.	None
Living	0.0%	0.0%
Kitchen	0.0%	0.0%
Dining	0.0%	0.0%
Utility	0.0%	23.9%
Fam / S	0.0%	41.6%
Toilet	25.7%	0.9%
Stairs	64.6%	0.0%

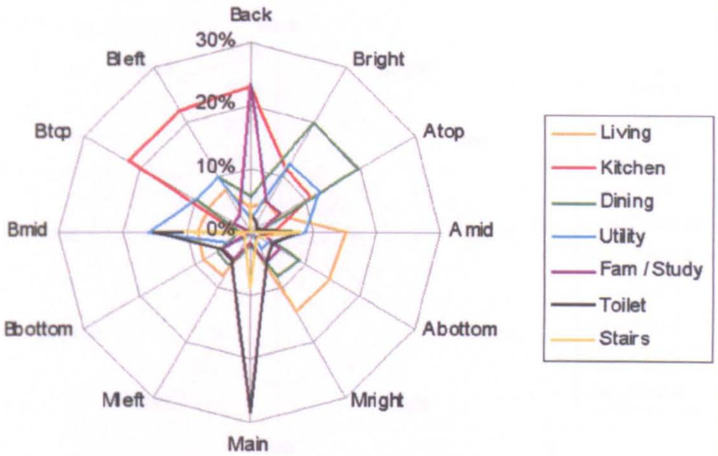


Fig 6.5.4.3 : Location of each room in a detached house

Figure 6.5.4.4 represents the most common position of each room each point on the graph representing a grid position. It may be seen that the house types in the database have a common position for each room, for example the living room is clearly more commonly found between Mright and Amid; and the kitchen is most commonly located between Btop and Back [Mid]. The information in figure 6.5.4.4 has been expressed in the form of a footprint with the most common position of each room as exhibited by figure 6.5.4.5 which represents a typical room layout for a detached home. The illustration on the left is typical for homes with floor areas over 120m^2, but where sites are much more dense more elongated shapes for detached housing are prevalent which reflect the semi-detached / terraced houses noted later in this section. These figures have been created from the information collected from Scottish building developers (summarised in Appendix E)

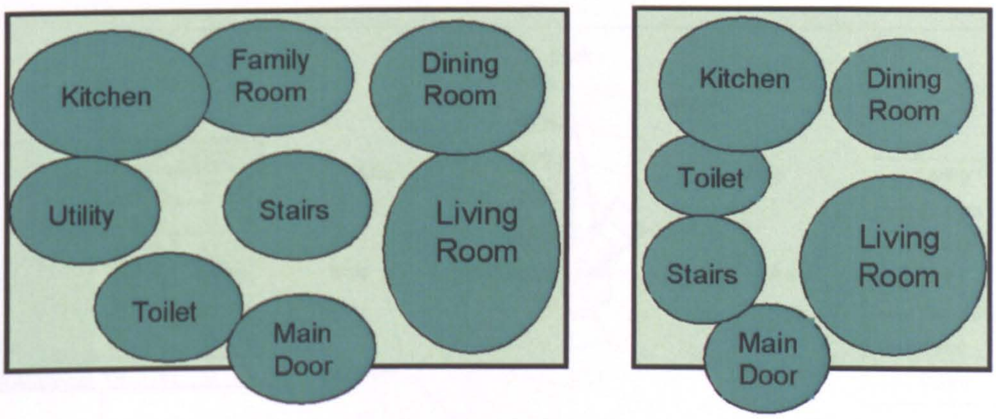


Fig 6.5.4.4 : Detached house room layout

Bungalow

	Int.	None
Living	0.0%	0.0%
Kitchen	0.0%	0.0%
Dining	0.0%	16.7%
Utility	0.0%	72.2%
Fam / S	0.0%	75.0%
Bath	5.6%	0.0%
Bed 1	0.0%	0.0%
Bed 2	0.0%	0.0%
Bed 3	0.0%	13.9%
Bed 4	0.0%	72.2%

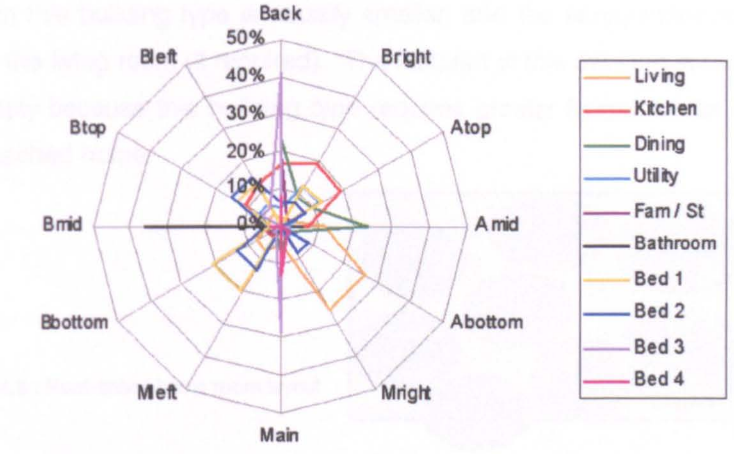


Fig : 6.3.4.5 Location of each room in a bungalow

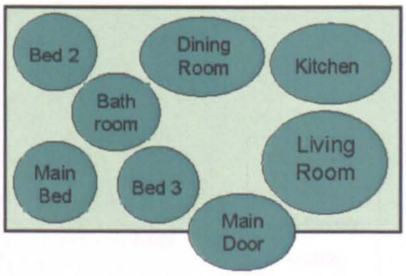


Fig 6.5.4.6 : Bungalow room layout

Similarly to the detached home, a most common room layout for a bungalow was created from the information in the database, summarised in figure 6.5.4.6. Excluding the bedrooms, the room layout is not dissimilar to that of the detached home.

Habitable Roof-space

	Int.	None
Living	0.0%	0.0%
Kitchen	0.0%	0.0%
Dining	0.0%	0.0%
Utility	0.0%	10.7%
Fam / S	0.0%	35.7%
Toilet	25.0%	0.0%
Stairs	64.3%	0.0%

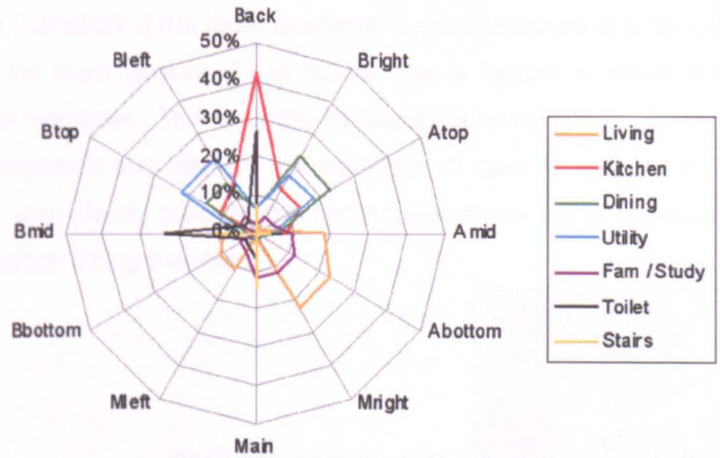


Fig 6.5.4.7 : Location of each room in a roof-space home

The homes with a habitable roof –space are, again, not dissimilar to the detached house, the main difference being the location of the family/ study room. From the information from the database, the living room in this building type is usually smaller, and the family room acts like an additional space for the living room (if required). The footprint of this dwelling is most commonly rectangular, simply because this building type requires greater footprint area for the same floor area of a detached home.

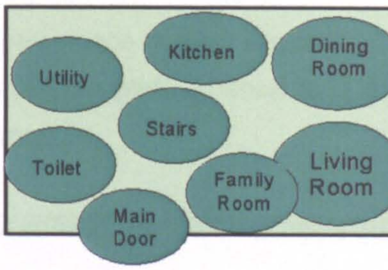


Fig 6.5.4.8 : Roof-space home room layout

Semi-Detached / Terrace House

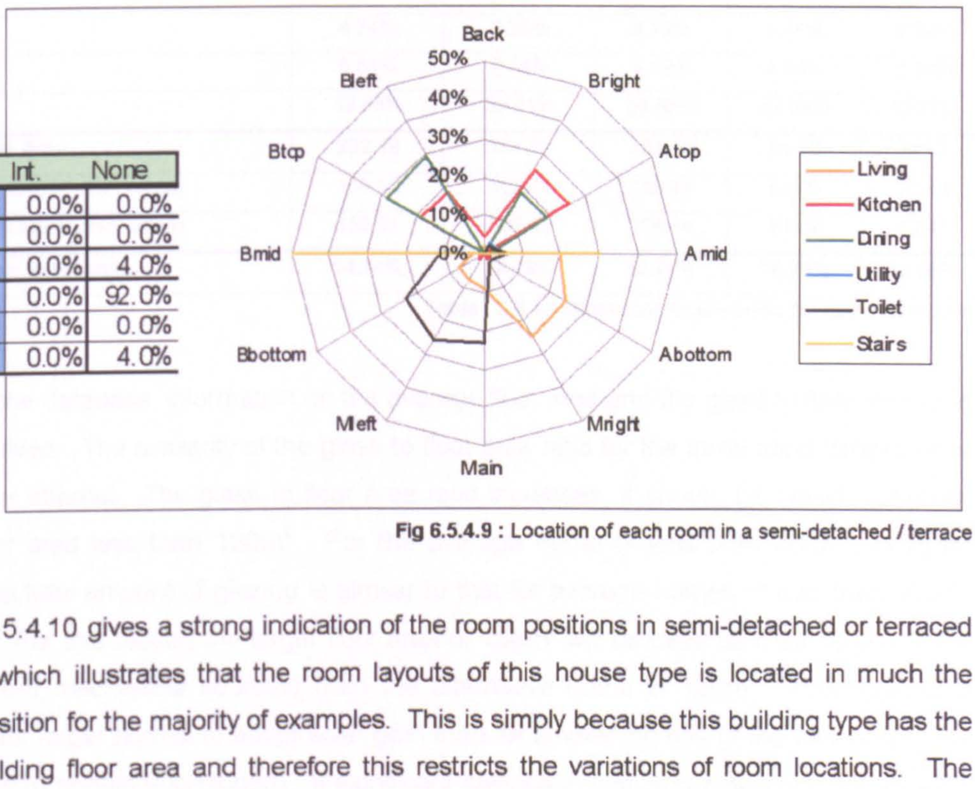


Fig 6.5.4.9 : Location of each room in a semi-detached / terrace

Figure 6.5.4.10 gives a strong indication of the room positions in semi-detached or terraced homes, which illustrates that the room layouts of this house type is located in much the same position for the majority of examples. This is simply because this building type has the least building floor area and therefore this restricts the variations of room locations. The footprints of these homes are also clearly shaped, the rectangular shape being the most common, with the shortest elevation facing the street.

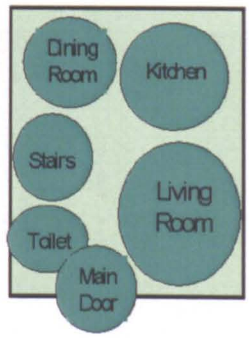


Fig 6.5.4.10 : Semi-detached / terraced home room layout

6.6 FURTHER PHYSICAL DATA FOR THE STANDARD AND PASSIVE SOLAR DATABASES

6.6.1 INFORMATION FROM STANDARD HOME DATABASE

The following table summarises the information garnered from the database. For each house type the average glazing area is expressed as a percentage of each elevation. The back elevation of a detached home, for example, has the most glazing, whilst for a roof-space home, the main elevation typically has the most glazing.

Table 6.6.1.1 : Glass to floor area ratios	**Detached**	**Bungalow**	**Roof-space**	**Semi**	**Terrace**
Main Elevation	40.05%	43.25%	49.46%	42.58%	43.48%
Side A	4.74%	9.98%	8.13%	1.16%	0.80%
Side B	5.81%	7.14%	4.12%	4.98%	3.34%
Back Elev	49.78%	39.71%	38.65%	52.04%	52.37%
Average Floor Area	**232.38**	**151.23**	**163.56**	**81.09**	**72.43**
Average FA (<500m^2 discounted)	158.50	109.41	156.44	81.09	72.43
Average FA (<300m^2 discounted)	130.61	109.41	156.44	81.09	72.43
Average Glass to FA ratio	**14.74%**	**14.48%**	**13.40%**	**16.79%**	**19.05%**

Table : 6.6.1.1 Glass to floor area ratio for each house type

Also from the database, information on the average floor area and the glass to floor area ratio can be derived. The similarity of the glass to floor area ratio for the three main categories is of particular interest. The glass to floor area ratio increases, it should be noted, in homes with a floor area less than 120m^2. For the average home of less than 300m^2, in figure 6.6.1.2, the total amount of glazing is similar to that for average homes of less than 500m^2 floor area. For this reason the larger floor area of 158m^2 will be used as it will require more heating (from mechanical sources) than the alternative home of 130m^2. It is more of a challenge for larger homes to adopt solar gain than for smaller homes (if the total amount of glazing was to remain unchanged). If significant savings in cost and emissions are possible with this home then smaller homes will, logically, also benefit.

Table 6.6.1.2 : Total Glazing area for each facade on each housing type	FA	G/FA	MAIN	A	B	BACK	TOTAL
Detached House (<500)	158.50	14.74%	9.36	1.11	1.36	11.63	**23.45**
Detached House (<300)	130.61	17.76%	9.40	0.85	0.98	11.50	**22.73**
Bungalow	109.41	14.48%	6.85	1.58	1.13	6.29	15.85
Habitable R-Space	156.44	13.40%	10.37	1.71	1.86	8.10	21.04
Semi-detached	81.09	16.79%	5.80	0.16	0.68	7.09	13.72
Terraced house	72.43	19.05%	6.00	0.11	0.46	7.23	13.80

The database information has been used to find the average glazing area for each elevation. Of particular interest is the significant reduction of total glazing area for the bungalow, due to fewer rooms having a portion of the total exterior wall/roof area. This table also shows the similarity between semi-detached and terraced homes.

The information from the database will provide the simple dimensional information needed to calculate heating loads for the model. Taking the two-storey detached home as an example, they have a average floor area of 158.5m^2, and this will give a perimeter of around 36m (8x10m footprint), with the ground floor being 79.25m^2 based on external dimensions. The building standard internal height for this type of dwelling is 2.4m (one-storey) giving a wall area of around 185m^2, including gables but excluding windows, roof-lights and doors. With a 30 degree pitched roof, the roof has an area of just over 100m^2. The database, therefore, has given a typical base model that can be used for further analysis. It should be noted that costs calculated for the passive solar database have been calculated on a £/m^2 basis so that costs for different floor areas may be determined.

6.6.2 BUILDING REGULATION DATA FOR CONVENTIONAL CONSTRUCTION

The following table details the information from the database as discussed, and also provides the minimum applicable u-values, provided by the building regulations. In the building regulations (Scotland) there are two categories ('a' and 'b') which are dependant on fuel type, 'a' being gas or electric and 'b' being all other fuel types. Only the U-values for category 'a' are given below since gas central heating is used. As this is a comparison of current against passive solar, and not the energy efficiency of boiler types, the most common boiler type (gas) has been chosen as the heating fuel, but this is discussed further in a following section. The u-values in this table follow the recent changes (2002 in Scotland) to the building regulations. Previous studies of passive solar, declaring savings of 10-80% on heating demand, were compared with buildings that have building regulations minimum u-values as quoted in this table.

Simple geometric dimensions and data for creating the **Base Model Home (Table 6.6.2.1)**:

DETACHED HOUSE		ELEMENT	U-VALUE	AREA (m^2)	
				<500	<300
FA (<500) = 158.50m^2		Pitched roof	0.20	101.20	75.34
Perimeter	37.00				
Height	2.40	External Wall	0.30	185.03	159.37
Living Area	19.81				
		Ground Floor	0.25	79.25	65.25
FA (<300) = 130.61m^2					
Perimeter	32.50	First Floor	-	79.25	65.25
Height	2.40				
Living Area	16.32	Windows, doors, rooflights	2.00	23.45	22.73

Of the two base models included in figure 6.6.2.1 the alternative with a floor area of 158.50m^2 will be used for this research as a representative 3/4 bedroom home for the North East of Scotland and if savings are achievable with this larger floor area then logically smaller homes will also benefit. Most homes in the North East of Scotland also fall within 75-200m^2 (see figure 6.5.3.1) and both the homes detailed in figure 6.6.2.1 fall within this range.

The following section discusses the elements of design that are incorporated in low-energy designs, their influence and benefits are discussed in full. It is important to note that the base model (detailed on the previous page) is used in these sections to illustrate benefits, but as yet passive solar is not used as a comparison.

6.7 DEVELOPMENT OF THE PASSIVE SOLAR DATABASE

Before the base housing model can be developed into various passive solar models the following characteristics were investigated more fully to determine limits and the effect that they may have upon a home.

- Insulation
- Glazing
- Ventilation
- Heating System

Insulation will be investigated to determine the benefits of super-insulation in a passive solar home. The case study at the beginning of this chapter suggested that super-insulation was the main reason for the success of this project. This research has investigated further to see if this is likely to be true for most passive models and whether there are any limits to the application of insulation in walls. Glazing has also been investigated as to the total amount of glazing in a home and the effect of varying the proportion of glazing that faces South. Ventilation was also an important issue in the case study, which concluded that more could have been accomplished with a better ventilation strategy. Finally, the heating of the home and more particularly, the heating system used in this analysis is detailed.

6.7.1 INSULATION

Figure 6.7.1.1 shows minimum insulation thickness required to meet building regulations across Europe, illustrating that the Scandinavian countries have greater insulation thickness. Scotland, which has slightly thicker insulation than the rest of Britain, has a minimum of 100mm (around a u-value of 0.29 for a timber stud wall). Compare this with a super-insulated home where the insulation levels are three times greater. This should mean approximately three times greater savings on heating costs, and similar savings in emissions. The super-insulated option in figure 6.7.1.1 is the insulation thickness used by Deveci, et al, (2000)

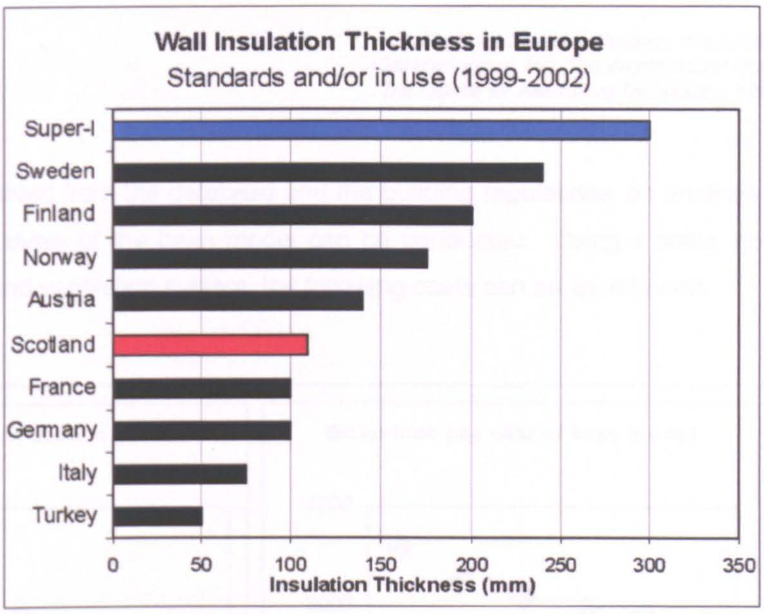


Fig 6.7.1.1 : Wall insulation thickness in various European countries *(adapted from various sources)*

So why not insulate a house with 400mm, 500mm, or above? Figure 6.7.1.2 illustrates that there is a threshold in benefiting from increasing insulation thickness. The following graph details the **life cycle costs** of insulation. What this shows is that with over 400mm of insulation there will be no **monetary** benefits in using more insulation. This is not to say that there are no further benefits in having insulation thicker than 500mm, but it does mean that a client would be spending initially and over the life of a building more than with 400mm of insulation.

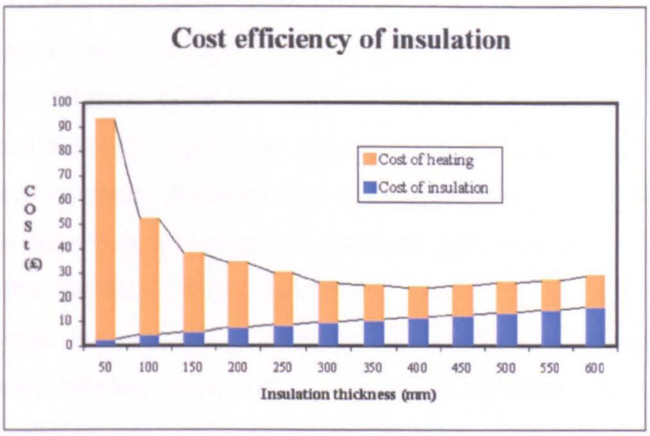


Fig 6.7.1.2 : Cost efficiency of insulation
(*Source:- Borer, Pat; The Whole House Book, The Centre for Alternative Technology, 1998*)

From the information collated from the database and the building regulations, an analysis of changing the insulation levels of the base model can be conducted. Using a basic, non-energy efficient heating and ventilation system, the following costs can be ascertained.

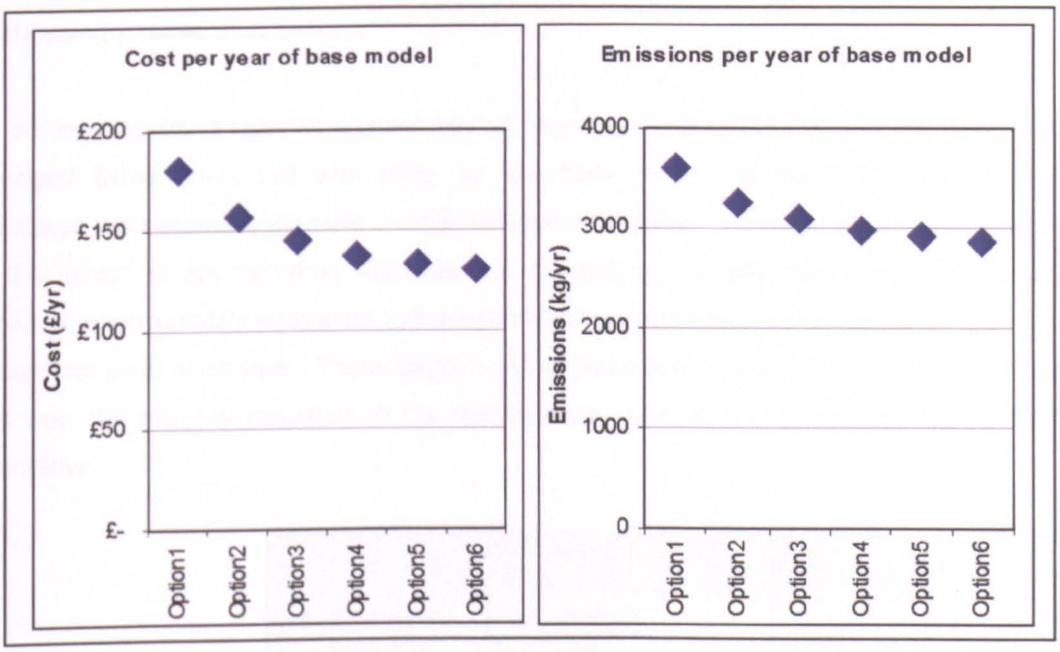


Fig 6.7.1.3 : Cost and emissions of a home with increasing thermal efficiency

Increasing the insulation levels of the base model alone, from building regulations minimum (option 1) to 600mm insulation thickness (option 6) illustrates that, though savings are accrued, they are not as great as would be anticipated. As the building regulations have increased (from an average of around 75mm in 1999 to 110mm in 2002) so the benefits of increasing insulation thickness above building regulations lessen. An argument against passive solar would therefore be: since insulation standards are likely to increase continually, the main driver being Government's objectives to reduce greenhouse gas emissions, why design passive solar if, in future, the benefits will be minimal? This is not a question answered in this research but it would be a continual problem for passive solar design. Regardless of this, basic passive solar heating costs nothing (requiring orientating south) and an optimised passive solar design includes insulation as one of its many facets. The fact that it does provide extra heating for little or no cost and that insulation will always be a part of a good passive solar design, will ensure that passive solar heating will remain popular in northern climates.

The next stage of this study, using BRE approved software, aimed to analyse a base model home, with the dimensions and building regulations minima as stated previously, incrementally increasing the insulation levels. This can then be used to compare with passive solar homes (both minimally insulated and super-insulated) to ascertain the benefits of choosing passive solar options.

To achieve results of benefits against varying degrees of insulation, the u-values have been changed **three** times per alternative, for the base model the following table (6.7.1.4) illustrates the necessary element u-value for each alternative. A whole house target u-value of 0.4 (which is approximately equivalent to building regulations minimum), 0.3 and 0.2 (which is approximately equivalent to the optimised insulation given in the figure 6.7.1.2) was chosen for each alternative. These target u-values have been used in the framework tool. In this way, the effect of insulation (if the rest remains identical) can be ascertained for each alternative.

		Element	Alt 1	Alt 2	Alt 3
			U-Value (a)		
Detached House 158.50 m^2		**Pitched Roof**	0.20	0.15	0.10
		Flat Roof	0.25	0.19	0.13
		External Wall	0.30	0.23	0.11
		Ground Floor	0.25	0.19	0.13
		First Floor	-	-	-
Perimeter	37.00	**Windows, doors, rooflights (metal)**	2.20	1.50	1.10
Height (m)	2.40	**Windows, doors, rooflights (PVC/Wood)**	2.00	1.35	1.00
Living Area	19.81				

Table 6.7.1.4 : Changing thermal efficiency standards of three alternatives

6.7.2 GLAZING

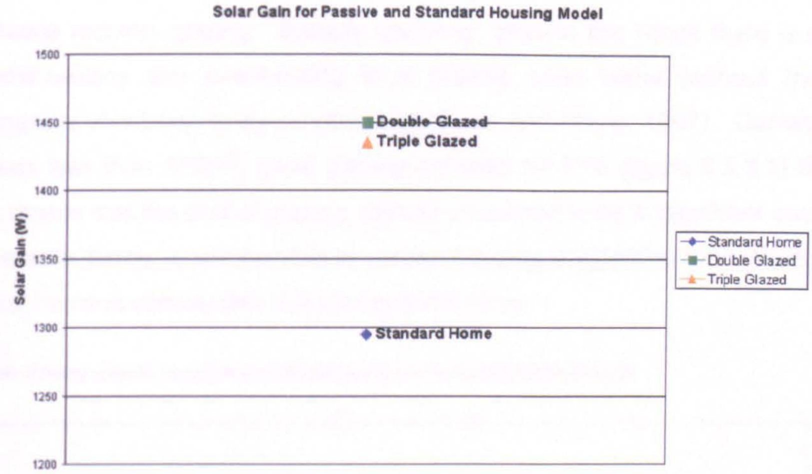


Fig 6.7.2.1 : Solar Gain for Passive and Standard Housing

Figure 6.7.2.1 illustrates the amount of solar gain that is achievable in a simple model of a passive solar home. The passive solar home here only achieves an additional 11% in solar gain over the standard home. Although this will, in an appropriately designed home, ensure that some cost and emission savings are made it also illustrates that there is not such a great difference between passive solar homes and standard homes. In this case the total amount of glazing was similar (15% Glass to Floor area in the Standard, 18% G/FA in the passive home) but the standard has only 50% of the glazing facing South (on the main elevation) and the passive solar home has 70%. The passive solar home has two types of glazing, triple and double (both with Low-E). There is not a big difference yet the triple glazing will ensure more heat is retained, which is an important consideration in an energy conserving home.

Glazing in any house is a balance, however, between heat loss and heat gain. Recent development in glazing technology has resulted in much more air-tight and insulating glazing units than ever before. Previously it was often the case that what heat has been produced by the heating element in a building quickly escapes through the glazing element, the frame or through poor draught proofing around a unit. New regulations mean that, for timber framed windows, double glazed, low-e windows are now necessary to meet regulations and as such these will form the base model specification, with a value of 2.00 (to meet whole house u-vale target of 0.4), and 1.35 (to meet target value of 0.3). Triple glazed windows will need to be specified to gain a u-value of 1.00 (to achieve a whole house target of 0.2).

From the analysis of housing types in the North East of Scotland (Appendix D and summarised in table 6.6.1.2) using current construction techniques the research has highlighted the fact that the amount of glazing in a modern home is now remarkably similar to that in a passive solar home. The passive solar home included in this research (section 6.2) and also in Borer & Harris (1997) and Yannas ([1], 1994) show that between 15-20% of the floor area of a home requires glazing. Broadly speaking, beyond this range there is a greater risk of under-heating and over-heating in a passive solar home (without the introduction of mechanical ventilation or air-conditioning) (Borer and Harris, 1997). Current specification of homes less than 150m^2, gives glazing between 14-17% (figure 6.5.3.1) of the floor area. This means that the cost of glazing, usually presumed to be a significant cost element in a passive solar home, is comparable to current housing suggesting that glazing cost in a passive solar home is comparable to a conventional home.

Fig 6.7.2.2 : Savings in heating dependant on various proportions and total amount of glazing

Figure 6.7.2.2 illustrates that for various glazing scenarios a difference of 12% in additional heating demand is possible. This figure also illustrates that the total amount of glazing (the legend provides these values expressed as the glass to floor area ratio) is not greater than a standard home. In this figure, 15% glass to floor area ratio with 90% of the glazing orientated south is the preferred alternative. If the proportion of glazing facing South was reduced by only 4% additional heating input would be required to ensure that heating demand is met in the home. Please note that the remaining glazing amount was equally distributed on each of the remaining orientations. These calculations were based on the specification for the case study at the beginning of this chapter.

The key difference between the two types of housing is, therefore, not in the amount or cost of glazing but in the positioning of glazing. Research is required to ascertain if this influences potential buyers, however. The arguments against a passive solar home with most of its glazing facing south are as follows:

- Homeowners may feel that they lack privacy and are living in a goldfish bowl, especially if the building faces the street and/or is in a highly dense site;
- A solid bank of glazing may lead to the perception that it is an expensive house to run or maintain;
- The homeowner may feel restricted in the positioning of the windows (the only view is to the south, when a better viewpoint is to the north);
- Other rooms in the dwelling may suffer from lack of windows, especially on the northern elevation of the building, and;
- Glare inside the home and also reflection of glass.

Current housing types have a greater balance of glass around their elevations, roughly 50-50% with the main elevation being the more common elevation to have the most glazing unless glazed patio doors are included in the design, on the back elevation. There are key advantages to having glazing on one side of a home, however.

- Rooms can be clearly zoned, and a home can work holistically to a given end
- The glazing can act to promote the healthiness of a home and the homeowner, homeowners in southern facing homes are more likely to buy similar orientation in their next home (Kachadorian, 1997)
- More daylight to specific areas of a home where needed, with task lighting for specific areas of a home such as the kitchen or bathroom
- Some potential homeowners may also perceive the glazing like a new package (state-of-the-art or modernist), and be encouraged to purchase the home.
- Reduced use of artificial lighting in main rooms of home (Yannas, [2], 1994).

As noted previously, to increase the target u-value of the overall home the specification of windows for each type of home will increase also. To create a range of passive solar alternatives, the glazing is incrementally changed (see 6.7.5.1 for full list of incremental changes). Passive solar glazing starts from 15% of the floor area and is incrementally increased until the passive solar glazing to floor area ratio is 30% at 2% incremental additions. The most relevant passive solar options that show important changes to heating costs, emission or appearance are chosen. The glazing area calculated is inclusive of all elevations, meaning that it is the total glazed area of the home. The total glazing facing south is taken to be three-quarters of the total glazing, so for 15m^2 of total glazing, this equates to just over 11m^2 of glazing facing south.

6.7.3 VENTILATION AND AIR TIGHTNESS

Ventilation, and in particular air tightness, are important aspects of low-energy design. The main reason for heat loss from a building is from drafts, either caused by design, by poor build quality or inadequate specification.

Figure 6.7.3.1 illustrates, using the base model home for analysis, the benefits of using air-tight construction by incrementally increasing air-tightness from building regulations minimum (option 1) to an extremely air-tight house with 0.25 ac/hr (option 6). Though option 6 is most unlikely to occur, it shows that there is a natural limit of around 0.5 ac/hr with option 4. Also there is no significant savings in emissions. Figure 6.7.3.2 shows how much can be saved using increased insulation thickness and more air-tight construction.

Figure 6.7.3.2 shows that combining two different methods for creating low-energy homes can pay increased dividends. The base model house, by increasing air-tightness and insulation, has halved the yearly cost (option6 – option1) and the emissions have similarly reduced significantly.

Making a building air-tight is a high risk strategy in low-energy terms, however, and it is not a passive method, especially for larger, multiple storey homes that cannot readily use passive means of ventilation. Of course natural ventilation is preferred over mechanical ventilation but this is not a realistic alternative for many rooms with sources of pollution. The benefits of using mechanical ventilation are that they can extract a pollutant from point of source, and the rate of heat loss can be more easily controlled, than say, opening a window.

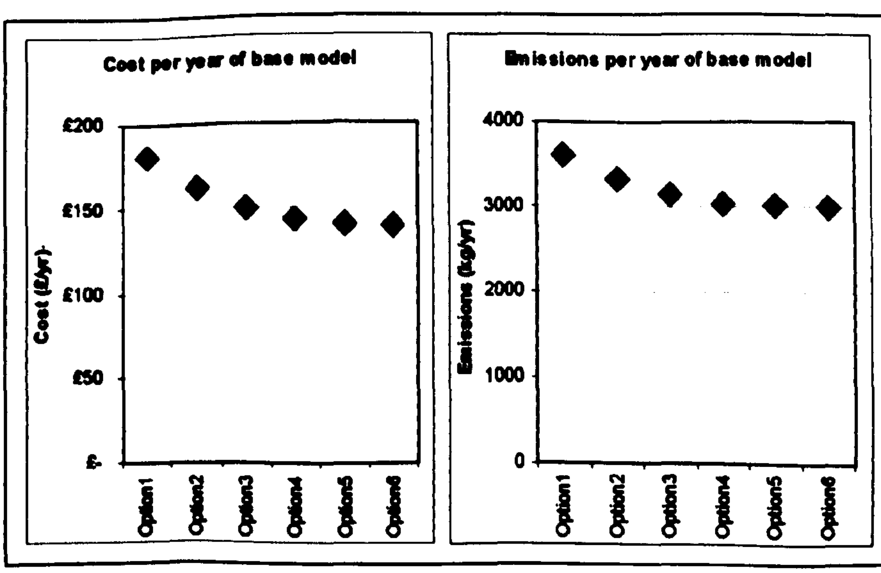


Fig 6.7.3.1 : Cost and emissions of a home by incrementally increasing air-tightness

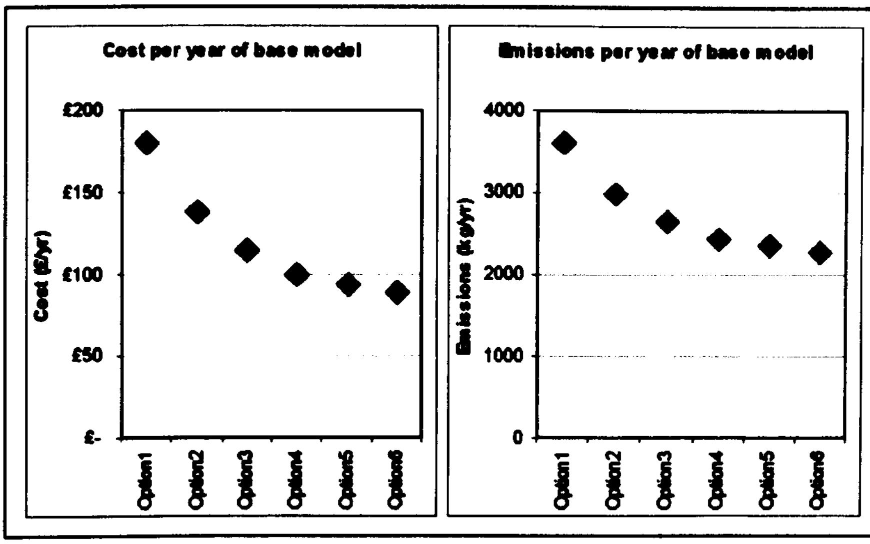


Fig 6.7.3.2 : Cost and emissions of a home combing better air-tightness with greater thermal efficiency

Ventilation of low-energy designs is a complex issue. Using mechanical ventilation solves most problems, as air can be filtered, but there is still significant risk of heat loss. This may be overcome, however, using mechanical heat recovery systems, or even whole house ventilation systems. Heat recovery systems are able to recover 60-70% of the exhausted heat from a home.

In this research a number of the passive solar options used adopt increased air-tightness. Due to the many problems of increasing air-tightness and the possible consequences for occupant health, the passive solar database will give options with and without increased air-tightness (as different alternatives).

6.7.4 HEATING A HOME USING A DEDICATED HEATING SOURCE

The type of heating fuel is a significant factor in the heating of a home that can most affect the costs and emissions of a home. In terms of sustainability it is what fuels these heating elements which affects emissions, but in terms of running and installation costs, a gas-fired central heating system is by far the most common system when a gas supply system is available. Turrent, *et al*, (1981) state that it took twenty years for the central heating system to take full hold in the housing market, and today the central heating system is standard in nearly all our new homes. The efficiency of these systems is, however, variable though modern gas systems can be over 90% efficient[1].

[1] http://www.sedbuk.com, Boiler Efficiency Database, Date last visited 25 Jan 2005 10:33

Gas cannot be realistically supplied to every site in the North East of Scotland and alternatives to gas include electric, oil and solid fuel sources. This research is interested, however, in comparing passive solar with the current cheapest fuel source, which happens to be gas, so that a passive solar home and a conventional home may be compared fairly.

With gas systems, building developers have a tendency to use industry minima rather than choose a boiler system that is energy efficient. Typical boiler efficiency is between 70-85%. An energy efficient boiler, 90+% (Sedbuk.com) and can achieve significant savings, but generally for common housing developments, without government incentive, these boilers are not specified for new housing. Significantly, these systems heat the water for the house also, and significant savings can also be achieved if a combination boiler is specified to heat the water. For these reasons, an **83% gas-fired combination boiler, central heating system** will be specified for the analysis between base and passive solar models. The adoption of alternative and renewable heating systems will be introduced within future variations of the tool. Gas central heating currently is used throughout the mass housing market in the North East of Scotland (except in more remote areas) and therefore for this reason is used as the standard heating system.

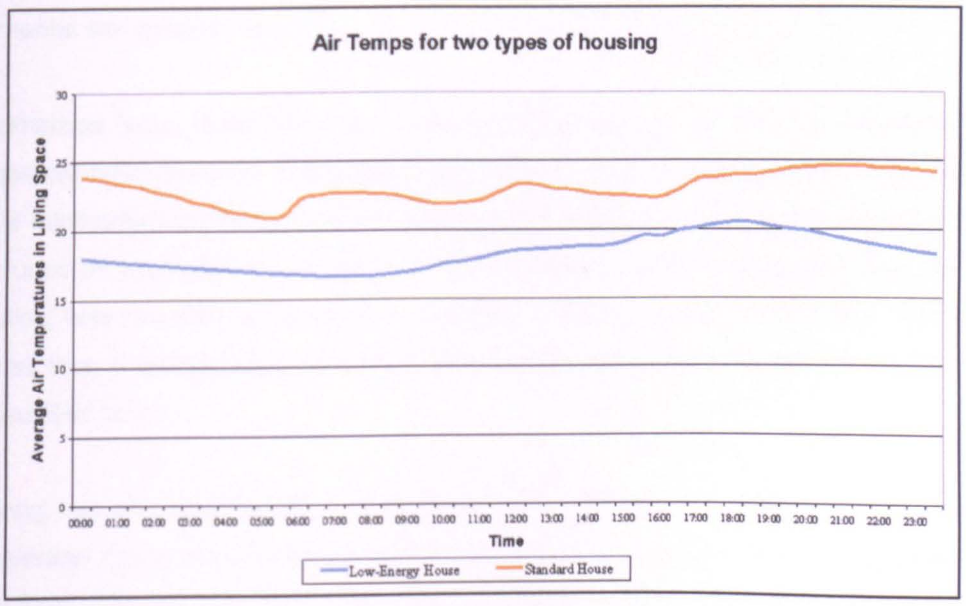


Fig 6.7.4.1 : Average daily indoor air temperatures of a passive solar home (low energy) against a standard home (research conducted by the Robert Gordon University in Glasgow)

Figure 6.7.4.1 illustrates the potential of low-energy designs (whole house target u-value of 0.27) against standard spec houses (Scottish building regulations minimum prior to 2002 changes), the analysis taken over a period of three winter months of two identical homes. As well as having significantly lower air temperature, which is directly proportional to energy use, than the standard alternative, the low energy design has a smoother usage pattern. Though this is somewhat subjective, depending on the individuals in the separate homes, and there preferences, it may be clearly seen that during the analysis in the standard home there are three distinct heating cycles, at approximately 5:30, 11:00 and 16:00. Compare this with the low-energy design, which continuously heats up during the day, implying that the heat gained within the house from the heating system, internal gains and solar gains is retained throughout the day without significant extra input on the coldest days.

The low-energy homes in this analysis are not significantly different from standard homes, relying on solar gain, super-insulation and air-tightness rather than any other features, so greater benefits can therefore be attributed to a better design. The figure highlights that conventional homes with central heating may be taken for granted and warmer temperatures above what is necessary can be anticipated. Low-energy homes discourage this possibility and ensure that fewer emissions are created.

6.7.5 THE ALTERNATIVES

The following (table 6.7.5.1) checklist details the variations used to create the passive solar database. The database was created from these types and used as an integral part of the environmental site assessment.

The alternatives were determined by incrementally changing the different elements that create passive solar designs. The target u-value of the standard home (termed base home) using the information garnered from the house type database and the target u-value is 0.42 (this includes all elements of the external building element as an average). This, for the Base option, was rounded up to create an average u-value of approximately 0.40. The base option was then thermally increased to achieve target u-values of 0.3 and 0.2, 0.2 being a super-insulated home.

The glazing was also incrementally changed from 15% glass to floor area, which was based on the average home as determined by the house type database. The glazing ratio was changed from 15%, to 17%, 20%, 25%, 30%. In addition, each alternative was calculated to determine the effect of changing the orientation. To determine this each alternative had its orientation incrementally changed to assess the effect, which would then be tested against information taken from Yannas ([1], 1994).

The air-tightness was also altered in a number of alternatives. Using the software a base air change rate is given as 0.99 (approximately 1), and this was changed to 0.89 and 0.79 respectively to ascertain the affect of this. More details of each of the alternatives follows.

Checklist for Passive Solar Database (table 6.7.5.1)

		U-Value	Glazing Type	Glazing to FA	South Facing	Ac/Hr*	Energy	Efficiency	Water
Base Option	a	0.4	DG, Low-E	Standard	48%	1	Gas	83%	Gas
	b	0.3	DG, Low-E	Standard	48%	1	Gas	83%	Gas
	c	0.2	TG, Low-E	Standard	48%	1	Gas	83%	Gas
Base 1	a	0.4	DG, Low-E	Standard	48%	1	Gas	83%	Gas
	b	0.3	DG, Low-E	Standard	48%	0.9	Gas	83%	Gas
	c	0.2	TG, Low-E	Standard	48%	0.8	Gas	83%	Gas
Base 2	a	0.4	DG, Low-E	Standard	60%	1	Gas	83%	Gas
	b	0.3	DG, Low-E	Standard	60%	1	Gas	83%	Gas
	c	0.2	TG, Low-E	Standard	60%	1	Gas	83%	Gas
Passive 1	a	0.4	DG, Low-E	20%	82%	1	Gas	83%	Gas
	b	0.3	DG, Low-E	20%	82%	1	Gas	83%	Gas
	c	0.2	TG, Low-E	20%	82%	1	Gas	83%	Gas
Passive 2	a	0.4	DG, Low-E	25%	90%	1	Gas	83%	Gas
	b	0.3	DG, Low-E	25%	90%	1	Gas	83%	Gas
	c	0.2	TG, Low-E	25%	90%	1	Gas	83%	Gas
Passive 3	a	0.4	DG, Low-E	25%	75%	1	Gas	83%	Gas
	b	0.3	DG, Low-E	25%	75%	1	Gas	83%	Gas
	c	0.2	TG, Low-E	25%	75%	1	Gas	83%	Gas
Passive 4	a	0.4	DG, Low-E	30%	75%	1	Gas	83%	Gas
	b	0.3	DG, Low-E	30%	75%	1	Gas	83%	Gas
	c	0.2	TG, Low-E	30%	75%	1	Gas	83%	Gas
Passive 5	a	0.4	DG, Low-E	18%	70%	1	Gas	83%	Gas
	b	0.3	DG, Low-E	18%	70%	1	Gas	83%	Gas
	c	0.2	TG, Low-E	18%	70%	1	Gas	83%	Gas
Passive 6	a	0.4	DG, Low-E	18%	70%	1	Gas	83%	Gas
	b	0.3	DG, Low-E	18%	70%	0.9	Gas	83%	Gas
	c	0.2	TG, Low-E	18%	70%	0.8	Gas	83%	Gas
Passive 7	a	0.2	TG, Low-E	18%	70%	0.65	Biomass	70%	Electric
	b	0.2	TG, Low-E	18%	70%	0.65	Gas	90%	Gas
	c	0.2	TG, Low-E	18%	70%	0.65	Biomass	70%	Biomass
Passive 8	a	0.2	TG, Low-E	18%	70%	0.45	Biomass	70%	Electric
	b	0.2	TG, Low-E	18%	70%	0.45	Gas	90%	Gas
	c	0.2	TG, Low-E	18%	70%	0.45	Biomass	70%	Biomass

** Air change rate would normally decrease relative to the amount of insulation in building envelope*

Table 6.7.5.1 Variation of each alternative

Base Option. The base option is derived from building regulations minimum for thermal efficiency, as of 1st April 2002, and sized according to a typical house built in the NE of Scotland (taken from the investigation of housing developers). From this data, the target u-value is 0.38 W/m^2K (approximately 0.40). To investigate the effect of super-insulation, alternatives were given target u-values of approximately 0.30 and 0.20 W/m^2K. The base option has a glass to floor area ratio of approximately 15% (average for a standard home, of which almost 50% of the glazing was on the back elevation of the home (table 6.6.1.1). The following figures are an extract from the data obtained from the BRE accredited software, showing the summary of figures when the main elevation is facing south:

Base Option 1. This alternative investigates the effect of changing the air-tightness (coupled with thermal efficiency changes) of a dwelling. All other aspects of the home are identical to that of the base option. In this option the standard air change rate (Ac/Hr) of 0.99 is changed progressively to 0.89 and 0.79, together with changing the u-values as for the base option.

Base Option 2. This alternative is identical to the elements of the base option however 50% of the glazing that was on the north elevation has been re-orientated onto the south elevation. This should offer a basic passive solar option, without any other changes to the building envelope. It should be noted that the total glazing area is identical to the base option (15%).

Passive Solar Option 1. This is the first passive solar alternative, and the principle here is only to change the total glazed area of a dwelling. In this alternative, the total glazed area is 20% of the floor area. Of the total glazed area, 82% of this area is south-facing glazing and, like the base option, the insulation levels are incrementally increased.

Passive Solar Option 2. This alternative investigates changing the total glazed area to 25% of the total floor area, the principles being the same as passive solar option one. Of the total glazed area, 90% of the glazing is south-facing.

Passive Solar Option 3. This alternative is almost identical to passive solar option two, the only change being that only 75% of the total glazed area is south-facing.

Passive Solar Option 4. The total glazed area is 30% of the floor area, with approximately 80% of the total glazing facing south.

Passive Solar Option 5. This alternative uses the same percentage areas of the solar home case study (Appendix B). This results in a total glazed area to floor area ratio of 18% with a south-facing total area of 70%, which is approximately 20m^2.

Passive Solar Option 6. Similarly to base option 1, the air-tightness of passive solar option five, is incrementally increased from the standard 0.99 Ac/Hr, to 0.89 and 0.79Ac/Hr respectively. Otherwise this option is identical to passive solar option five.

Passive Solar Option 7a, 7b and 7c. In these alternatives, the most efficient house type from passive solar option 6 is used to investigate the savings achieved from using alternative heating systems, meaning that the target u-value is 0.2 W/m^{2}K for each choice. Notable changes to these alternatives are that the glazing is now triple glazed, low-e, gas-filled. This results in an air-tightness of 0.66Ac/Hr. The a, b and c suffixes denote different heating systems (different from previous alternatives also). Option 7a is a simple wood burning stove with electric immersion heater; Option 7b is a gas combination boiler with 90% efficiency and; Option 7c is a wood burning stove, providing heating and hot water.

Passive Solar Option 8a, 8b and 8c. These alternatives are identical to the options detailed in passive solar options 7a, 7b and 7c. The difference is the increased air-tightness from 0.66 to 0.45 ac/hr (0.45 ac/hr being that achieved by the 'Zero heating' house). This should illustrate the best case scenario that is capable of being built with simple building materials and quality construction. Note that the ventilation system remains unchanged, but an alternative ventilation system may be required for homes that are as air-tight as this option.

BASE OPTION SUMMARY

(main elevation facing south)

Fig 6.7.5.2 Technical description of house,
Fig 6.7.5.3 Solar gains from home,
Fig 6.7.5.4 Space heating costs,
Fig 6.7.5.5 Summary of costs and emissions

Main Elevation Facing South	Area	U-V	AxU
Heat Losses and Heat Loss Parameter	m^2	W/m^2K	W/K
Windows, double-glazed, Low E	1.36	2.00	2.45
Windows, double-glazed, Low E	11.63	2.00	20.93
Windows, double-glazed, Low E	1.11	2.00	2.00
Windows, double-glazed, Low E	9.36	2.00	16.85
Windows Total			**42.23**
Doors	4.36	2.00	**8.72**
Roof	101.20	0.20	**20.24**
Exposed Wall	185.03	0.30	**55.51**
Ground Floor	88.00	0.25	**22.00**
Ventilation Heat Loss			**124.81**
Heat Loss Coefficient, W/K			**273.50**
Heat Loss Parameter (HLP), $W/m^2/K$			**1.73**

Solar Gains	Area m^2	Flux W/m^2	AxU W/K
Windows, double-glazed, Low E	1.36	15.00	20.40
Windows, double-glazed, Low E	11.63	9.00	104.67
Windows, double-glazed, Low E	1.11	15.00	16.65
Windows, double-glazed, Low E	9.36	22.00	205.92
Windows Total			**347.64**
Solar Access Factor			**1.00**
Solar Gains (UK Average)			**347.64**
Total Gains (W)			**1348.72**
Gains/Loss Ratio (GLR)			**4.93**
Utilisation Factor (G/L)			**0.97**
Useful Gains (W)			**1313.67**

Main Elevation Facing South	Energy	Emission Factor	Annual Emissions
Carbon Dioxide Emissions	GJ/yr		kg/year
Water Heating	14.14	54	764
Space Heating, Main	48.32	54	2609
Space Heating, Secondary	0.00	0	0
Electricity for Pump and Fans	1.99	142	283
Total CO2 (Space and Water), t/year			**3.7**

Main Elevation Facing South	
Software Figures Summary	
Av U-Value (W/m^2K)	**0.38**
SAP	**82**
CO_2 emssions (kg/yr)	**3602.00**
Air Change Rate (Ac/Hr)	0.99
Heat Loss Parameter (W/m^2K)	1.73
Total Internal Heat Gains (W)	1001.08
Total Solar Gains (UK Av, W)	1348.72
Useful Solar Gains (UK Av, W)	1313.67
Mean Internal Temperature	18.43
Degree Days	1697.27
Useful Energy Requirement (GJ/yr)	40.11
Efficiency of boiler	*83%*
Space Heating Fuel (GJ/yr)	**48.32**
Electricity for Fans and Pumps (GJ/yr)	1.99
Space Heating - Main System	£ 180.73
Water Heating Cost	£ 52.88
Pump/Fan Energy Cost	£ 39.21
Standing Charges	£ 28.00
Total	**£ 300.82**

Cost and benefits of each passive solar alternative in the database

The following pages (figure 6.7.5.6) diagrammatically express the potential savings that each option has over the 'base option', the option that is most likely to be commonly built in the North East of Scotland. The diagrams should be read from left to right, with potential savings from increased levels of insulation increasing from left to right, and loosely from top to bottom where the alternatives generally incrementally increase in terms of total glazed area and potential savings.

At the top of the page a key is provided and this details what the value listed for each alternative is, those values being useful solar gain, energy use, space heating costs, total heating costs and CO_2 emissions. Solar gain is used to indicate the benefit of changing glazing areas and whether the heat loss to heat gain ratio are critical.

The energy use is included to illustrate the energy required to heat a home, and the energy use after including the boiler efficiency is also included where applicable. For example, taking the base option that has a target u-value of 0.3, there is an 18.9% energy saving over the primary base option. This means that the energy use is 9,105kWh/yr, and with a boiler efficiency of 83% (standard) this equates to a total energy use of 10,967kWh/yr.

The space heating costs and potential savings are included. The heating costs are only a proportion of the total household energy costs therefore these costs are also included. Therefore the total cost saving is also included detailing the saving possible when water heating costs are included.

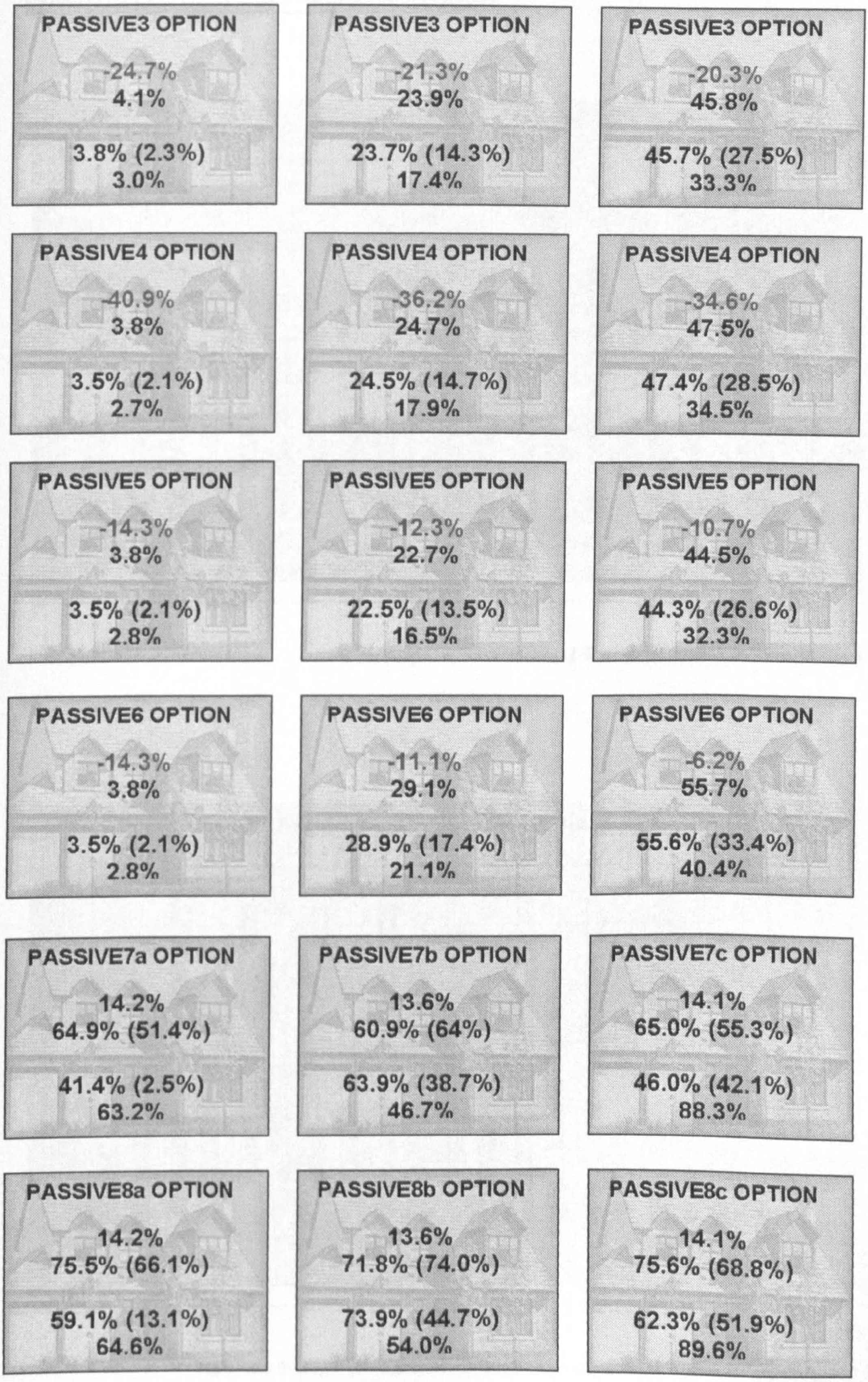
Finally, the potential savings of CO_2 emissions, an indicator of all household pollutants, is ascertained and expressed in the diagrams. All passive solar models created in the following database are directly south facing.

KEY

Useful Solar Gains
Energy/yr (kWh/yr)
Required Energy/yr by boiler (kWh/yr)
Space Heating Cost (Total Cost of Heating)
CO2 emissions (kg/yr)

Increasing Thermal Standards

2002 Building Regs	Target U-value (approx) 0.3	Target U-value (approx) 0.2
PRIMARY BASE OPTION **1297** W **11220** kWh/yr (13,520 kWh/yr) £181.31 (£301.40) **3618.4** kg/yr	**BASE OPTION** 1.7% 18.9% 18.9% (11.2%) 13.7%	**BASE OPTION** 1.1% 40.9% 40.7% (24.5%) 29.6%
BASE1 OPTION 0.0% 0.0% 0.0% (0.0%) 0.0%	**BASE1 OPTION** 1.4% 26.0% 25.8% (15.5%) 18.9%	**BASE1 OPTION** 4.7% 52.6% 52.4% (31.5%) 38.2%
BASE2 OPTION -7.3% 3.6% 3.3% (2.0%) 2.6%	**BASE2 OPTION** -5.1% 22.2% 22.0% (13.2%) 16.1%	**BASE2 OPTION** 3.9% 39.5% 39.3% (23.6%) 28.7%
PASSIVE1 OPTION -21.6% 4.3% 4.0% (2.4%) 3.1%	**PASSIVE1 OPTION** -18.4% 23.9% 23.6% (14.2%) 17.3%	**PASSIVE1 OPTION** -17.4% 45.7% 45.5% (27.4%) 33.2%
PASSIVE2 OPTION -26.5% 4.3% 4.0% (2.4%) 3.1%	**PASSIVE2 OPTION** -22.9% 24.2% 24.0% (14.4%) 17.5%	**PASSIVE2 OPTION** -21.8% 46.3% 46.1% (27.7%) 33.6%


PASSIVE3 OPTION
-24.7%
4.1%
3.8% (2.3%)
3.0%
PASSIVE3 OPTION
-21.3%
23.9%
23.7% (14.3%)
17.4%
PASSIVE3 OPTION
-20.3%
45.8%
45.7% (27.5%)
33.3%
PASSIVE4 OPTION
-40.9%
3.8%
3.5% (2.1%)
2.7%
PASSIVE4 OPTION
-36.2%
24.7%
24.5% (14.7%)
17.9%
PASSIVE4 OPTION
-34.6%
47.5%
47.4% (28.5%)
34.5%
PASSIVE5 OPTION
-14.3%
3.8%
3.5% (2.1%)
2.8%
PASSIVE5 OPTION
-12.3%
22.7%
22.5% (13.5%)
16.5%
PASSIVE5 OPTION
-10.7%
44.5%
44.3% (26.6%)
32.3%
PASSIVE6 OPTION
-14.3%
3.8%
3.5% (2.1%)
2.8%
PASSIVE6 OPTION
-11.1%
29.1%
28.9% (17.4%)
21.1%
PASSIVE6 OPTION
-6.2%
55.7%
55.6% (33.4%)
40.4%
PASSIVE7a OPTION
14.2%
64.9% (51.4%)
41.4% (2.5%)
63.2%
PASSIVE7b OPTION
13.6%
60.9% (64%)
63.9% (38.7%)
46.7%
PASSIVE7c OPTION
14.1%
65.0% (55.3%)
46.0% (42.1%)
88.3%
PASSIVE8a OPTION
14.2%
75.5% (66.1%)
59.1% (13.1%)
64.6%
PASSIVE8b OPTION
13.6%
71.8% (74.0%)
73.9% (44.7%)
54.0%
PASSIVE8c OPTION
14.1%
75.6% (68.8%)
62.3% (51.9%)
89.6%

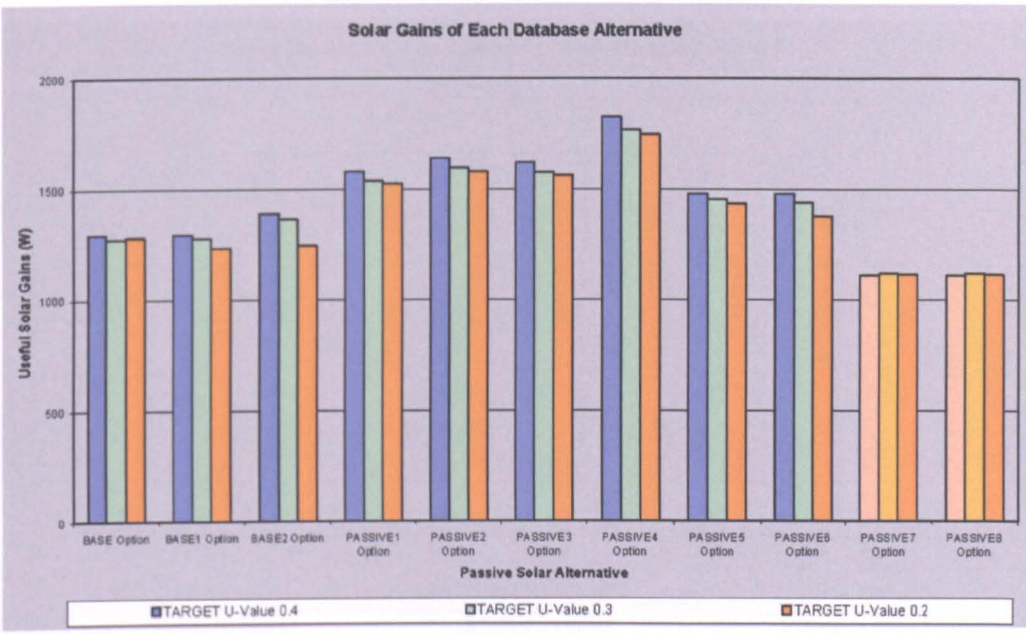


Fig 6.7.5.7 Solar gains of each database alternative

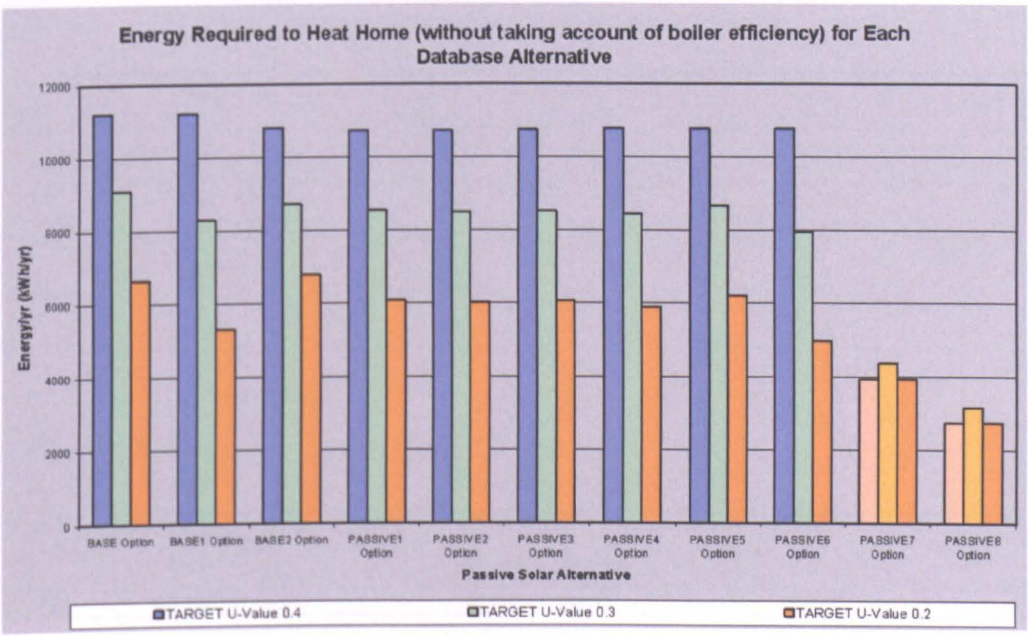


Fig 6.7.5.8 Energy required (without addition for boiler efficiency) for each database alternative

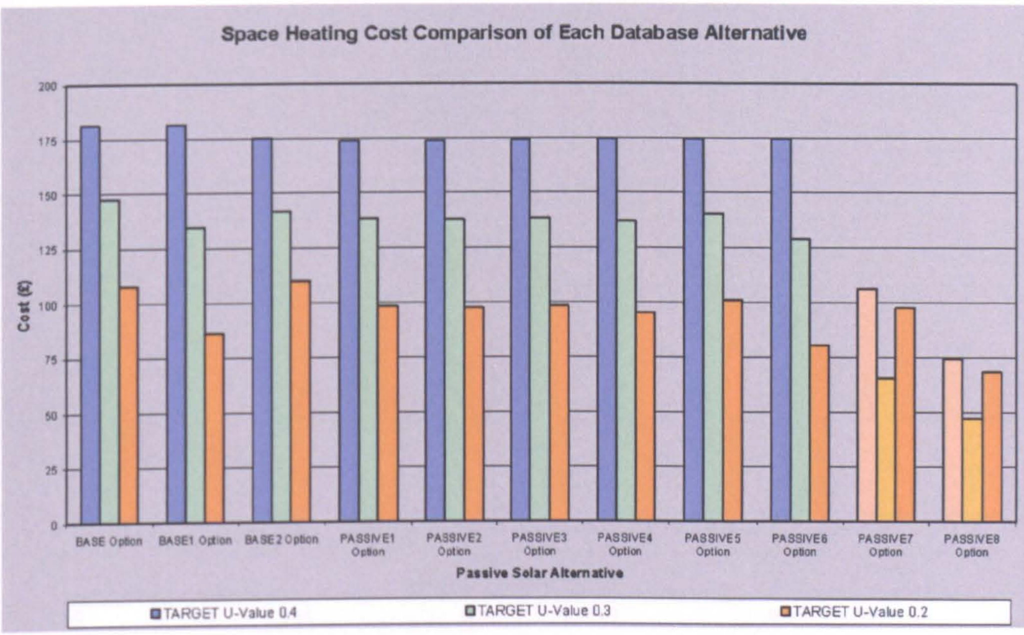


Fig 6.7.5.9 Space heating cost comparison of each database alternative

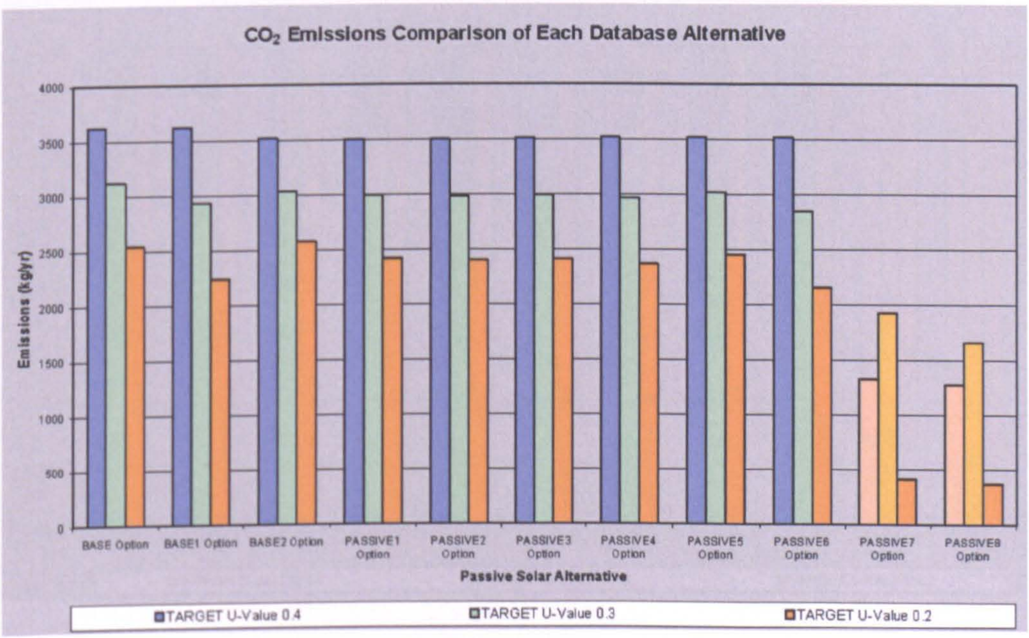


Fig 6.7.5.10 CO_2 emissions comparison of each database alternative

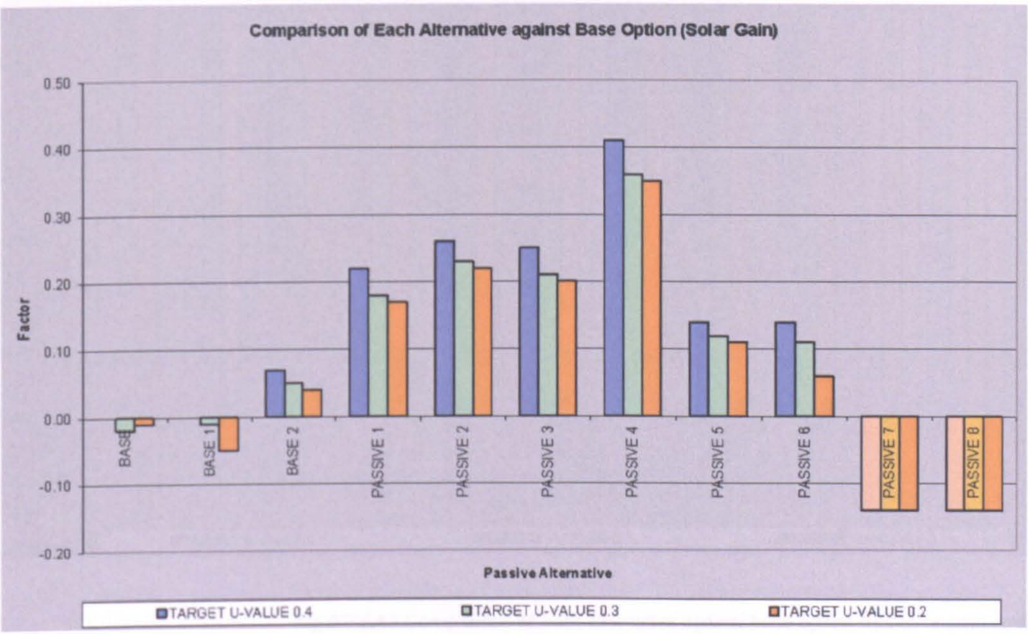


Fig 6.7.5.11 Comparison of each alternative against base option

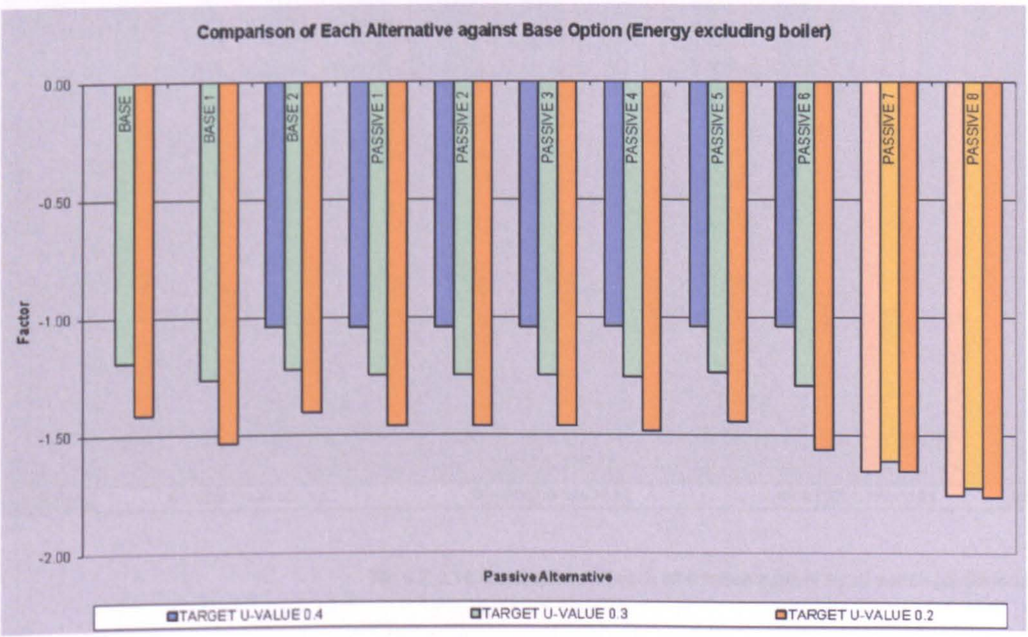


Fig 6.7.1.12 Comparison of each alternative against base option (energy without boiler)

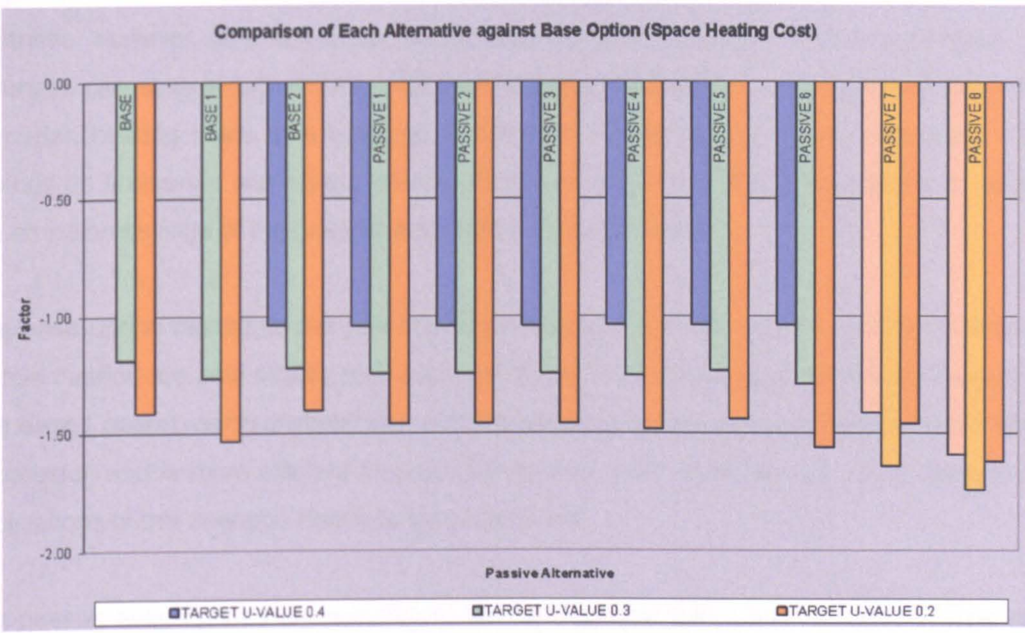


Fig 6.7.5.13 Comparison of each alternative against base option (space heating cost)

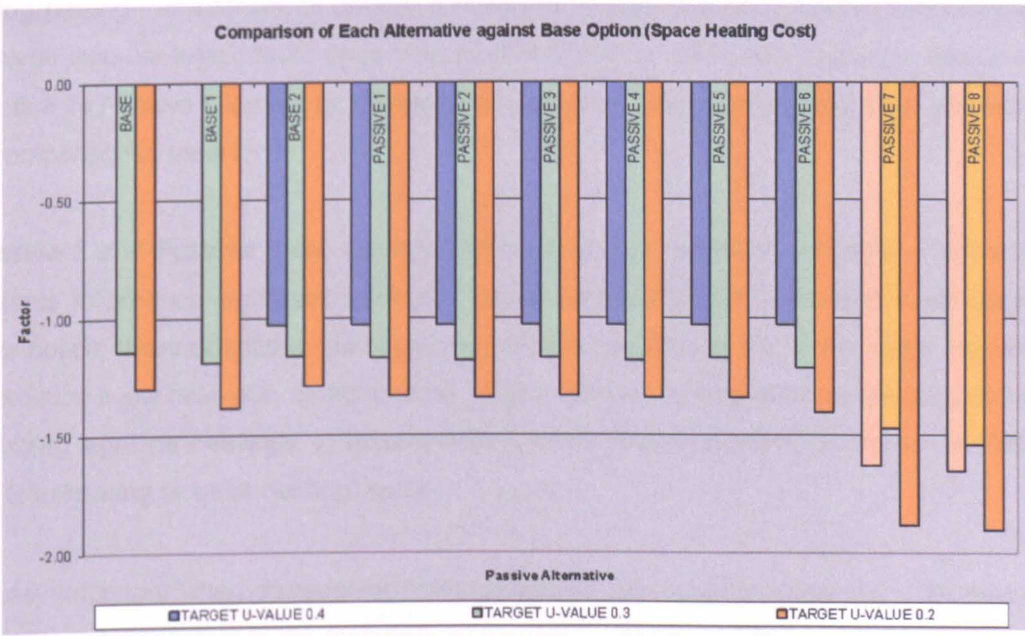


Fig 6.7.5.14 Comparison of each alternative against base option (emissions)

From the analysis most passive solar options save around 25% to 45% in monetary costs at target u-values of 0.3 and 0.2 W/m^{2}K respectively against the base alternative. Air-tightness, however, is a key factor when reducing heating costs. From the analysis, air-tightness can save a further 10%. Of the total cost of heating, including space, water and pump/fan heating costs, this adds up to between a quarter and a third reductions. The savings on emissions are equally as important and with this in mind it should be noted that the emission savings of the passive solar homes are significant

The **base** option highlights the potential of increasing insulation levels; the savings attained by this method are only slightly less successful than the passive solar options (Passive 1-5). The **base1** option, using air-tightness and insulation to reduce costs, proves to be extremely successful, and is more efficient than simple passive solar methods. In future research the implications of this scenario needs to be ascertained.

The passive solar options are remarkably similar (**Passive 1-5**). The heat loss to heat gain ratio means that there is little difference between **Passive 5** and **Passive 4** in terms of cost savings. Passive 4 has 40m^2 of south-facing glazing and Passive 5 has only 20m^2 of south facing glazing. In addition, in passive 5 there will be less chance of temperature swings in extreme external temperature (less chance of overheating and under-heating). **Passive 6**, identical to Passive 5 except for increased air-tightness, produces the best solar alternative, in comparison to **base1**.

Passive 7 and **Passive 8** are examples of housing that use more expensive, mechanical systems to produce significant savings. Based on the Passive 5, the best case passive solar option, these adapt the use of glazing which is gas-filled to add to the super insulation to produce a low heat-loss, air-tight home. Highly efficient heating systems are used as well, providing significant savings, in excess of 60% of the heating costs at best which is 50% of the total heating (+ water heating) costs.

Equally important when considering heating systems, are exhaust emissions. The savings are directly proportional to the monetary cost savings. Base1 and Passive 6, which primarily use air-tightness to reduce energy use, are the best at reducing CO_2 emissions.

For example, some alternatives were specified with non-fossil fuel heating systems, in this case a wood burning (biomass) stove. In some cases, emissions savings of up to 90% can be achieved by these heating systems simply because they will not be needed in a super-insulated home except in the most adverse conditions in winter. The major restrictions to adoption in the mass market would be sustainability of the fuel source. The initial heating period is slow and if is used for water heating, as well as the heating of the home, the speed and efficiency restricts its use especially in larger homes.

From the details provided by the passive solar database and illustrated by the figures on the previous pages, a number of interesting points may be made:

- A passive solar home with $40m^2$ or more south facing glazing is approximately comparable to one that has, for example, $20m^2$. That is to say a passive solar home does not need to rely on a large amount of the glazing facing south. This is due to the effect of the heat loss to heat gain ratio. While south facing glazing increases, the heat loss to heat gain ratio decreases, equalising any benefits gained. In addition, the home with more south glazing is more likely to suffer from glare and greater variances in temperature. In short, with a holistic design principle, which includes super-insulation, glazing no more than 18% of the floor area is sufficient to heat a moderately sized, passive solar home.

- The heating energy that is required to heat each alternative is similar regardless of the amount of south facing glazing. To gain the most benefit, air-tightness, glazing, ventilation and insulation all need to be combined in a holistic design approach.

- Changes to each alternative have a monetary consequence. Avoidance of major cost increases in design is avoided for options (passive) 1-6. However, for Passive 4 (30% glazing to floor area ratio) the expected increases of cost would be about 20%. For Passive 5 the additional cost would be around 3%. These costs are based on the additional glazing required for each home and are for general reference only.

- The savings achievable on the Emissions from the homes in the passive solar database are between 30-40%. Passive 7 and Passive 8 alternatives shows that the difference in the efficiency and varying the type of heating system can make significant impacts in emissions. This is particularly relevant for the biomass systems used.

The analysis of individual homes has shown that significant savings can be achieved, but not **only by passive solar means**. These savings need to be applied to a whole housing site and this is what the framework tool will aim to model.

6.7.6 EFFECT OF ORIENTATION ON THE HOMES IN THE PASSIVE SOLAR DATABASE

The table 4.3.1.1b in Chapter four details the effect of orientation on a modern passive solar home. Figure 6.7.5.15 shows these figures graphically, the additional heating input expressed as a percentage. The figures from Yannas ([1], 1994) are based on a passive home from the early nineties, the details and specification of which are not known. The passive model is based on the 'zero heating' home, which is discussed in section 6.2 and more fully in Appendix B. The base model is a standard home as described in section 6.6 with thermal standards equivalent to building regulations minima. Significant difference may be seen between the 1994 and 2002 data on passive homes, which is most likely attributable to the changes in building thermal efficiency standards in the intervening period but could also be because the size of the building (floor area) are different. Insulation thickness has doubled in the last decade (from 50mm to over 100mm in Scotland). The base model home has an 'arc' opposite to that of the other alternatives. This is because the main elevation, the elevation with the main access, is assumed to face South. This elevation has slightly less glazing than the back elevation, thus the figures are inverted. The main elevation of the passive homes is where most of the glazing is focused.

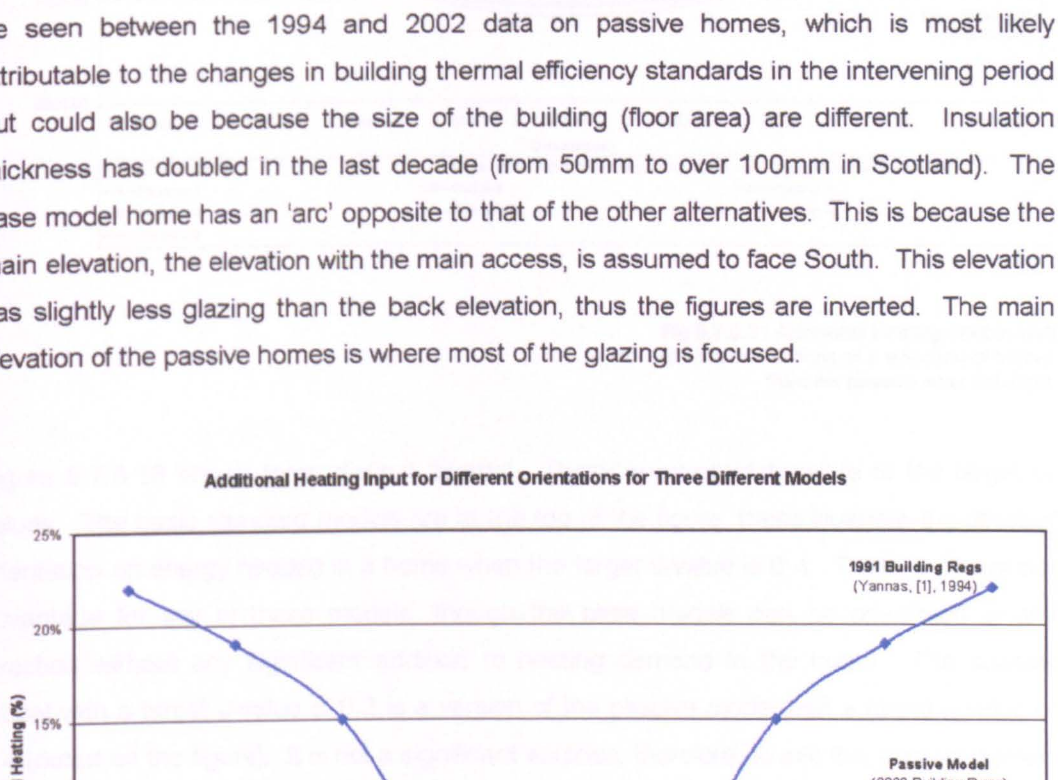


Fig 6.7.6.1 : Additional heating input for different orientations for three different models.

It should be noted that figure 6.7.5.15 relates to additional percentage heating input. That is to say, each alternative above will have a different heating input in kWh. To illustrate this, figures 6.7.5.16 details the effect of orientation of a selection of homes from the database (specifications of which are detailed in table 6.7.5.1 and the values in figure 6.7.5.6).

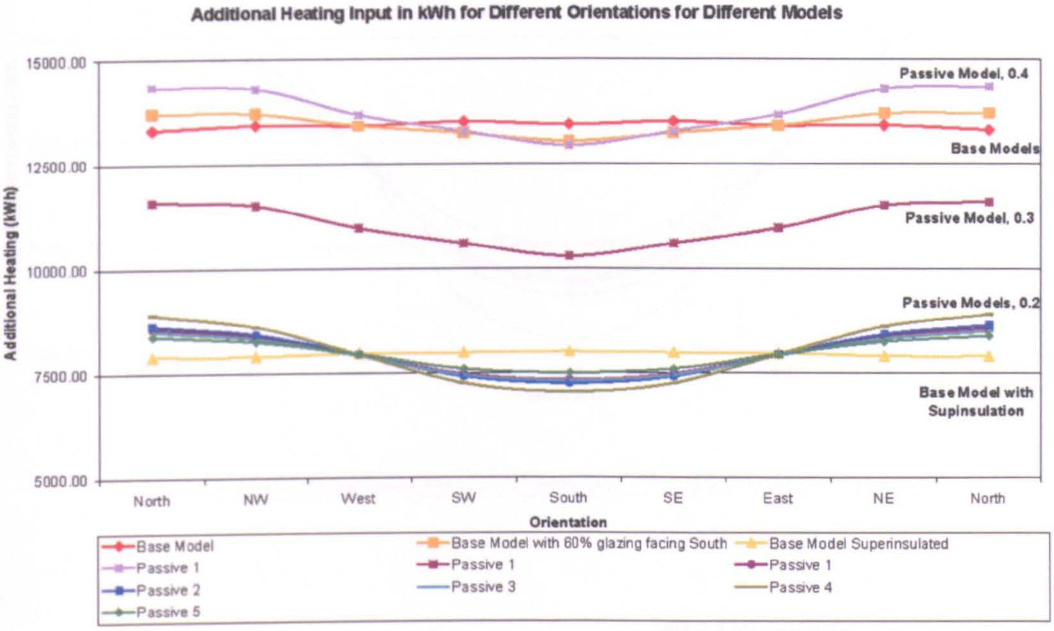


Fig 6.7.6.2 : Additional Heating Input in kWh for different orientations of a selection of homes from the passive solar database

Figure 6.7.5.16 shows three distinct 'bands'. These approximately relate to the target u-values. The basic standard models are at the top of the figure, these illustrate the effect of orientation on energy needed in a home when the target u-value is 0.4. There is no distinct advantage for any of these models, though the base models can be orientated in any direction without any significant addition to heating demand in the home. The passive model with a target u-value of 0.3 is a version of the passive model with a target u-value of 0.4 (noted on the figure). It is not a significant surprise, therefore, to see five passive models with target u-values of 0.2 (please see table 6.7.5.1 for specifications of these models) to be similar in depiction. As may be seen orientation has a similar effect on each of these models, the saving of energy is a result of decreasing the target u-value. As an alternative an optimised base model with super-insulation is included as a comparison ('Base Model Super-insulated'). This alternative is not dependant on orientation, but where the passive solar homes face South, South West or South East less energy in these homes are required. To illustrate this point, figure 6.7.5.17 details passive solar options 1-5 at target u-value 0.2 and compares against the base model with super-insulation again with a target u-value of 0.2.

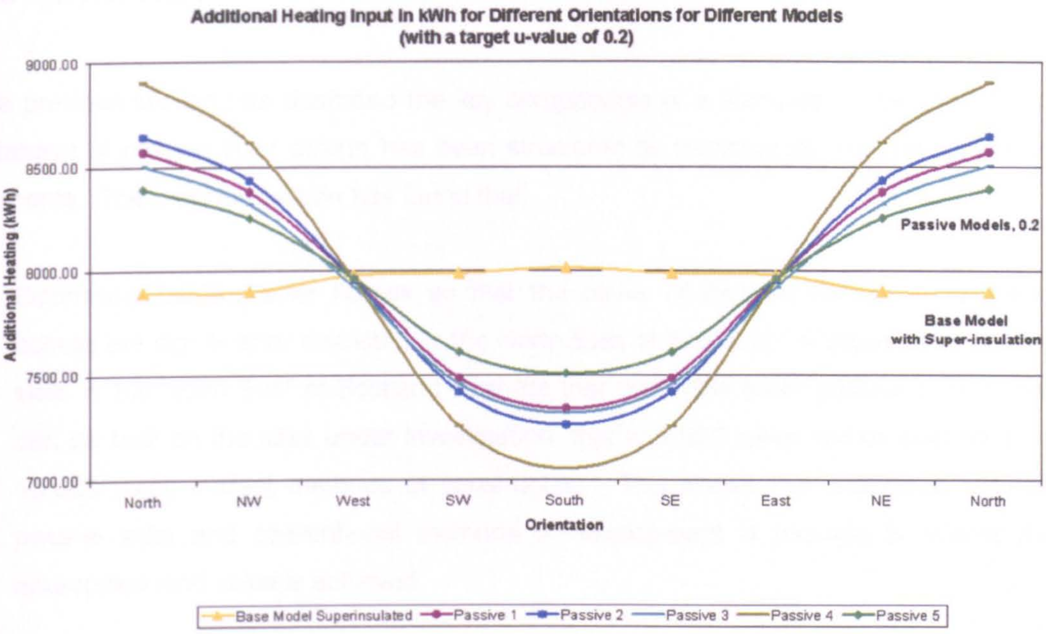


Fig 6.7.6.3 : Additional Heating Input in kWh for different orientations of a selection of homes from the passive solar database with a target u-value of 0.2

The above figure illustrates that each passive solar design follows a similar profile while the super-insulated home is not dependant on orientations. It is a combination of these two types, arguably, that could be used in housing developments in northern climates.

In the following chapter, the data detailed in this chapter will be used in the framework tool for the environmental site assessment.

6.8 SUMMARY

The previous section has illustrated the key components of a standard home and how the database of passive solar design has been structured by incremental changes to different elements. The previous section has found that,

- Optimising passive solar homes so that the power of the sun can gain year round access are significantly restricted in the North East of Scotland. Analysis of a variety of sites in the North East of Scotland illustrate that over 15% fewer passive solar homes can be built on the sites under investigation, that is 1,500 fewer homes built for every 10,000 using current methods of construction. This shows that a trade-off between passive solar and conventional methods of development is required to ensure that appropriate land value is achieved.

- The problem is particularly persistent for low cost homes, homes that are 125m^2 or less total floor area.

- A database of standard house types has been created in order to find a typical home in the North East of Scotland. Analysis of this data highlights the fact that room layout and total glazing area are not significantly different from housing developer's current house types. This has significant implications for cost as this makes costs of passive solar homes more comparable with current construction, costs of a passive solar home being more comparable to a conventional home.

- The various elements (insulation, ventilation and heating) of construction and are investigated and analysed as to their potential benefit to passive solar homes.

- The passive solar database is created. The use of this database is central in the framework tool for an environmental site assessment. The database shows that passive solar design provides significant savings in cost and emissions over current 'standard' housing. The following chapter will determine the effect these houses will have in a housing development.

7 Development of an Environmental Site Assessment Tool

7.1 INTRODUCTION

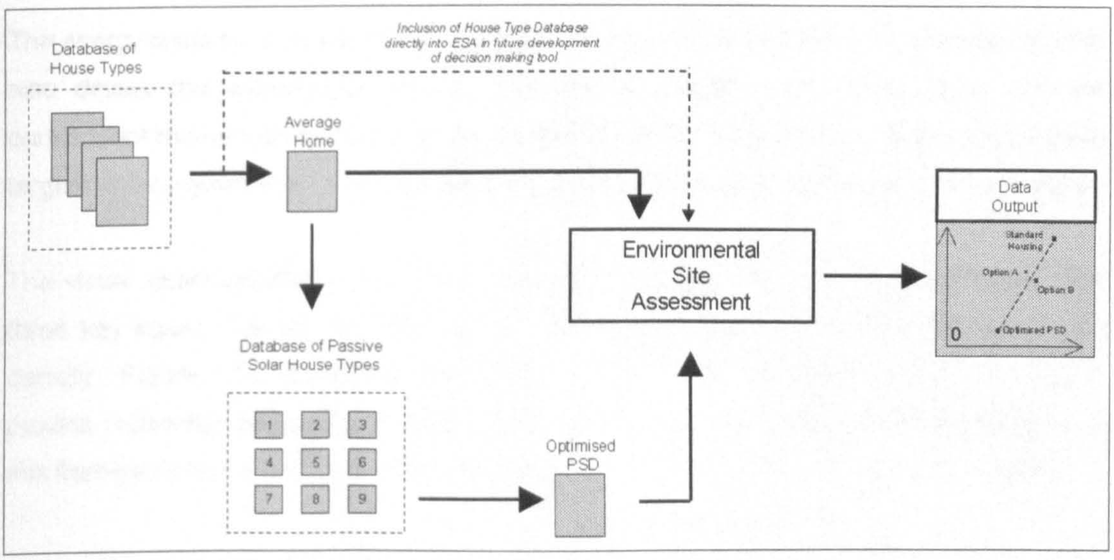


Fig 7.1.1 The Framework for an Environmental Site Assessment

The previous chapter detailed the construction of a database of simple geometric data from standard house types taken from Scottish housing developers and the above figure illustrates how the database will be included in the site assessment tool. In future developments of the tool, housing developers may be asked more specific questions about their house types as and when they change so that the data for the environmental site assessment can be kept up to date (an option for this is given in figure 7.1.1 as a dotted arrow). For this research simple geometric forms will be relied upon, however.

The previous chapter also investigated the effect of changing various elements of passive solar designs (insulation, ventilation, glazing, etc) that will be incrementally changed to create a database of passive solar house types and an optimised passive solar alternative (see figure 6.7.5.1). In this case, it should be noted, a passive solar home is used as an exemplar of a more sustainable development. As stated in previous chapters, and more thoroughly highlighted in the case study analysis, a passive solar home has a number of advantages, and is an ideal environmental design technique for a number of basic energy conserving methods.

Both the standard home type and the optimised passive solar house type are essential to the assessment procedure as they are used as indicators in the data output of standard housing against optimised passive solar. Used as indicators they can determine how environmentally conserving (in terms of cost) and how environmentally friendly (in terms of emissions) the site can be. The ESA recognises that there are trade-offs required between current construction methods and environmental methods of development, because of the need for high density on sites. The ESA will, however, aims to promote more sustainable development.

The energy costs for a typical home will be determined in this chapter. This previous chapter also details the construction of the database of passive solar house types and the consequent mathematical tools required to determine the trade-offs required to meet density targets on any given site. Their application in the framework tool will be given in the chapter.

The visual representation of the data output for the framework tool will be provided. The three key issues that will be displayed on this representation will be emissions, cost and density. Figure 7.5.2 shows the data output as part of the pilot study, which was used to provide recommendations for change. Future development in the visual representations of this framework tool is also provided in this chapter and figure 7.5.4 illustrates the potential.

7.2 INITIAL PRODUCT DEVELOPMENT

7.2.1 DATA COLLATING

The data collected from the sources in this chapter have been used to create the environmental site assessment procedure. The main aim of this assessment procedure is to give the planner of a development an idea of the trade-off costs associated with a particular density for a particular site. Passive solar design, chosen for the reasons described in previous chapters, is the exemplar of a more sustainable development.

The environmental site assessment brings together all the relevant data for calculating the energy costs and emissions for various house types. This section details the input data, the necessary data collation and a representative data output technique to demonstrate a framework tool for future development. There is a minimum of three alternatives being calculated for the assessment tool and these are for:

- **Standard homes.** Developments, as they stand, do not require the determination of spacing by the tool as they are set by the user. These homes meet building regulation minimum standards in thermal efficiency.

- **Passive Solar Homes.** These developments are chosen from a passive solar database and require the spacing to be determined on a north south axis, **matching the density** of the proposed (standard homes) development.

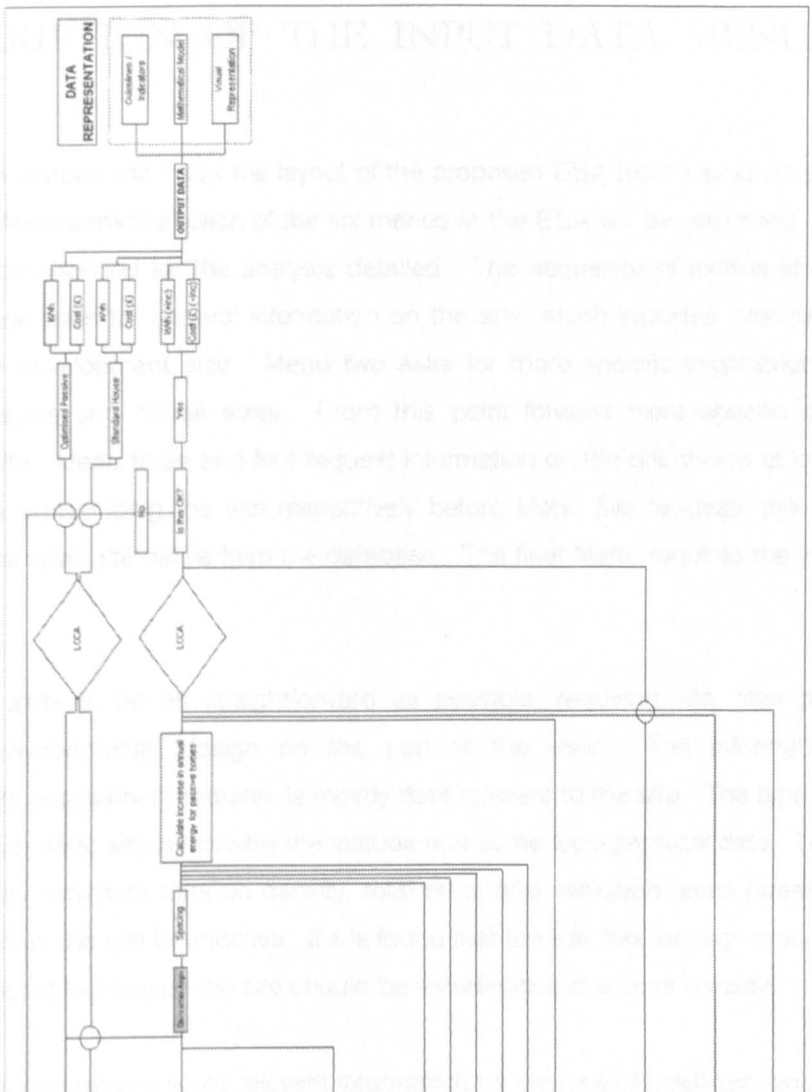
- **Optimised Passive Solar Homes.** As a third option, each optimised passive solar home is spaced to gain the optimal performance in terms of passive solar gain for the entire year. This usually results, in northern latitudes, of a **reduced density**. To reiterate, the difference over the passive solar homes and standard homes above is that the **density is not the same** as for the standard homes.

7.2.2 PRODUCT DEVELOPMENT AND INTRODUCING THE INPUT DATA

The flow chart (Fig 7.2.2.1) on the following page details the decision making and system processes in the ESA. The shaded area details the input data required by the site assessment user. As stated, the information at the planning stage of a development is limited and the input data in this process reflects this. From this information, since it is limited, databases of simple geometric housing types have been created to ascertain typical height and footprints of dwellings automatically.

Figure 7.2.2.1 (a larger version is available in Appendix C) details the inner workings of the framework tool (see Appendix A). Using simple geometric sections and footprints of dwellings and also basic unit area energy costs the tool calculates the whole life costs of each site. Before determining whether the information satisfies the objectives of the site, the tool then uses a comparative analysis between minimum building regulations, the alternative chosen and an optimised passive solar layout. The optimised passive solar layout is the alternative **not restricted by the density** of the site while the other two alternatives are **restricted by the density set by the developer** or planning department.

The final box of the flow chart indicates the data output as being guidelines or indicators, a mathematical model or a visual representation. The preferred alternative of the three options is a visual representation and this is more fully explained later in the chapter and in the recommendations.


INPUT DATA
DATA REPRESENTATION
OUTPUT DATA
LCCA
LCCA
LCCA

7.3 DESCRIPTION OF THE INPUT DATA MENUS IN THE ESA

The layout of this chapter will follow the layout of the proposed ESA tool. Using an example site in Westhill (Aberdeenshire) each of the six menus in the ESA will be described with the relevant information needed for the analysis detailed. The sequence of menus should be logical. Menu one asks for general information on the site, which includes information on location and the development size. Menu two asks for more specific information of the individual plots sizes and house sizes. From this point forward more specific detail is needed on the site. Menu three and four request information on the orientation of buildings and obstructions surrounding the site respectively before Menu five requests the user to select the passive solar alternative from the database. The final Menu requires the WLC for the project.

The input data aims to be as straightforward as possible, requiring very little previous experience of environmental design on the part of the user. The information the environmental site assessment requires is mostly data relevant to the site. The type of data required is location data, which includes the latitude and some topographical data. The data input also requires minimum data on density, total area, and exclusion areas (areas not to be developed) within the site boundaries. If it is found that the site has too high a density for a passive solar layout to be used the site should be investigated at a lower density.

The data user will also require some relevant information on the type of dwellings required on a site. This information relates to any relevant trade-off and overshadowing calculation, which inherently requires more specific data in order to calculate obstruction angle.

A basic street layout is required in the analysis so that accurate orientation may be found and compared to passive solar design. The site, therefore, requires some detailed thought as to site layout before relevant data may be given. The remaining data is garnered from the databases and tables created for simple design choice.

7.3.1 MENU ONE : CONSIDERING HOUSING LAYOUT

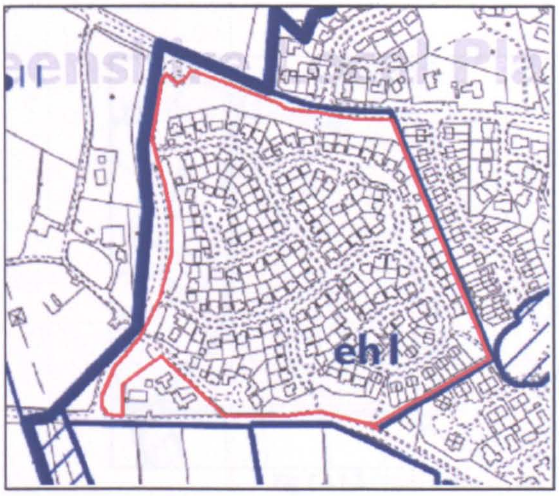


Fig 7.3.1.1 Site 'eh1', Westhill, Aberdeenshire

The example site (see figure 7.3.1.1) is taken from the Aberdeenshire local plan. The designation given for this site in the Westhill section is 'eh1'. Westhill is one of a number of satellite towns and villages which have dramatically increased in size in the past two decades. This trend is set to increase with up to 650 houses on five sites having been built or to be built in the next few years with possibly in excess of 500 homes on three sites in future. On menu one (fig 7.3.1.2) some simple information for this site can be taken from the local plan, developer site information and scaled maps.

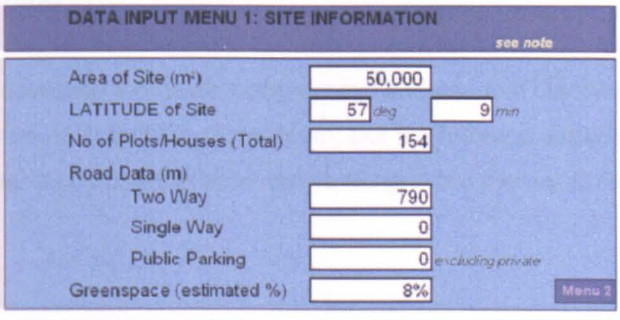


Fig 7.3.1.2 Data input menu 1 : Site Information

Menu one allows the basic minimum data on a site to be included in the calculation. Critical information included in this menu includes the area of the site, number of homes anticipated for the site and location of the site, which is expressed as latitude but may also be expressed as a postcode (in future). Each site will include space for a particular type of road layout, including parking, and again with future development this may become more specific, but with this exemplar single, double and public parking is included. In addition, green-space is included, which is an aspect of site design that may include deep boundaries, public footpaths, playing fields or similar.

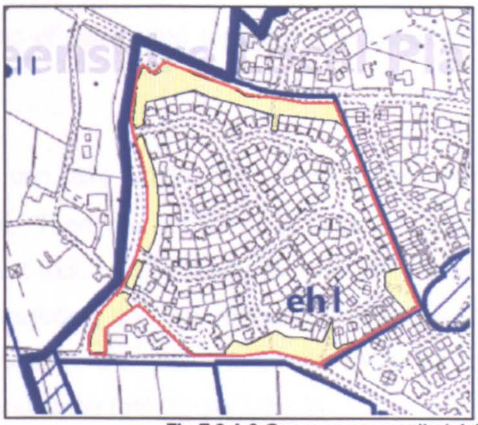


Fig 7.3.1.3 Green-space on site 'eh1'

Green-space is a common concept in modern housing layouts. They may take the form of buffer zones between the roads and housing (on site 'eh1' on figure 7.3.1.3 roads on the south, west and north have green-space buffer-zones) or they can be communal spaces in or around the development (an area of communal space is provided on the eastern boundary of the site). In a proposed passive solar development this space is excluded from the analysis. Green-space is seen as an essential benefit for any development and it is an aspect of site development which, in future, may increase in importance. For the site above, it is estimated that approximately 4,500 m^2 of the site is given to green-space (8%).

Site conditions and layout planning

The environmental assessment tool assesses the basic topographical features and planning of a development. Chapter four covers each topic in more depth, but the following aspects relate to the assessment tool as aspects you need to know before filling in the menus of the tool:

Site location and development density. For passive solar homes, site location is the first critical aspect of the design. The assessment tool assesses the effect that latitude has on any development and compares solar altitude with obstruction angle to determine any problem. Combined with this, the development density, in northern climates, has been analysed. This has determined that for higher latitudes passive solar developments become prohibited by overshadowing distances. Therefore, for passive solar developments to be adopted a method of coming to a form of 'trade-off' is needed, with the necessary analysis of the effect this has on physical aspects, such as space heating costs.

Site geometry and topography. A favourable site geometry and topography can make a significant difference to a passive solar home development. In the assessment tool this is exhibited by the calculation of the slope angle. The assessment is inherently restricted by its two dimensional nature, however a basic method of calculating topography is used (see figure 7.3.2.1).

Roads and access. Roads and access to a site can take up to 15% of a site, and add considerably to a developments construction cost. Therefore, a method of determining the road width and type is included in the assessment tool. A site developer should consider varying aspects in relation to roads and access, including one way instead of two way road layout and / or centralised car parking reducing roads on the site. It is these aspects which are included in the assessment tool in the first menu of the tool (figure 7.3.1.2)

Plot frontage and depth. The assessment tool calculates the plot frontage and depth from basic geometrical shapes (footprints) taken from a database. These are used to determine overshadowing and obstruction angles, both of which are dependant on the site density.

7.3.2 MENU TWO : BASIC HOUSE INFORMATION

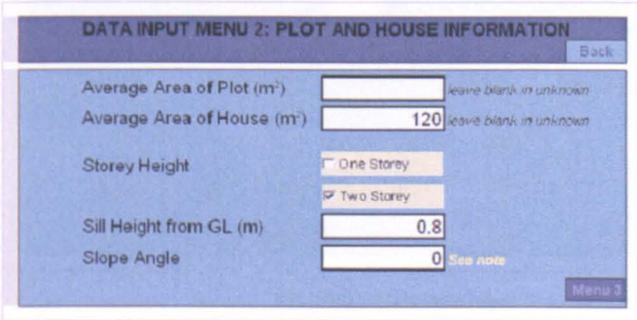


Fig 7.3.2.1 Data input menu 2 : Plot and House Information

The second menu in the environmental site assessment details more specific aspects of the site, which are important in finding the footprint, storey height and overshadowing of a dwelling from the relevant databases. As such, the average area of plot and average area of a house will need to be known. As an exemplar, this analysis only assumes one type of house, but inclusion of further house types would be straightforward. In addition, if data on the house or plot areas are unknown default values will be used calculated from the site area and number of homes on the site, based on UK averages. Basic storey types will need to be known, and it should be recognised again that this is an exemplar, and only one storey height type may be chosen as the worst case scenario default. It would be advised, however, that if storey height was unknown, the tallest building type on the site should be chosen. More specific data on the home is needed to determine the sill height, and this may provide specific problems for the analysis (passive solar house types only). In most passive solar homes the glazing is down to ground level, but a more favourable spacing distance (and therefore greater density on a site as a whole) may be achieved if the glazing is raised above ground level. The final two criteria of menu two may seem like menu one definitions regarding 'site information', however this data again directly relates to the spacing between passive solar homes only, and therefore is included as an aspect of menu two. Favourable changes to both the sill height and the slope angle can make a passive solar home more energy conserving.

Menu two gives the plot and house information of **one** housing type, but for any given real site scenario it is recognised that various house types may be used. In future development of the ESA, menu two would be duplicated, perhaps several times for several house types. An immediate question would be asked in this menu as the number of house types on a site and from this the number of duplicate menus may be determined.

7.3.3 MENU THREE : ORIENTATION

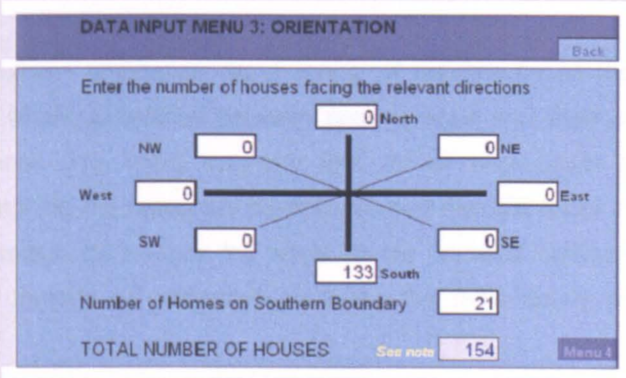


Fig 7.3.3.1 Data input menu 3 : Orientation

Menu three details the orientation of each house type. Though all passive solar homes may be assumed to face south, future development of the assessment procedure will use a variety of environmentally friendly and sustainable methods of construction which will not necessarily rely on site orientation. This menu will also ascertain the number of homes on the southern boundary, for passive solar purposes only, as overshadowing does not restrict these homes unless otherwise instructed by menu four.

Table 7.3.3.2 Additional heating input for different orientations* due to reductions in solar gain

	S	SE	E	NE	N
Passive Solar Option (2002 B Regs)*	0%	3%	8%	10%	11%
Basic (standard) Option	1%	1%	1%	0%	0%
Basic (standard) Option with some PS	8%	7%	4%	1%	0%

Based on 70% glazing on main (south) facing as per the zero heating home

From Yannas ([1], 1994), which used the 1991 building regulations, the difference between facing due south compared to east (or west) equates to approximately 15% in reduced heating demand. If the same analysis with the 2002 (Scotland) changes to the thermal efficiency of the building regulations is undertaken, the (approximate) result are that these values will be reduced by almost half. Insulation, therefore, has a significant role in making a passive solar home not dependant on orientation, and it is logical to assume that on sites where due south orientation is more difficult to achieve a compensational increase in insulation would ensure that passive solar could still be used though the risk of overheating (or under-heating) would need to be assessed.

The important criteria for **Scottish** developments, arguably, is that to be passive solar they need to face directly south more so than their equivalent at lower latitudes. It is suggested that housing in the North-East of Scotland should not stray further from being south facing than the BRE recommended limit of 25°, though with the modern thermal efficiency standards the consequences of varying orientations are dramatically reduced.

It is not possible to provide a southern orientation, for a variety of reasons for all the dwellings in a layout, and this is where a balance between passive solar and thermal standards can be achieved. Yannas ([1], 1994) suggests that, "in all such cases a judgement will need to be made weighing the respective advantages and disadvantages of an off-south orientation." This research determines the effect of any trade-off between standard and passive options, in regards to orientation by using the table above as reference.

7.3.4 MENU FOUR : EXTERIOR OBSTRUCTIONS

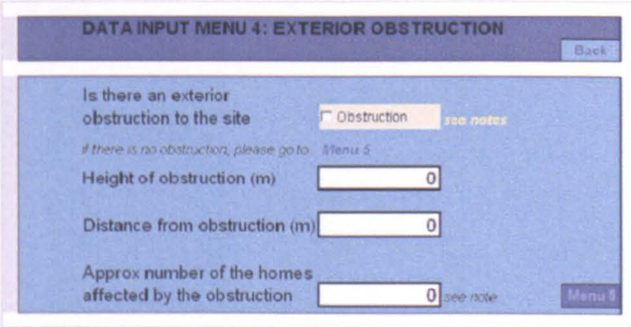


Fig 7.3.4.1 Data input menu 4 : Exterior Obstruction

Menu four calculates the optimum passive solar arrangement for homes obstructed by exterior elements around the site. These may be topographical features or man made structures of any kind, the height of which needs to be known. The distance to the object also needs to be (approximately) calculated. In addition, the number of homes that this feature affects needs to be known, and in this case the menu asks for a total number of homes, although this assumes that the site layout has also been determined. An alternative method, if the exact site layout is unknown, is to calculate the area of overshadow is on the site and determine the number of houses affected by the information garnered from menu two (divide affected area by plot area).

Overshadowing and Calculating Site Conditions from the Information Collected in Menus One to Four

Overshadowing is the first aspect that the environmental site assessment determines. This is achieved by converting the buildings on a site into simple geometric shapes based on known averages. That is, average house size, average plot width, average plot depth, and so on. Future evolutions of the tool may use local averages, but in this case UK averages have been determined. These simple geometric values are placed in tabular (database) sheets.

The reason for calculating the overshadowing distance based on the density of the site is so that the obstruction angle may be determined. If the obstruction angle is greater than the minimum midday solar altitude, then the site density is such that northerly buildings are obstructed from solar gain for part of the year (in the winter). From this knowledge, a user may make two key decisions:

a) Reduce site density
b) Proceed with investigation, and determine effect on (additional) heating load

Obstruction Angle and Solar Altitude

$$\operatorname{Tan}\Theta = \frac{H}{X}$$

$$X = \frac{H}{\operatorname{Tan}\Theta}$$

Θ = Obstruction angle (deg)
H = Height of obstruction (m)
***X** = Spacing (m)*

Fig 7.3.4.2 Equation for calculating spacing (Yannas, [1], 1994, p52)

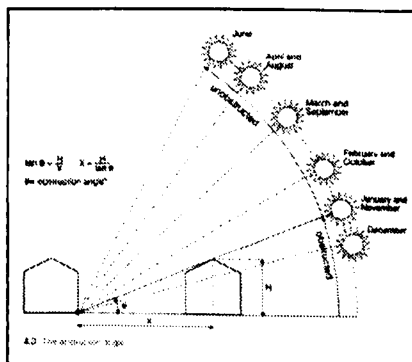


Image 7.3.4.3 Obstruction Angle, Source: Yannas ([1], 1994)

This has been described previously but to reiterate, the obstruction angle is the angle (*θ*) from the ridge of the obstruction to the ground level of the obstructed dwelling. The resultant distance is the spacing between dwellings (the overshadowing distance). For Aberdeen the lowest solar altitude is around 9° (lowest angle during winter) and from this the maximum spacing can be calculated, with the additional information of the height of the obstruction needed. With this tool, however, the obstruction angle is calculated based on simple geometric shapes taken from a database, which determines the spacing between dwellings for a particular density. The obstruction angle of the site is then compared with the solar altitude. See the following section, 'spacing guidelines' for more information.

The following figure is an extraction of a spreadsheet used to determine the solar altitude at a given date, at any latitude (provided in menu one, figure 7.3.1.2). As the worst case scenario (lowest angle) is around the shortest day, this gives the necessary information to establish the maximum overshadow distance for a site, allowing the tool to determine the optimum passive solar density (as a comparative between standard and recommended).

Calculation of Solar Altitude and Solar Azimuth for Northern Hemisphere			
Data requirements: latitude, date, local civil time, longitude, longitude of time zone			
	Day	Month	
Date	22	12	
	Hours	Mins	
Local Civil Time (24-hour clock)	12	0	*In UK Local Civiltime is GMT*
	Degrees	Seconds	
Latitude of site	57	24.0	
Results			
Solar Altitude	9.2		*If negative it means sun is below the horizon*
Solar Azimuth	0.3096 W		*Solar Azimuth measured clockwise from due south (northern hemisphere). Values +ve after solar noon*
sunrise hour angle	47.3		*Measured from south*
daylength	6.31 hrs		
sunrise solar time	8.85 hrs		
sunset solar time	15.15 hrs		

Fig 7.3.4.4 Spreadsheet used to calculate solar altitude

Overshadowing on the Site

In this assessment tool, obstructions are classified as either:

a) Interior (of the site), for example housing
b) Exterior (to the site), for example vegetation

The assessment tool is capable of determining both obstructions and establishing the effect on the houses heating load. This is based on calculating the obstruction angle these obstructions create, as above (figure 7.3.4.2). It may also be the case that there are different types of interior obstructions, causing different obstruction angles. Although the tool has not been developed to encompass multiple internal or external obstructions of varying types, future evolutions would be able to categorise these features into 'zones of effect'. That is to say, the buildings affected by overshadowing by the obstruction (determined on the lowest solar altitude for that latitude) are defined as a zone and treated separately from other zones within the site.

Calculating the spacing

There are ways in which a passive solar home, in areas where overshadowing is a problem, can become a more viable option. These methods may include changing the slope of a site, staggering dwellings, and so on. A simple method is to raise the height of the glazing of the ground up to sill level or possibly higher if feasible. For this reason menu two (figure 7.3.2.1) asks for sill height and slope angle of the site. The following table is used in the assessment tool and aids in determining the effect of changing the sill level (assumed to be ground level if not stated otherwise).

Table 7.3.4.5 Reduction in the spacing between dwellings due to the sill height being raised from the ground level (Yannas, [1], 1994)

Sill height*	GL	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0
Reduction in spacing*	-	0.8	1.3	2.0	2.8	3.4	4.0	4.6	5.2	5.8	6.4
Sill height	1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.8	1.9	2.0	
Reduction in spacing (m	7.0	7.6	8.2	8.8	9.4	10.0	10.6	11.2	11.8	12.4	

** All in metres*

The assessment tool also considers a sloping site. This aspect can be dealt with more easily with software capable of determining three-dimensional information, but the assessment as it stands is limited to two dimensions. This limits the amount of information which may be utilised and the automation of the process. In this case, an average slope angle can be used to determine the effect of this feature on a development. The equation to encompass aspects of the determination of spacing can be expressed in the following equation (see chapter 5 for explanation of the abbreviations):

$$X = \left(\frac{H - s}{\tan \Theta} \right) - sh$$

s = Reduced height from sill level (m)
sh = reduced spacing due to angle of slope (m)

Fig 7.3.4.6 Equation to find actual spacing

As this research has already stated and as site investigations have established, a passive solar development has a lower dph when compared to standard housing layouts at high latitudes such as the North East of Scotland. Data, therefore, is required to determine the effect of some overshadowing for short parts of the year. The following table is used in the environmental site assessment to determine the increase in the space heating costs (SHC) of a home when overshadowing is unavoidable.

Table 7.3.4.7 Percentage increase in space heating energy requirements (Yannas, [1], 1994)

Obstruction Angle	2	4	6	8	10	12	14	16	18	20
Increase in SHC (%)	-	-	1.0	2.0	3.0	4.5	6.0	8.5	10.8	12.2
	22	24	26	28	30	32	34	36	38	40
	14.1	16.8	18.9	20.8	22.4	24.4	25.6	27.8	29.0	30.9

Both these tables are typical values for a home with around 60-70% of the glazing facing south.

Protection from Wind through Landscaping, Gardens and Open Spaces

Chapter four introduces this aspect of passive solar designs. The principle being the reduction in the exposure to cold winds during the winter months and opening the building to the cooling winds of the summer. As suggested, this may be achieved by a combination of the following aspects.

- The staggering of buildings or irregular patterns of groups of dwellings;
- Mixed-use development or ensuring taller dwellings on site are used as obstructions against the prevailing wind;
- Grouping of dwellings to mimic courtyards; and,
- The more traditionally use of embankments, bushes, shrubs and trees to create shelter belts.

The site assessment tool, however, does not incorporate these features due to the fact that they are site specific. For instance, the topography may ensure that wind direction in the summer and winter months may be different from one site to another. Further, in depth study, of various locations in the UK is needed to advance the current limitations of this form of environmental design. It should be noted, however, that this can be an important aspect of any design, and typical statistics suggest that adopting the above features in a development may ensure that a 10-15% saving may be achievable on sites that are otherwise exposed (Borer and Harris, 1997). The determination of the effect of wind direction may be included, in future, in menu one (figure 7.3.1.2).

7.3.5 MENU FIVE : PASSIVE SOLAR DATABASE SELECTION

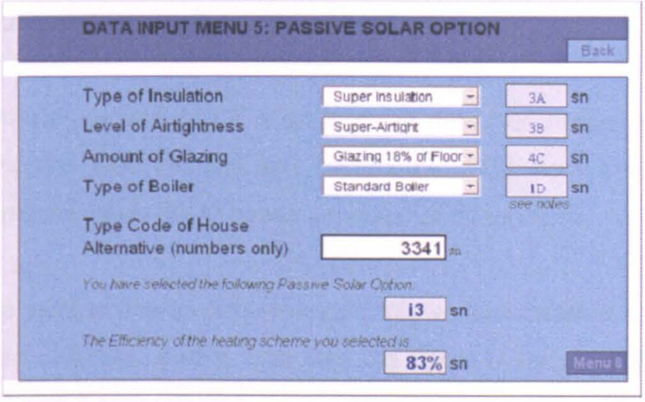


Fig 7.3.5.1 Data Input Menu 5 : Passive Solar Option

Menu five is the passive solar house type database (described in chapter six and statistics given in 6.7.5.6), which in future development may also include a variety of environmental elements to determine the trade-offs required to maximise density, if needed. This menu type has been chosen because it allows a certain degree of control of the specification of various aspects of passive solar. Though this method is limited by the incremental method chosen to create the database it can clearly be used to select various aspects of a passive solar design more easily than calculating the costs for each individual home. Alternatives to this method may include a single menu linked directly to the passive solar database where you could choose each option as packages, such as 'passive 1' or 'passive 2' and so on. This requires more expertise and knowledge of the differences in the database on the part of the user though it would make selection easier.

The exact house type is chosen by code, and to choose a final house type you type the first notation of each element, that is if the type of insulation is 'super-insulation', then the code is '3A' therefore the code of house alternative is '3'. This is repeated for each element of the passive solar database. Future development of this database will change this menu format by being more intuitive, but should only include more elements of environmental design. It should be noted again that this is an exemplar and though this selection process is manual to some extent, future development would see a more automated response to the selection of an environmental house type from the database. It should also be noted that from menu five onwards more technical expertise is required from the user; therefore there will need to be more guidelines after this stage.

The passive solar home database

The passive solar database is created using a home that is approximately 158.50m^2, based on the typical home sizes in Scotland. This house is in fact larger than the average house built in Scotland, but this house will be used for comparative purposes only and costs calculated from this 'base' home, as it is termed, will be reduced to a unit of floor area. The costs may then be compared for houses for varying floor sizes.

This floor size has been reached on the premise that it is an average detached home, with the typical reception rooms and modern type kitchen and bathrooms. The floor size is indicative of a ground floor area of approximately $80m^2$ based on external dimensions.

The following figure details the home used to change incrementally into various passive solar alternatives. In addition the standard u-values used to calculate the target U-values of 0.4, 0.3 and 0.2 are also detailed (alt 1, 2 and 3 respectively).

		Element	Alt 1	Alt 2	Alt 3
			U-Value (a)		
Detached House 158.50 m^2		**Pitched Roof**	0.20	0.15	0.10
		Flat Roof	0.25	0.19	0.13
		External Wall	0.30	0.23	0.11
		Ground Floor	0.25	0.19	0.13
		First Floor	-	-	-
Perimeter	37.00	**Windows, doors, rooflights (metal)**	2.20	1.50	1.10
Height (m)	2.40	**Windows, doors, rooflights (PVC/Wood)**	2.00	1.35	1.00
Living Area	19.81				

Table 7.3.5.2 Target U-values for each alternative of the base house

The passive solar database calculates data on each house alternative using BRE accredited software used to calculate the SAP rating. This software has a number of limitations but allows the collating of data on each house type simply. Some rules and assumptions were made to create this database (details of the database are in section 6.7.5).

- The only variables that change to create the passive solar database are the amount of glazing (primarily south-facing glazing), glazing type, thermal efficiency and air-tightness. The database converts this data into a unit rate so that it may be applicable to homes other than the size specified.

- The elements of the design which remained the same were the energy type (gas) and the boiler efficiency (an efficient and modern 83% for each alternative). All appliances and mechanical ventilation are identical.

- It was assumed that the heating system specified for each alternative did not deteriorate in efficiency over its life cycle and that the system used did not lose efficiency.

7.3.6 MENU SIX : WHOLE LIFE COST INFORMATION

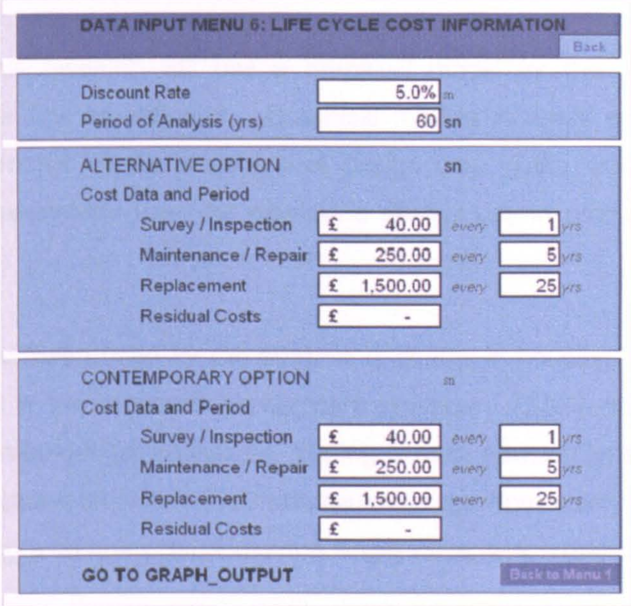


Fig 7.3.6.1 Data Input Menu 6 : Life Cycle Cost Information

The final menu lists the necessary life cycle information. Currently this menu is automated, and various aspects of it require active knowledge of the relevant information, for example replacement cost or repair costs are not items a planner of a development may have readily at hand. This menu is, however, an exemplar of the information required and in future developments may only require the selection of a period of analysis.

The most notable aspect of any assessment procedure that includes costs and products, which undergo constant evolution and change, is the updating of information. Information on costs of all types, be they energy or LC costs, in future developments of this assessment procedure, could be included in a centralised source that may update programmes via the web, post, etc. More commonly used methods of updating these types of information is the constant evolution of the assessment procedure itself with various versions, created annually or when significant changes to building regulations are made.

This section has made an effort to highlight the fact that this assessment procedure is an evolutionary framework for an environmental site assessment using incremental changes to a passive solar home. It is used to compare current methods of construction with optimised passive solar design, both of which have been discussed in the previous chapter. The following sections of this chapter go through the calculation aspects of the environmental site assessment in more detail.

7.4 FRAMEWORK TOOL FOR AN ENVIRONMENTAL SITE ASSESSMENT

The methodology identifies that this research will use a graphical model for the data representation of the environmental site assessment. Graphical models illustrate more clearly than any other method, complex issues of subjective design data (Tufte, 2001). Graphical models have not been extensively used for displaying energy use in housing, however.

More commonly, a rating system has been used for the analysis of energy in housing, the most notable and commonly used is the standard assessment procedure (SAP) rating scheme, and there are other rating methods for emissions. Rating of each housing type in this analysis is an option, but can cause tension. The main disadvantage from using the rating method is that it tends to group a complex issue into one single value, which does not show the full picture.

A graphical model of data representation is chosen for this analysis, as it is a comparison between three distinct parties. The first comparative alternative is the current method of construction, the second is the optimum method of construction and the third, fourth, fifth, and so on, comparative alternative is the environmental option with the trade-offs required to meet the density requirements of the building and planning developers. In addition, this assessment procedure needs to combine the life cycle costs aspects of the analysis and the non-monetary costs. The non-monetary costs in this case are the CO_2 life cycle emissions from the site, but may be any aspect of environmental rating or environmental indicator. A representation of this type of model is given in the following figure.

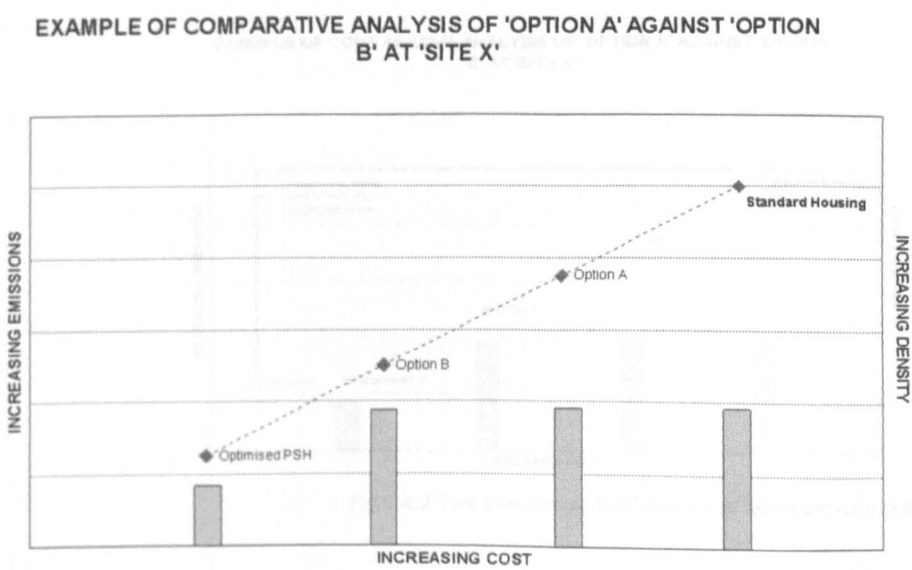
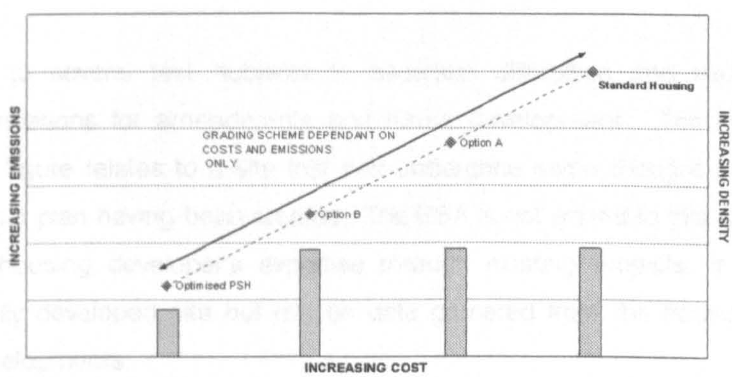


Fig 7.4.1 Data representation technique

The figure above is an example only, showing a comparison of the four alternatives using a standard heating system. The line connecting the standard housing and the optimised passive solar housing illustrates the use of the same heating system. That is to say, any home using the same heating system (with the same efficiency) will fall directly between these two comparative alternatives. From the figure, the two options may be analysed in detail, and gives detailed information to the planner of this development. Both options are between standard and optimised alternatives, so they are more environmentally friendly than current methods of construction but significant trade-offs are required to meet the density targets of the site.

Comparing option A with B, it could be noted that they are similar. The two options are significantly different, however, Option B being more expensive yet having fewer emissions, and Option A is less expensive with higher emissions. Though a level of technical knowledge is required a user can determine, which two criteria (life cycle cost or emissions) offer the better alternative. It should be added that the cost figure is based on life cycle costs rather than individual annual costs for a site.

EXAMPLE OF COMPARATIVE ANALYSIS OF 'OPTION A' AGAINST 'OPTION B' AT 'SITE X'



EXAMPLE OF COMPARATIVE ANALYSIS OF 'OPTION A' AGAINST 'OPTION B' AT 'SITE X'

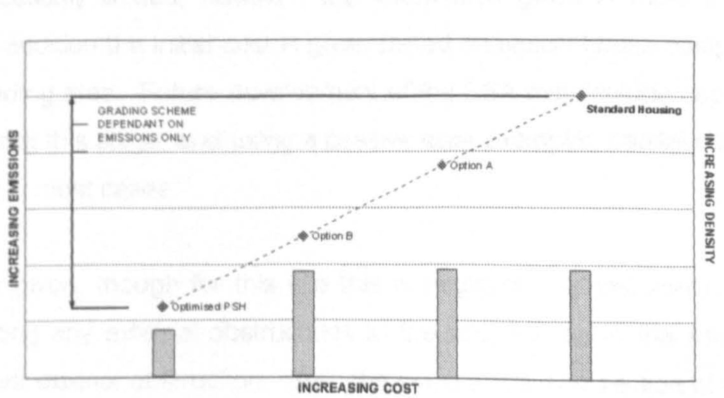


Fig 7.4.2 Two alternative interpretations of rating the data output

Various rating or grading schemes are possible based on the visual model represented and this should be further developed in future evolutions of this research. A rating system may be designed to favour on environmental aspect or a cost aspect, as represented in the above figures. The figure on the left clearly favours the option that is more environmentally friendly, if fewer CO_2 emissions are a sign of such. Whereas the figure on the left describes them as equal though this rating scheme is dependent on the efficiency of the heating system remaining the same for each option. A third option can be created where the most cost efficient system is chosen at the expense of a more environmentally friendly option. Care, therefore, is needed if rating systems are used in order to determine options in a comparative analysis, because it easy to misrepresent data using rated systems.

7.5 TESTING THE TOOL

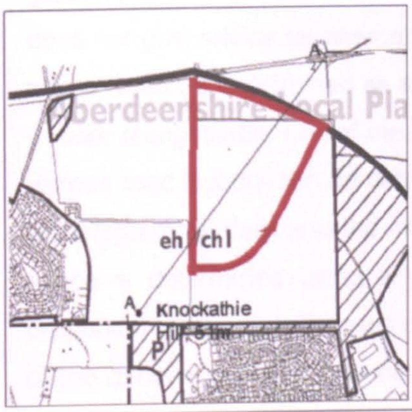
The environmental site assessment has undergone several tests and revisions until a working framework was created. The working programme was tested with a local site in Ellon, 7.5.1 which describes the site in full. There is limited data on the site and some assumptions are made but this is a typical example of the type of development prior to any significant construction.

The site data were given to several test subjects to ascertain difficulties and make observations and recommendations for amendments and future development. The site information on the following figure relates to a site that has undergone some thought and development, with a site layout plan having been created. The ESA is not limited to this site of development, and with housing developer's expertise through existing projects, it is possible not to require a fully developed site but rely on data garnered from the housing developers past housing developments.

The site information is necessarily limited, however, the information given is more than enough to fulfil the ESA. In addition the initial cost is given based on typical house costs of developments in the surrounding area. Future development of the ESA may include capital costs in their LCCA, however at this stage, and using a passive solar exemplar, capital costs are deemed to be equivalent in most cases.

In addition the site slope is given, though for this site this is negligible (almost zero). A section is also taken indicating any external obstructions to the site, but again the site is fortunate to have no significant exterior obstruction. Both the slope angle and section of the site to determine external obstructions does mean that a site investigation is necessary to complete the ESA, though some assumptions may be made if accurate maps are available.

OPTIMISING PASSIVE SOLAR DESIGN



SITE INFORMATION

Area of homes 100-135m^2 (take average to be around **115**m^2).

Typical cost of 3-5 bed houses is £85,000-£145,000.

Total number of homes planned for site is **139**, total area of site **60,000**m^2.

Green-space area of site approx **12%**, around boundary and some pathways.

Total length of roads is **605**m

Latitude of site is **57°24'**

Slope of Site (note that a negative value denotes a high to the south, and a positive a high to the north)

Steepest Gradient	**-2.602** degrees
Shallow Gradient	**1.909** degrees
Typical (average) Gradient	**-0.041** degrees

There are no permanent obstructions to the south of the boundary of the site for over 150m, where a built up area of Ellon starts, though the Aberdeenshire plan highlights this area for housing development in the future.

Site Location: ELLON, "Greenacres", Knockathie, AB41

Jonathan Scott, PhD

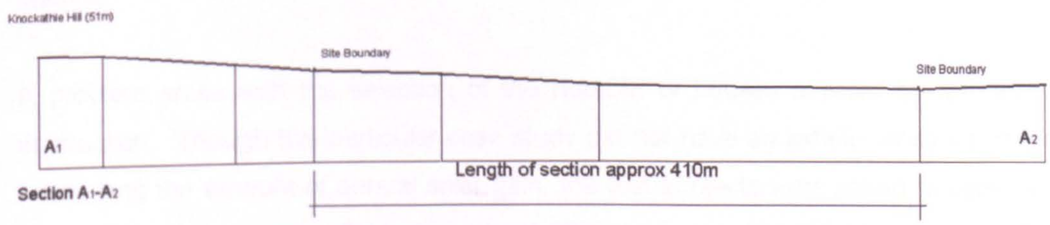


Fig 7.5.1 Test site in Ellon

The following points and observations were made after completion of the subject testing.

- Concern was raised as to the general aesthetic and clarity of the input menus, and it was suggested that pictorial methods of site selection would be more applicable.

- The exclusion of site area criteria raised some questions as to the road data and the green-space. In particular the road data currently is only included in unit area terms but does not give advice for alternative road layouts automatically. In regards to the green-space, which is determined as a percentage, advice was given to change this method to a more recognisable unit of measure (m^2). The road data is currently an exemplar, and various road layouts can be determined in future developments by allowing a layering of the programme data and the creation of various road types in a database. The green-space is determined using a percentage method in order quickly to determine the proportion of site given to uses other than housing. The percentage method is reflective of the general nature of the information at this stage since accurate information at this stage in a design is unlikely. A planner would be more likely to be aware of the proportion of the site needed for green-space rather than the accurate unit of measure amount.

- Concern was expressed about aspects of menu two. In particular, for example, the option of one or two storey was believed to be too simplistic and selection of a slope angle could be misconstrued. The main recommendation from this observation is further pictorial reference (as sections of simple building forms) certainly in the selection process of storey height, sill height and slope angle.

- Concern over the method of selecting the orientation was expressed about menu three, and this has been rectified to include this recommendations.

- Questions were raised as to the problem of multiple obstructions to the exterior of site, either topographical or man-made. Further developments may have to incorporate this feature.

- A problem arose with the selection of the number of houses affected by an exterior obstruction. Though this particular case study did not have an exterior obstruction that would limit the amount of annual solar gain, the test subjects were asked to determine the number of homes affected if Knockathie Hill was significantly higher. The observation from this assessment detailed that the test subjects were unable to determine accurately the number of homes affected, therefore an alternative method of selection may be needed. Using GIS could overcome this problem without the need for manual data input.

- A problem with the data input in menu five arose, where the type of passive solar option is chosen from the database created. It was observed that the test subjects required more guidance when selecting the specific elements of a passive solar home and therefore a simplified version might be required. It should be recognised that future developments would have the selection of the passive solar alternative from a database more automated than it currently is.

- The same is true for data input menu six in regards to the life cycle cost information and a more automated selection process of the life cycle costs should be developed.

- Some minor mathematical and tabular problems were also identified with the testing and as far as possible these have been corrected.

Figure 7.5.2 on the following page detail the data output from the testing of the Greenacre site at Ellon. Observation of this chart allows further problems associated with the environmental site assessment, and these include:

- Small variations in the data input of the first three menus may result in significant cost changes to the 'standard housing'. This is not an error of the assessment procedure, but with how the data in figure 7.5.1 is interpreted by the user. For example, determining how many homes were on the southern boundary and therefore were unobstructed could alter the cost and emissions for standard housing. This may be overcome with more familiarisation with the system but is more probably due to the need for more guidelines to use the framework tool.

- The method of choosing the passive solar option is limited and needs further development to avoid errors with future research.

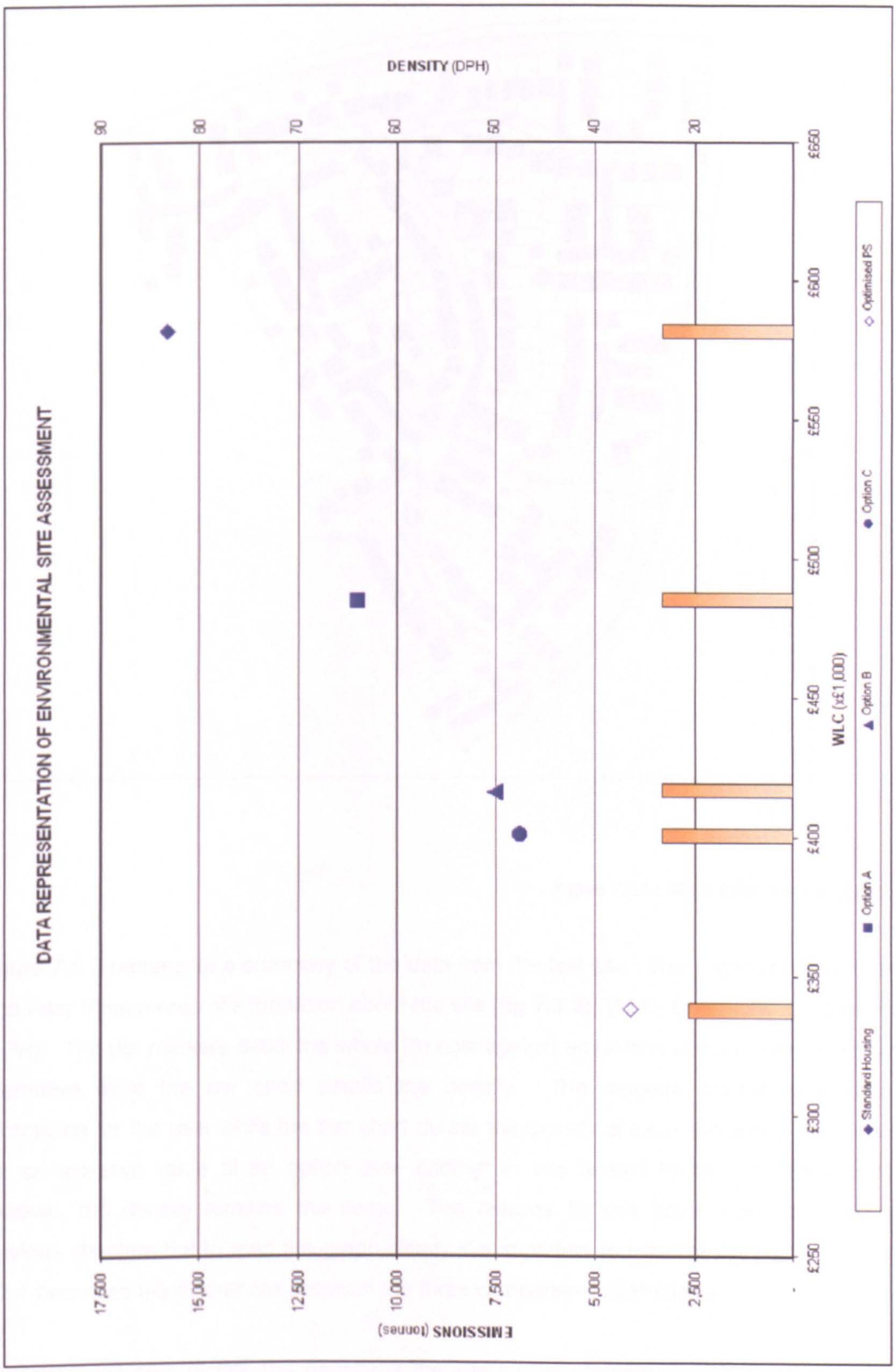


Fig 7.5.2 Data representation from test site

Data Presentation of the Output

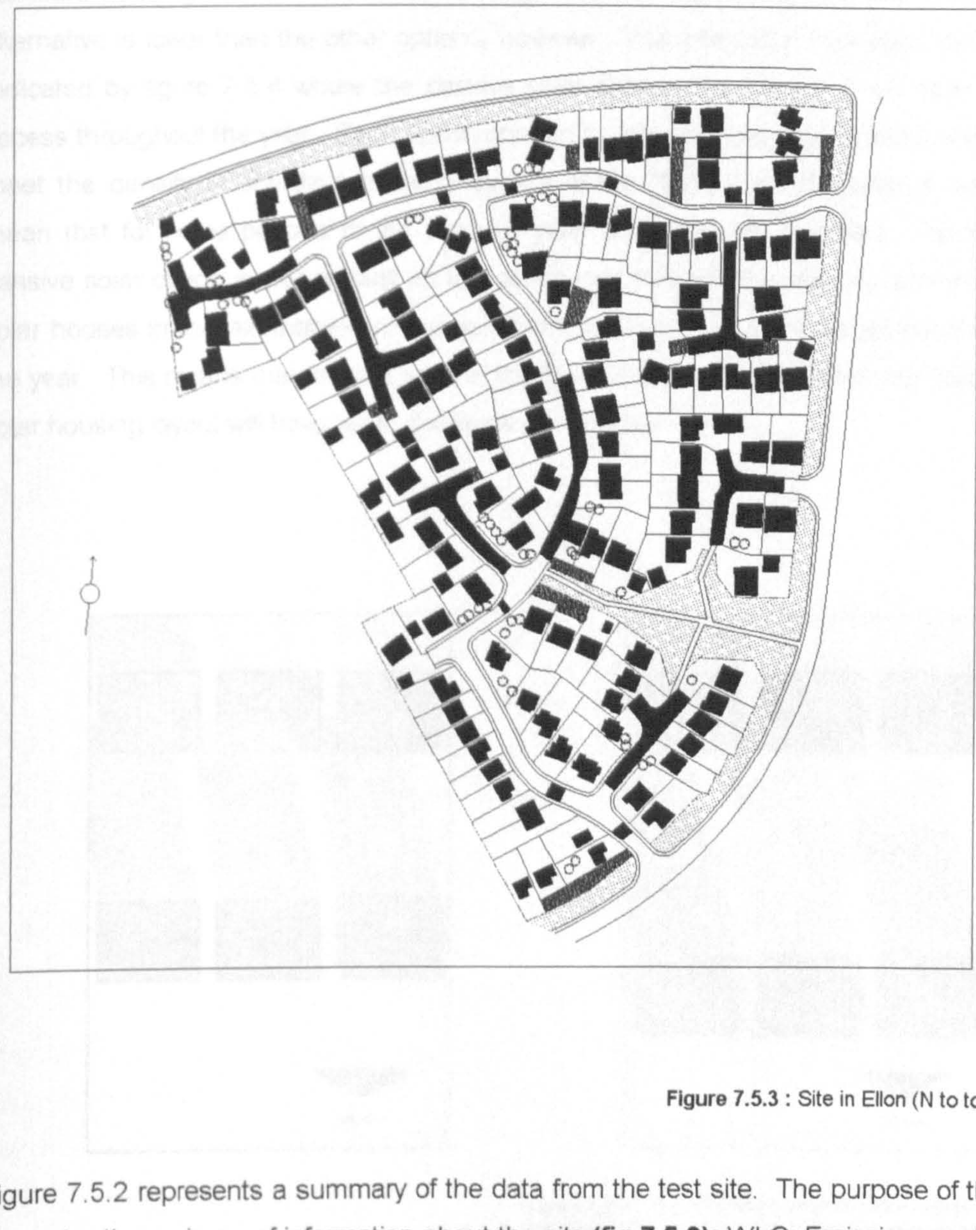


Figure 7.5.3 : Site in Ellon (N to top of page)

Figure 7.5.2 represents a summary of the data from the test site. The purpose of this chart is to relay three pieces of information about the site **(fig 7.5.3);** WLC; Emissions and Density (DPH). The dot markers detail the whole life cost against emissions of each housing layout alternative while the bar chart details the density. The markers provide quantitative information for the user while the bar chart details the density of each site option to indicate the comparative value of an option over another in site related terms. In this project, however, the density remains the same. The reasons for this have been described in previous chapters but to read the graph clearly it is important to reiterate the point. Section 7.2.1 describes the differences between the three comparative alternatives.

Housing developers dictate the density of the site for the standard housing option. Each option in figure 7.5.2 has an identical number of houses on the site as for the standard housing layout as it is an aspect of this project for the density to remain the same for each option. Future development of the tool may change this so that the density will vary between standard housing and environmental housing. The density for the optimised passive solar alternative is lower than the other options, however. This alternative has been optimised as indicated by figure 7.5.4 where the passive solar options (on the right) will have full solar access throughout the year. Each option chosen by the user may require some trade-offs to meet the density of standard housing layouts in the North East of Scotland, which may mean that for some periods of the year full solar access is not provided. The optimised passive solar option is **not reliant** on the density set by standard housing and the passive solar houses in this alternative are spaced ('optimised') to gain full solar access throughout the year. This means that in most sites in the North East of Scotland the optimised passive solar housing layout will have fewer dwellings per hectare.

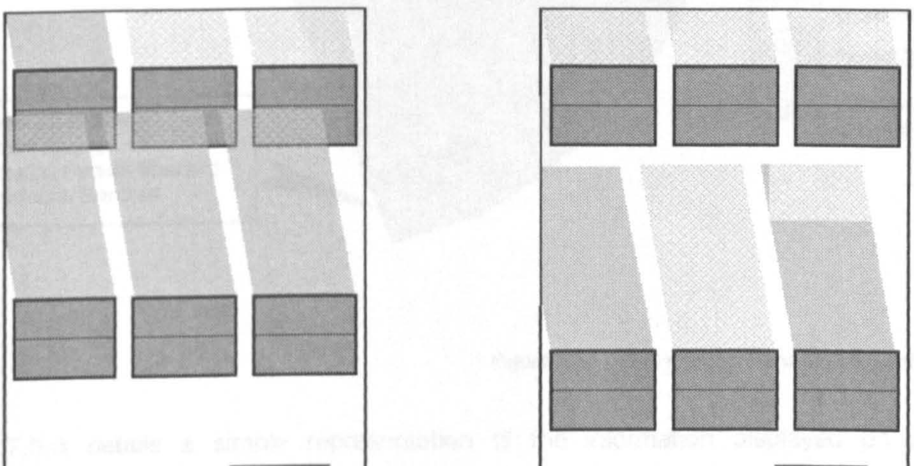


Figure 7.5.4: The difference between alternatives committed to meeting density targets (left) and optimised passive solar layouts

The density aspect has been included in the data representation (figure 7.5.2) of the framework tool for an environmental site assessment to add value assessment for the user. In future other value aspects could be added for example the increase in initial expenditure is a possibility. The use of software such as CAD and GIS could expand the amount of information represented by a tool, however, by displaying the information on two-dimensional or three dimensional maps or plans.

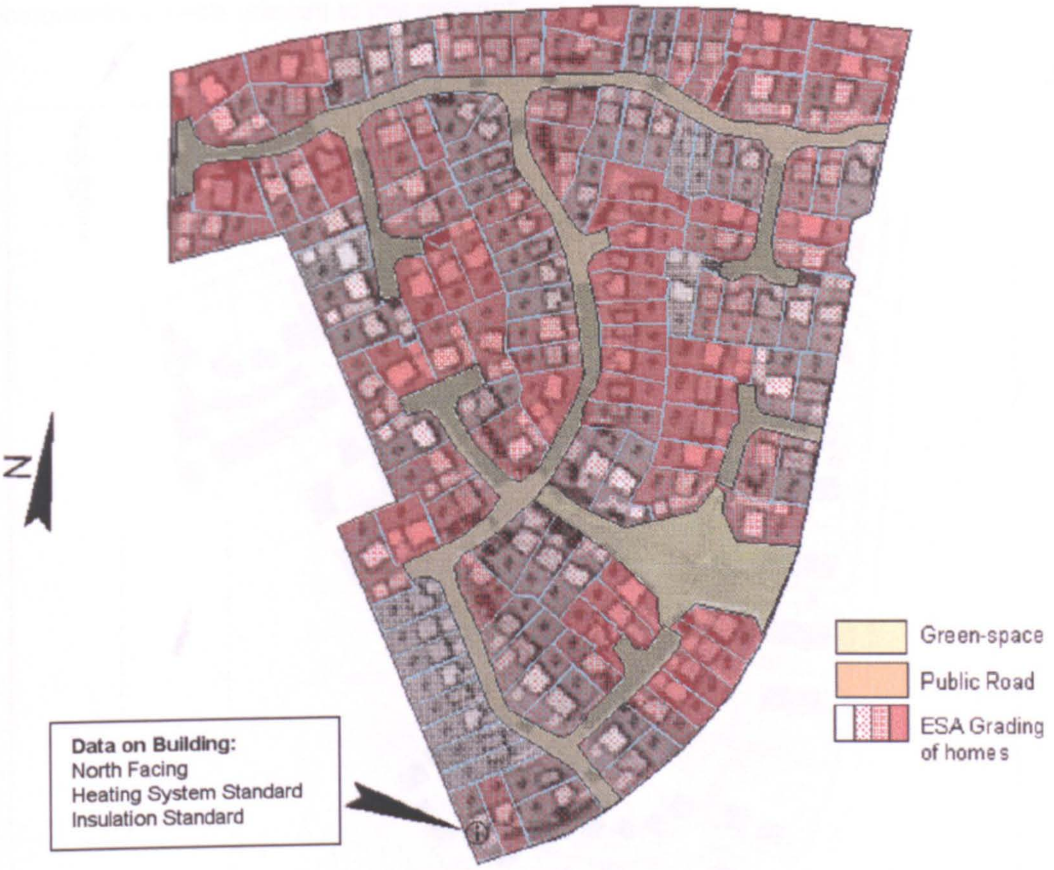


Figure 7.5.5 : Data representation on a Map of the Site

Figure 7.5.5 details a simple representation of the information displayed on a two-dimensional plan. Clearly defined are the important aspects of modern housing developments such as the road layout and green-space while the housing plots are individually graded. Grading has limitations in this format, that is it cannot display various complex issues, therefore from this general overview more detailed information could then be provided on an individual plot / home to provide the user with information (or a reason) as to why this home may perform less well than neighbouring plots / homes. A strategy for improvement may then be devised.

From this information, and with a detailed analysis of the layout of the housing development, recommendations for the arrangement of housing and specification of housing may then be made in future developments of this tool. Figure 7.5.6 is an illustration of one such recommendation where the housing has been re-arranged to incorporate aspects of passive solar heating. The density of the site, however, is identical to that specified in figure 7.5.1. To arrange the housing to approximately face South, the road layout has been changed although the total length of roads is approximately similar. The same house types have been used where applicable. Please note that this is only an example of one option and only incorporates aspects relevant to this research.

Figure 7.5.6 : Example of a Proposed Site

More information on the future development of the tool is given with the recommendations.

7.6 SUMMARY

The aim of this chapter was to develop the framework tool for an environmental site assessment which uses passive solar homes as an exemplar of a more sustainable development. The chapter has detailed the following;

- The data input menus were introduced and their main functions described. The future development of the data input menus was also detailed in regards to their application to GIS or a similar mapping programme.

- The development of the tables and databases relevant to the calculation of the ESA were described and introduced into the framework tool. The calculation process, in particular, of the overshadowing, is described as well as the relevant trade-offs required to meet the density targets stipulated in the North East of Scotland.

- The data representation is described with the method of data output being a visual model. The data output uses comparative alternatives to compare options chosen from the passive solar database.

- A test site is used on test subjects so that errors and observation can be made on the usability and performance of the environmental site assessment. Minor changes will be made to the ESA but major critical problems will form the basis for the recommendations of research.

8 Conclusions and Recommendations for Future Research

8.1 MAJOR CONCLUSIONS

A formal approach to housing development is provided in this research, which in this case uses **passive solar design as an exemplar of a more sustainable approach to housing developments**. The major result of this work was that a strategy for a framework tool, which uses a comparative analysis of different site housing options, was developed. Used at the planning stage of a housing development, it may predict the potential benefits of different alternatives from simple geometric data arranged in a series of databases.

The following six conclusions relate to the six objectives set out in Chapter One.

1. This research defines passive solar design thus, "Passive solar **heating** is a holistic approach to building design, reducing the dependence on non-renewable methods of heating during winter without overheating during summer, optimising strategies of passive solar design to create more sustainable housing developments giving environmental, economic and comfort benefits over conventional methods of construction".

   An appropriately designed PSD can displace the majority of the fuel that would be used in a conventionally designed speculatively built home in the NE of Scotland, reducing dependence on fossil fuel resources. A PSD can reduce heating cost and achieve emission reduction of up to 80% (Deveci, et al, 2001) over current conventional methods of construction, though typically heating cost and emission reductions of around 50% are achieved affordably by ensuring there is a well insulated building envelope, the required orientation is correct and overshadowing is minimised.

2. There are two cost significant features in a basic PSD, glazing and increased thermal efficiency. This research highlights the fact that savings in heating demand are achievable in a PSD without significant additional glazing over a standard house. The additional cost of providing a thermal efficient building envelope is, as a result of increasing thermal standards, not expensive. Successful passive solar houses have been built in the UK that do not have any significant additional cost and require no fossil fuelled heating system (Deveci, et al, 2000) and research on one house is included in Appendix B.

3. There are a number of difficulties with Passive Solar heating when applying the principle to housing developments:

1) Orientation can limit site layout with all the buildings required to face south – this is a problem in high northern latitudes such as the North East of Scotland. The necessary spacing between houses in northerly cities (at higher latitudes than Edinburgh) increases more rapidly for small changes to latitude.

2) There is reluctance to change in the construction industry. In addition, changes that housing developers perceive as increasing the cost of build and potentially threatening a return on investment are perhaps understandably given a cautious response.

3) Land value in most places is so high that it forces a housing developer to maximise profits through increasing density.

4) UK Government housing targets are continually increasing, making it difficult in northern climates for passive solar design to be adopted in large, mass housing developments.

4. The optimum density in northern climates for passive solar designs is limited by overshadowing of obstructions within the site. A site investigation of this problem was undertaken in the North East of Scotland, with 43 sites with detached housing layouts which are either under construction or to be constructed on. Investigation of sites in the North East of Scotland highlighted that the maximum density achievable using common passive solar practice is 19 dwellings per hectare (varies depending on latitude). Investigation of densities on the same sites using current methods of housing development indicates that densities are slightly higher the average being approximately 23 dwellings per hectare. This is an average across the NE of Scotland, the figure did not vary depending on latitude.

Table 8.1.1 Average dph for sites in the NE of Scotland	**Sites Investigated**	**Total no. of homes calculated for each development**	**Average DPH**
Conventional Construction	43	5,534	23
Passive Solar Design		4,468	19*

** Calculated at various latitudes in the North East of Scotland*

The main conclusion from this is that overshadowing in northern climates is such that it limits the number of houses on each site and this research investigates how this problem may be overcome.

5. Various housing types were investigated for inclusion in a number of databases. 'Standard housing' was defined and investigated so that simple geometrical housing data could form a database. In addition a passive solar database of various options was also created. The data is arranged in tabular and database format for simplified and automated extraction of data but also with a view to the future development of the tool. The databases allow selection of alternatives automatically given some basic, general specification. Appendix A provides an example of how the tables were used in the framework tool.

The passive solar database was created by incrementally changing orientation, glazing, thermal efficiency and air-tightness. Running costs on basic PSD changes show that a typical saving on heating of up to 50% is possible using this technique. The following table notes the savings possible from the various design alternatives created from the Primary (base) option. An analysis of these results show that the passive alternatives exhibit a remarkable consistency and upon further analysis it shows that an optimised PSD needs only a 17-18% glazing to floor area ratio to achieve maximum benefits, ratios greater than this have similar savings in costs and emissions. Of this 17% glazing to floor area, anywhere around 60-80% is orientated to the south. 17% glazing to floor area is quite common with most standard housing of this type having an average 15% glazing to floor area ratio. This indicates that PSD does not need significant amounts of additional glazing, but rather needs that glazing to be re-orientated south.

Table 8.1.2 Passive solar database summary	Estimated Cost Saving			Estimated Emission Saving		
House Variation	Alt1	Alt2	Alt3	Alt1	Alt2	Alt3
Primary	-	18.9%	**40.7%**	-	13.7%	**29.6%**
Base 1	0.0%	26.0%	**52.6%**	0.0%	18.9%	**38.2%**
Base 2	3.3%	22.0%	**39.5%**	2.6%	16.1%	**28.7%**
Passive 1	4.0%	23.6%	**45.5%**	3.1%	17.3%	**33.2%**
Passive 2	4.0%	24.0%	**46.1%**	3.1%	17.5%	**33.6%**
Passive 3	3.8%	23.7%	**45.7%**	3.0%	17.4%	**33.3%**
Passive 4	3.5%	24.5%	**47.4%**	2.7%	17.9%	**34.5%**
Passive 5	3.5%	22.5%	**44.3%**	2.8%	16.5%	**32.3%**
Passive 6	3.5%	28.9%	**55.6%**	2.8%	21.1%	**40.4%**
Passive 7	**41.4%**	**63.9%**	**46.0%**	**63.2%**	**46.7%**	**88.3%**
Passive 8	**59.1%**	**73.9%**	**62.3%**	**64.6%**	**54.0%**	**89.6%**

The ESA strategy incorporates the capacity to establish life cycle effects of heating costs and emissions, future developments of LCC could also incorporate more cost aspects than this exemplar study provides.

6. The environmental site assessment is a planning decision making tool which assesses various environmental criteria against current methods of construction and advises as to the potential of environmental alternatives given the site density required by the developer. The input data is basic, resulting in simple geometric housing shapes being used to represent a typical home. These are derived from analysis of standard housing types in Scotland. The databases are an important part of the tool using information on housing, such as costs and sizes that can be displayed simply and automated.

The strategy for an environmental site assessment was tested by the research. The pilot testing in this research (Chapter Seven) was only used to provide recommendations for changes in the current programming and not to ascertain if it was useful (to the intended user) or to provide a prediction. These recommendations are detailed in 7.5. Pilot testing is a critical method of ensuring that a software based tool does not have any errors and is essential in finding the benefit of such a tool for end users. As such Pilot testing would be recommended throughout each stage of the development of this tool.

In summary, a framework tool for the comparison of environmental sites, using passive solar design as an exemplar, has been developed. The tool uses current methods of development for comparison against passive solar layouts and establishes the need for trade-offs to meet the objectives of housing developers (to encourage use of environmental designs). It has the potential to make housing developments more sustainable and, hopefully, improve housing quality. In this, the tool developed works and is user friendly.

8.2 RECOMMENDATIONS FOR FUTURE RESEARCH

Passive solar heating in this research is used as an exemplar of a more sustainable housing future. It was not the intention of this research to ignore other methods of providing the same results, alternatives which are equally applicable and capable of providing for a more sustainable housing future, such as community heating schemes, wind power, water conservation, etc. Future research into strategies for an environmental site assessment will incorporate these alternative sustainable options and investigate the effect housing density places upon them.

The strategy developed, therefore, is only the foundation for future research. The research specifically chose passive solar heating for it's ability to be quantified, but other more qualitative alternatives will need to be incorporated. The next seven recommendations highlight the key areas where the strategy developed could be further explored in future research.

8.2.1 GEOGRAPHICAL INFORMATION SYSTEMS (GIS)

This research recognises the fact that there are many facets to environmental design and sustainable housing which cannot be fully developed in a single piece of research. Such research requires a multi-disciplinary approach. This project has, however, recognised that future development of this tool would take the form of a mapping, prediction tool of some description.

Geographical Information Systems (GIS) is a generic type of system that could be used for modelling of this nature and is particularly adept at producing visual models. GIS is currently being used to some extent by planning departments already, making adaptation of a GIS model straightforward. The key to the model is not to make it additional work, but complement the existing structure for planning housing layouts, to broaden the existing framework.

GIS technology is used for development planning (exhibited by the Aberdeenshire local plan), as well as scientific investigations and resource management. In the strictest sense, GIS is a computer system capable of assembling, storing, manipulating and displaying geographically referenced information, such as site boundaries, roads and footprints of homes, in a three dimensional perspective if necessary (Longley, *et al*, 2001).

The use of simple geometrical shapes, localised knowledge and basic values of cost and emissions in the environmental site assessment has been a direct result of the intention to adopt Geographical Information Systems (GIS) in future as the main method of representing the data. Although this research has not used GIS, it is a mapping tool that is set to become progressively more used as a planning decision making tool in the next decade as it can add value to data (Heywood, et al, 1998). With the increased growth for value assessment of products and data in all sectors of industry GIS is set for an integral role in decision making (Heywood, et al, 1998). The current research uses Microsoft Excel for its noted usability and easy computation functions, but future adaptability of the software needs to be explored fully. GIS (Geographical Information Systems) can be used as a planning tool, which in the future is likely to replace the conventional methods for the development of local areas.

The advantages of a visual (3D) model for assessing a environmental development are better for explaining the potential to non-experts if the data is complex (Tufte, 2001), and will likely benefit the designer and housing developer earlier in the design stage (which is the intention) in order to progress through a fast track planning application. Morris and Therivel (2001) state the main advantages as long-term costs saving and the overall strategic planning of organisations.

Morris and Therivel (2001) describe the basis of a GIS system as a number of, "databases where the information is spatially referenced." In the strictest sense, GIS is capable of assembling, storing, manipulating and displaying geographically referenced information, such as site boundaries, roads and footprints of homes, in a three dimensional perspective if necessary. If a system such as this could recognise the outline of a simple building, and designate it according to a database of environmental design options, it could offer a quick method of analysing small, medium and large developments for non-experts.

GIS can use information from different sources, in most forms. The primary requirement for the source data is that the locations for the variables are known. Locations are annotated by x, y and z co-ordinates of longitude, latitude and elevation, or by such systems as postcodes, roads and grid reference markers. Any variable that can be located spatially, such as the over-shading of a house, can be fed into a GIS system. Mathematical, or tabular information, can also be added to give a map-like form. With the information that the GIS system can provide easily at hand, it may be foreseen that it could be used to provide an environmentally friendly housing map of Scotland.

The possible approaches for using GIS from an environmental aspect are more fully described in Morris and Therivel (2001) and a general introduction to GIS is provided by Heywood, *et al*, (1998).

8.2.2 EXTENSION OF DATABASES AND DATA COLLECTION

The databases in this research are limited. Future development of this tool will ensure that the systems used to predict various changes to housing developments need to incorporate more than the single housing type used in this research. The project will grow to incorporate not only detached housing, but also various other housing forms. The databases could also be incorporated more into the selection process of the site. In particular the database of standard housing types could be more fully incorporated, in future, into the menus.

The databases and the cost prediction model will require more accurate data on existing housing (these values change yearly). The housing developer needs to play a more integral role in the creation of these databases, where significant design changes to their housing portfolios need to be submitted to planning departments and included in their site proposals. The lack of performance data on the existing housing stock is a problem. This has always been a problem with the housing industry, in that even though they are capable and have access to important information in regards to demographics, heating type, housing type, and more, housing developers do not record the performance of their buildings accurately. A framework for the collection of data on housing is needed in order to establish realistic trends on housing use and performance.

8.2.3 LIFE CYCLE COSTING

Life cycle costs are used to some extent in this analysis, though these are limited by the nature of the user (the process needs to be simple). A simplified method of life cycle costing is needed where the data is achieved without significant knowledge on the part of the decision maker. Combination with the prediction model can overcome this problem, similar in nature to an internet based correction feed.

Life cycle costing is also limited in this research because PSD, chosen as an exemplar, has costs similar to that of a standard home. PSD is an environmental concept which can be affordable (Deveci, et al, 2001). In this research the heating systems were identical as this research was comparing changes to orientation, glazing, insulation and air-tightness and not the heating systems. There was no real change to the specification or building materials of the homes and as such there were no real differences in maintenance or residual costs. Therefore only the WLC of the running costs were compared. Alternative environmental concepts (such as biodiversity) will have significantly different LCC costs and this makes the need for a more simplified LCC model imperative and incorporated into the site assessment in future.

8.2.4 AESTHETIC DIFFERENCES BETWEEN ALTERNATIVES

A major problem with any environmental design is the concept of uniqueness. Commonly, it is thought that the aesthetics of environmental designs vary dramatically from those of current methods of construction, and this is seen as a negative aspect in regards to the value of the home (by some). This does not need to be the case. Data in this research, for example, shows that glazing area in a PSD is similar to that of current methods of construction. In this case the glazing is concentrated on one façade facing south raising questions of privacy and security. This aspect in comparison to current methods of construction needs further analysis. In particular, the preferred housing type for the mass housing market needs to be established as this will ensure the sustainability of much of the housing currently being built.

8.2.5 COST DIFFERENCES BETWEEN CAPITAL AND OPERATIONAL COSTS

The non-monetary benefits (such as the 'healthy home' principle) of a home needs to be investigated. One such concept to investigate would be to determine whether spending more initially means that the home will become healthier. Although the two are not intrinsically linked, the housing industry needs to establish the additional amount a homebuyer is willing to pay for environmental home. In addition, the benefits of spending more initially to save in long term emissions needs to be established. In particular, when is the payback and how do you establish the payback of non-monetary issues of design, for example emissions, bio-diversity or resource efficiency? In general, there is little physical information on benefits of various environmental concepts. There needs to be a more structured and formal approach to the adoption or subsidising of environmental concepts and in general greater effort is needed to ensure that costs of mechanical environmental systems are reduced to improve payback and encourage adoption. For example photovoltaic panels require initial cost reduction of at least 80-90% before acceptable paybacks are realised for the average homebuyer. Currently only a 50% possible grant is currently available.

8.2.6 DETAILING ITEMS OF COST SIGNIFICANCE

A problem with cost prediction is that it tends to be grouped into a lump sum (that is total energy costs will include water heating, space heating, ventilation and standing charges). Although this is ideal in providing an overview of costs, especially for the layperson, itemised costs can aid in finding individual problem areas more readily. It may be the case, however, that for more complex scenarios energy costs are high but emissions are low (as for electricity from a sustainable source), and in this case a more detailed cost breakdown may be required in order to make a more informed decision. This may be the case when a site utilises more than one environmental principle for the whole or part of a site. It may also be the case that there is such a large site that different environmental issues need to be addressed at different locations on the site. In these cases, a framework for focusing the site assessment or making a more detailed projection is required.

Accuracy of costs was based on software prediction tools. These tools give a basic value for the operational costs in a home but actual costs in real homes may differ due to location, errors in design or construction, heating system or type, and demographic. Future developments of this tool should use existing housing for more accurate data though new developments in heating will require an element of prediction. This tool, however, is used as a comparative analysis and therefore actual costs are not used in analysis but the comparative cost between alternatives is important. All savings quoted, therefore, are potential costs rather than actual costs.

8.2.7 PLANNING

The framework tool for an environmental site assessment which has been produced in this research requires investigation with planning departments. Certain objectives are clear if the tool is to be used by planners in that it should not add to the current workload, it should reduce delays for planning acceptance in some cases and should also interact easily with existing procedures and systems in the planning process. Further investigation as to the role and need of a tool such as created in this research needs to be investigated.

This research has noted the difficulty for environmental professionals to determine between an environmental design and one that claims to be environmentally friendly. In effect, partly due to the complex nature of environmental design and sustainability, there are many areas in housing of this type where it is difficult to claim that it is environmentally friendly or it is not. An environmental site assessment would, to some extent, be able to analyse each site to determine the potential of environmental designs and in this overcomes this problem to a vast extent. However, there needs to be further education in the issues of environmental design for the planners (and other key decision makers) in housing development once the current level of knowledge in planning departments is established.

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APPENDIX A
ENVIRONMENTAL SITE ASSESSMENT

Environmental Site Assessment Worksheet (Version 1.12)

Menu 1 : Site Information

Area of Site (m^2) (1)

Latitude of Site (degrees and seconds) Degrees (2a) Seconds (2b)

Latitude =**(2a)**+**(2b)**/60 (2c)

Date Day 22 (3) Month 12 (4)

Day number =DATE(2,**(4)**,**(3)**)-DATE(1,12,31) (5)

Local civil time (24hr clock) Hours 12 (6a) Mins 00 (6b)

LCT =**(6a)**+**(6b)**/60 (6c)

Day angle =360/365.25*__(5)__ (7)

Solar declination =180/PI()*ASIN(0.3978*SIN(PI()/180*(**(7)**-80.2+1.92*SIN(PI()/180*(**(7)** -2.8))))) (8)

Eqn of time =-0.128*SIN(PI()/180*(**(7)**-2.8)) - 0.165*SIN(PI()/180*(2*__(7)__+19.7)) (9)

Solar time =**(6c)**+**(9)** (10)

(Please note that longitude of site is assumed to be unknown)

Solar hour angle =15*(**(10)**-12) (11)

Solar altitude =180/PI()*ASIN(SIN(PI()/180*__(2c)__)*SIN(PI()/180*__(8)__)+COS(PI()/180*__(2c)__)*COS(PI()/180*__(8)__)*COS(PI()/180*__(11)__)) (12)

Number of plots / houses (total) (13)

Road data

Two way (length in m) (14a)

One way (length in m) (14b)

Public parking (excluding private driveways) (m^2) (14c)

Green-space (estimated %) (15a)

Green-space (m) =**(15a)***__(1)__ (15b)

DPH of site =**(13)**/(((**(1)**-**(15b)**))/10000) (16)

Area of site (for housing only) =**(1)**-((**(14a)***4.5+**(14b)***2.6+**(14c)**)-**(15b)** (17)

Menu 2 : Plot and House Information

Average area of plot (m^2) (18a)

Note that default value national average 360m^2

If unknown,

Av area of plot =**(17)**/**(13)** (18b)

Av area of plot =IF(**(18a)**="",**(18b)**,**(18a)**) (18c)

Average area of houses (m^2) (19a)

Note that default value national average 135m^2

If unknown,

Av area of house =**(18c)**/(360/135) (19b)

Av area of house =IF(**(19a)**="",**(19b)**,**(19a)**) (19c)

TABLE 1 **(tb1)** : SIMPLE GEOMETRIC FOOTPRINTS							
Total Floor Area (m^2)	90	100	110	120	130	140	150
Ground Floor Area	45	50	55	60	65	70	75
Typical Footprint	6 x 7.5	6 x 8	7 x 8	7 x 8.5	7 x 9	8 x 9	8 x 9.5
Depth of house	6	6	7	7	7	8	8

Nearest floor area =CEILING(**(19c)**,10) (20)

Typical Depth of house =HLOOKUP(**(20)**,**(tb1)**,4) (21)

Note table area shaded

TABLE 2 **(tb2)** : PLOT DEPTHS							
TFA (m^2)	90	100	110	120	130	140	150
Width of house	7.5 (a)	8 (b)	8 (c)	8.5 (d)	9 (e)	9 (f)	9.5 (g)
Approx W of plot	=(a)+1.5 (a1)	=(b)+1.5 (b1)	=(c)+1.5 (c1)	=(d)+1.5 (d1)	=(e)+1.5 (e1)	=(f)+1.5 (f1)	=(g)+1.5 (g1)
Av plot area	**=(18c)**	**=(18c)**	**=(18c)**	**=(18c)**	**=(18c)**	**=(18c)**	**=(18c)**
Depth of house	**=(18c)**/ (a1)	**=(18c)**/ (b1)	**=(18c)**/ (c1)	**=(18c)**/ (d1)	**=(18c)**/ (e1)	**=(18c)**/ (f1)	**=(18c)**/ (g1)

Typical depth of plot =HLOOKUP(**(20)**,**(tb2)**,5) (22)

Note table area shaded

Estimated spacing =**(22)**-(**(21)**/2) (23)

TABLE 3 **(tb3)** : SIMPLE HEIGHTS							
Height to ceiling	2.4	(h1)					
Floor depth	0.3	(fd1)					
Depth of house **(tb1)**	6 (d1)	6 (d2)	7 (d3)	7 (d4)	7 (d5)	8 (d6)	8 (d7)
Roof height (35 deg)	=TAN(PI()/180*35)*((d1)/2)						(rh1)
Roof height (35 deg)	=TAN(PI()/180*35)*((d2)/2)						(rh2)
Roof height (35 deg)	=TAN(PI()/180*35)*((d3)/2)						(rh3)
Roof height (35 deg)	=TAN(PI()/180*35)*((d4)/2)						(rh4)

Roof height (35 deg)	=TAN(PI()/180*35)*((d5)/2)						(rh5)
Roof height (35 deg)	=TAN(PI()/180*35)*((d6)/2)						(rh6)
Roof height (35 deg)	=TAN(PI()/180*35)*((d7)/2)						(rh7)
Roof height (20deg)	=TAN(PI()/180*20)*(d1/2)						(rh8)
Roof height (20deg)	=TAN(PI()/180*20)*(d2/2)						(rh9)
Roof height (20deg)	=TAN(PI()/180*20)*(d3/2)						(rh10)
Roof height (20deg)	=TAN(PI()/180*20)*(d4/2)						(rh11)
Roof height (20deg)	=TAN(PI()/180*20)*(d5/2)						(rh12)
Roof height (20deg)	=TAN(PI()/180*20)*(d6/2)						(rh13)
Roof height (20deg)	=TAN(PI()/180*20)*(d7/2)						(rh14)
TFA (m^2)	90	100	110	120	130	140	150
One storey	=(h1)+ (rh1)	=(h1)+ (rh2)	=(h1)+ (rh3)	=(h1)+ (rh4)	=(h1)+ (rh5)	=(h1)+ (rh6)	=(h1)+ (rh7)
Two Storey	=(h1)+ (fd1)+ (rh8)	=(h1)+ (fd1)+ (rh9)	=(h1)+ (fd1)+ (rh10)	=(h1)+ (fd1)+ (rh11)	=(h1)+ (fd1)+ (rh12)	=(h1)+ (fd1)+ (rh13)	=(h1)+ (fd1)+ (rh14)

Height of one storey =HLOOKUP(**(20)**,**(tb3)**,2) (24a)

Note table area shaded

Height of two storey =HLOOKUP(**(20)**,**(tb3)**,3) (24b)

Storey Height (answer **1** or **2** storey) (25a)

Storey height =IF(**(25a)**=1,**(24a)**,**(24b)**) (25b)

Sill height (m) (26)

Note that default value is 0m

TABLE 4 **(tb4)** : REDUCTION IN SPACING DUE TO SILL HEIGHT

Sill height	0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0	1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.8	1.9	2.0
Reduction in spacing	0	0.8	1.3	2.0	2.8	3.4	4.0	4.6	5.2	5.8	6.4	7.0	7.6	8.2	8.8	9.4	10.0	10.6	11.2	11.8	12.4

Reduction in spacing =HLOOKUP(**(26)**,**(tb4)**,2) (27)

Slope Angle (degrees) (28)

Note that from north[high] to south is +; south[high] to north is -

Reduction in height =TAN(PI()/180***(28)**)*(**(23)**) (29)

Obstruction Angle =180/PI()*ATAN(((**(25b)**-**(26)**-**(29)**)/**(23)**)) (30a)

Minimum spacing =((**(25b)**-**(29)**)/(TAN(PI()/180)***(12)**)))-**(27)** (31)

Calculated for optimised passive design

Plots sizes width =HLOOKUP(**(20)**,**(tb2)**,3) (32a)

depth =((HLOOKUP(**(20)**,**(tb1)**,4))/2)+**(31)** (32b)

Area =**(32a)***(**32b)** (32c)

No. of plots of Optimised PSD =**(17)**/**(32c)** (33)

Menu 3 : Orientation

Orientation of House (N,S,E,W,NE,NW,SE,SW) (34a)

Number of houses with this orientation (34b)

Orientation of House (N,S,E,W,NE,NW,SE,SW) (35a)

Number of houses with this orientation (35b)

Orientation of House (N,S,E,W,NE,NW,SE,SW) (36a)

Number of houses with this orientation (36b)
(Repeated for each orientation)

Number of homes on Southern Boundary (unobstructed) (37)

TABLE 5 (**tb5**) : INCREASE IN HEATING DUE TO ORIENTATION

Orientation	S	SE	E	NE	N	NW	W	SW
Passive alternative	0%	3%	8%	10%	11%	10%	8%	3%
Base alternative 1	1%	1%	1%	0%	0%	0%	1%	1%
Base alternatives 2 & 3	8%	7%	4%	1%	0%	1%	4%	7%

Menu 4 : Exterior Obstruction

Is there an exterior obstruction *(yes – 1 / no – 0)* (38)

Height of obstruction (39)

Distance from obstruction (40)

Actual height =IF((**38**)=1,(**39**)-(TAN(PI()/180*(**28**))*((**40**)))-(**26**),0) (41)

Actual distance =IF((**38**)=1,(**40**)-(**27**),0) (42)

Number of houses affected (43a)

Houses affected =IF((**38**)=1,(**43a**),0) (43b)

Obstruction angle =IF((**38**)=1,180/PI()*ATAN((**41**)/(**42**)),0) (44)

Menu 5 : Passive Solar Option

Type of Insulation
Select from menu either 1, 2, or 3 (45)

SELECTION MENU	
Type of insulation	Designation
Standard	1

Energy-efficient	2
Super	3

Level of air-tightness

Select from menu either 1, 2, or 3 (46)

SELECTION MENU	
Level of air-tightness	Designation
Standard	1
Intermediate	2
Super	3

Amount of Glazing

Select from menu either 1, 2, 3, 4, 5, 6 or 7 (47)

SELECTION MENU	
Amount of Glazing	Designation
Standard	1
Standard, 50% facing South	2
15% TFA	3
18% TFA	4
20% TFA	5
25% TFA	6
30% TFA	7

Type of Boiler (for most options, the 'standard' boiler is default – 1)

Select from menu either 1, 2, 3 or 4 (48)

SELECTION MENU	
Type of boiler	Designation
Standard	1
Biomass with electric HW	2
Energy-efficient gas boiler	3
Biomass heating & HW	4

Key code for database =**(45)_(46)_(47)_(48)** (49)

For example, assume all standard then key code would be 1111

KEY CODES		1	2	3
Base Option	a	=1A+1B+1C+1D	=2A+1B+1C+1D	=3A+1B+1C+1D
Base 1	b	=1A+1B+1C+1D	=2A+2B+1C+1D	=3A+3B+1C+1D
Base 2	c	=1A+1B+2C+1D	=2A+1B+2C+1D	=3A+1B+2C+1D
Passive 1	d	=1A+1B+5C+1D	=2A+1B+5C+1D	=3A+1B+5C+1D
Passive 2	e	=1A+1B+6C+1D	=2A+1B+6C+1D	=3A+1B+6C+1D
Passive 3*	f	=1A+1B+6C+1D	=2A+1B+6C+1D	=3A+1B+6C+1D
Passive 4	g	=1A+1B+7C+1D	=2A+1B+7C+1D	=3A+1B+7C+1D
Passive 5	h	=1A+1B+4C+1D	=2A+1B+4C+1D	=3A+1B+4C+1D
Passive 6**	I	=1A+1B+4C+1D	=2A+2B+4C+1D	=3A+3B+4C+1D
Passive 7	j	=3A+3B+4C+2D	=3A+3B+4C+3D	=3A+3B+4C+4D
Passive 8***	k	=3A+3B+4C+2D	=3A+3B+4C+3D	=3A+3B+4C+4D

*As Passive 2, but 75% of Glazing faces South instead of 90%, ** As Option 5, but increasing air-tightness
*** As Option 7 but increases Air-tightness from a value to 0.45Ac/Hr

TABLE 6 **(tb6)**	
Key Code	House Type
1111	a1
1111/	b1
1121	c1
1151	d1
1161	e1
1161/	f1
1171	g1
1141	h1
1141/	i1
3342	j1
3342/	k1
2111	a2
2211	b2
2121	c2
2151	d2
2161	e2
2161/	f2
2171	g2
2141	h2
2241	i2
3342	j2
3342/	k2
3111	a3
3311	b3
3121	c3
3151	d3
3161	e3
3161/	f3
3171	g3
3141	h3
3341	i3
3344	j3
3344/	k3

Alternative Chosen =VLOOKUP(**(49)**,**(tb6)**,2,FALSE) (50)

Increase in cost due to Orientation

For Base alternative 1 =IF(**(50)**="a1",1,IF(**(50)**="a2",1,IF(**(50)**="a3",1,0))) (51a)

For Base alternative 2 =IF(**(50)**="b1",2,IF(**(50)**="b2",2,IF(**(50)**="b3",2,0))) (51b)

For Base alternative 3 =IF(**(50)**="c1",2,IF(**(50)**="c2",2,IF(**(50)**="c3",2,0))) (51c)

For all alternatives =IF(**(51a)**+**(51b)**+**(51c)**>0,**(51a)**+**(51b)**+**(51c)**,3) (51d)

House Orientation 1 =IF(**(51d)**=1,HLOOKUP(**(34a)**,**(tb5)**,3), (52)
IF(**(51d)**=2,HLOOKUP(**(34a)**,**(tb5)**,4),
HLOOKUP(**(34a)**,**(tb5)**,2)))

House Orientation 2 =IF(**(51d)**=1,HLOOKUP(**(35a)**,**(tb5)**,3), (53)
IF(**(51d)**=2,HLOOKUP(**(35a)**,**(tb5)**,4),
HLOOKUP(**(35a)**,**(tb5)**,2)))

House Orientation 3 =IF(**(51d)**=1,HLOOKUP(**(36a)**,**(tb5)**,3), (54)

IF((51d)=2,HLOOKUP((36a),(tb5),4),
HLOOKUP((36a),(tb5),2)))

Repeated for each orientation

Annual running cost increase caused by overshadowing (see table below)

TABLE 7 (tb7) : COST INCREASE DUE TO OVER-SHADOWING																				
Ob angle	2	4	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40
% Increase	0	0	1	2	3	4.5	6	8.5	10.8	12.2	14.1	16.8	18.9	20.8	22.4	24.4	25.6	27.8	29.0	30.9

% Increase for main site areas	=IF((30)<(12),0,CEILING((30),2)) =HLOOKUP((55a),(tb7),2)	(55a) (55b)
% Increase for due to exterior obstruction	=IF((44)<(12),0,CEILING((44),2)) =HLOOKUP((56a),(tb7),2)	(56a) (56b)

FINDING COSTS AND EMISSIONS FOR HOUSING ALTERNATIVES ON SITE

TABLE 8 (tb8) : KWH (m^2)									
		1	2	3	A	B	C		
Primary	a	70.7886	57.4096	41.8361	=IF((50)="a1",a1,"")	=IF((50)="a2",a2,"")	=IF((50)="a3",a3,"")	=sum(A+B+C)	
Base1	b	70.7886	52.3836	33.5538	=IF((50)="b1",b1,"")	=IF((50)="b2",b2,"")	=IF((50)="b3",b3,"")	=sum(A+B+C)	
Base2	c	68.2403	55.0736	42.8271	=IF((50)="c1",c1,"")	=IF((50)="c2",c2,"")	=IF((50)="c3",c3,"")	=sum(A+B+C)	
Passive1	d	67.7447	53.8702	38.4382	=IF((50)="d1",d1,"")	=IF((50)="d2",d2,"")	=IF((50)="d3",d3,"")	=sum(A+B+C)	
Passive2	e	67.7447	53.6578	38.0135	=IF((50)="e1",e1,"")	=IF((50)="e2",a1,"")	=IF((50)="e2",a1,"")	=sum(A+B+C)	
Passive3	f	67.8863	53.8702	38.3674	=IF((50)="f1",f1,"")	=IF((50)="f2",f2,"")	=IF((50)="f3",f3,"")	=sum(A+B+C)	
Passive4	g	68.0987	53.3038	37.1640	=IF((50)="g1",g1,"")	=IF((50)="g2",g2,"")	=IF((50)="g3",g3,"")	=sum(A+B+C)	
Passive5	h	68.0987	54.7196	39.2877	=IF((50)="h1",h1,"")	=IF((50)="h2",h2,"")	=IF((50)="h3",h3,"")	=sum(A+B+C)	
Passive6	I	68.0987	50.1891	31.3594	=IF((50)="i1",i1,"")	=IF((50)="i2",i2,"")	=IF((50)="i3",i3,"")	=sum(A+B+C)	
Passive7	j	24.8468	27.6784	24.7760	=IF((50)="j1",j1,"")	=IF((50)="j2",j2,"")	=IF((50)="j3",j3,"")	=sum(A+B+C)	
Passive8	k	17.3432	19.9624	17.2724	=IF((50)="k1",k1,"")	=IF((50)="k2",k2,"")	=IF((50)="k3",k3,"")	=sum(A+B+C)	
								=SUM(above)	(57)

TABLE 9 (tb9) : COST (m^2)								
		1	2	3				
Primary	a	£ 1.14	£ 0.93	£ 0.68	=IF((50)="a1",a1,"")	=IF((50)="a2",a2,"")	=IF((50)="a3",a3,"")	=sum(A+B+C)
Base1	b	£ 1.14	£ 0.85	£ 0.54	=IF((50)="b1",b1,"")	=IF((50)="b2",b2,"")	=IF((50)="b3",b3,"")	=sum(A+B+C)
Base2	c	£ 1.11	£ 0.89	£ 0.69	=IF((50)="c1",c1,"")	=IF((50)="c2",c2,"")	=IF((50)="c3",c3,"")	=sum(A+B+C)
Passive1	d	£ 1.10	£ 0.87	£ 0.62	=IF((50)="d1",d1,"")	=IF((50)="d2",d2,"")	=IF((50)="d3",d3,"")	=sum(A+B+C)
Passive2	e	£ 1.10	£ 0.87	£ 0.62	=IF((50)="e1",e1,"")	=IF((50)="e2",a1,"")	=IF((50)="e2",a1,"")	=sum(A+B+C)
Passive3	f	£ 1.10	£ 0.87	£ 0.62	=IF((50)="f1",f1,"")	=IF((50)="f2",f2,"")	=IF((50)="f3",f3,"")	=sum(A+B+C)

Passive4	g	£ 1.10	£ 0.86	£ 0.60	=IF((50)="g1",g1,"")	=IF((50)="g2",g2,"")	=IF((50)="g3",g3,"")	=sum(A+B+C)	
Passive5	h	£ 1.10	£ 0.89	£ 0.64	=IF((50)="h1",h1,"")	=IF((50)="h2",h2,"")	=IF((50)="h3",h3,"")	=sum(A+B+C)	
Passive6	I	£ 1.10	£ 0.81	£ 0.51	=IF((50)="i1",i1,"")	=IF((50)="i2",i2,"")	=IF((50)="i3",i3,"")	=sum(A+B+C)	
Passive7	j	£ 0.67	£ 0.41	£ 0.62	=IF((50)="j1",j1,"")	=IF((50)="j2",j2,"")	=IF((50)="j3",j3,"")	=sum(A+B+C)	
Passive8	k	£ 0.47	£ 0.30	£ 0.43	=IF((50)="k1",k1,"")	=IF((50)="k2",k2,"")	=IF((50)="k3",k3,"")	=sum(A+B+C)	
								=SUM(above)	(58)

Boiler efficiency =IF((48)="1",83%,IF((48)="2",60%, (59)
For this project only IF((48)="3",90%,IF((48)="4",60%,""))))

kWh (per dwelling) : direction #1 =((((57)*(20))*(52))*(1+(55b)))*(59) (60a)

For site =(34b)*(60a) (60b)

Cost (per dwelling) : direction #1 =(((58)*(20))*(52))*(1+(55b)) (60c)

For site =(34b)*(60c) (60d)

kWh (per dwelling) : direction #2 =((((57)*(20))*(53))*(1+(55b)))*(59) (61a)

For site =(35b)*(61a) (61b)

Cost (per dwelling) : direction #2 =(((58)*(20))*(53))*(1+(55b)) (61c)

For site =(35b)*(61c) (61d)

kWh (per dwelling) : direction #3 =((((57)*(20))*(54))*(1+(55b)))*(59) (62a)

For site =(36b)*(62a) (62b)

Cost (per dwelling) : direction #3 =(((58)*(20))*(54))*(1+(55b)) (62c)

For site =(36b)*(62c) (62d)
Repeated for each orientation

No of homes unobstructed =IF((43b)>(37),0,(37)-(43b)) (63)

kWh (per dw) : Unobstructed =(((57)*(20))*100%)*(59) (64a)
Note that the default orientation for unobstructed buildings is south (100%)

For site =(63)*(64a) (64b)

Cost (per dw) : Unobstructed =((58)*(20))*100% (64c)

For site =(63)*(64c) (64d)

kWh (per dw) : Exterior Ob =((((57)*(20))*100%)*(1+(56b)))*(59) (65a)
Note that the default orientation for obstructed (ext) buildings is south (100%)

For site =(43b)*(65a) (65b)

Cost (per dw) : Exterior Ob =(((58)*(20))*100%)*(1+(56b)) (65c)

For site =**(43b)***(**65c)** (65d)

OPTIMISED PASSIVE HOUSING

Note that best passive solar house type is designation "k2"

kWh From **(tb8)** (66)
Cost From **(tb9)** (67)

Number of homes (optimised) =IF(FLOOR(**(33)**,1)>**(13)**,**(13)**,FLOOR(**(33)**,1)) (68)

kWh (per dw) : Optimised =(((**66)***(**20)**)*100%)*(**59)** (69a)

All housing faces south therefore 100% orientation factor is default

For site =**(68)***(**69a)** (69b)

Cost (per dw) : Optimised =((**67)***(**20)**)*100% (69c)

For site =**(68)***(**69c)** (69d)

STANDARD HOUSING

House type

Note that base house type has designation "a1"

kWh From **(tb8)** (70)
Cost From **(tb9)** (71)

kWh (per dw) : Standard =((**70)***(**19c)**)*(**59)** (72a)

For site =**(13)***(**72a)** (72b)

Cost (per dw) : Standard =(**71)***(**19c)** (72c)

For site =**(13)***(**72c)** (72d)

Menu 6 : Life Cycle Cost Information

Discount rate (73)

Period of Analysis (74)

ALTERNATIVE OPTIONS : COST DATA AND PERIOD

Survey / Inspection Cost (75a) Yrs (75b)

Note that both the approx cost and when the cost incurs is required

Maintenance / Repair Cost (76a) Yrs (76b)

Replacement Cost (77a) Yrs (77b)

Residual costs Cost (78a) Yrs (78b)

MAINTENANCE, etc, COSTS

Survey / Inspection Year **1** (79a)

Note that year 1 is a numerical value of 1, year 2 = 2, and so on

	=IF(((**75b**)=0),"",(IF(MOD((**79a**),(**75b**))= 0,(**75a**),"")))	(79b)
	Year **2**	(79c)
	=IF(((**75b**)=0),"",(IF(MOD((**79c**),(**75b**))= 0,(**75a**),"")))	(79d)
	Repeated up to,... Year **60**	(79e)
	=IF(((**75b**)=0),"",(IF(MOD((**79e**),(**75b**))= 0,(**75a**),"")))	(79f)

Maintenance / Repair

Year 1	=IF(((**76b**)=0),"",(IF(MOD((**79e**),(**76b**))= 0,(**76a**),"")))	(80a)
Year 2	=IF(((**76b**)=0),"",(IF(MOD((**79c**),(**76b**))= 0,(**76a**),"")))	(80b)
Up to, ...		
Year 60	=IF(((**76b**)=0),"",(IF(MOD((**79e**),(**76b**))= 0,(**76a**),"")))	(80c)

Replacement

=IF(((**77b**)=0),"", (IF(MOD((**79a**),(**77b**))= 0,(**77a**),"")))	(81a)
=IF(((**77b**)=0),"",(IF(MOD((**79c**),(**77b**))= 0,(**77a**),"")))	(81b)
=IF(((**77b**)=0),"",(IF(MOD((**79e**),(**77b**))= 0,(**77a**),"")))	(81c)

Residual

=IF(((**78b**)=0),"",(IF(MOD((**79a**),(**78b**))= 0,(**78a**),"")))	(82a)
=IF(((**78b**)=0),"",(IF(MOD((**79c**),(**78b**))= 0,(**78a**),"")))	(82b)
=IF(((**78b**)=0),"",(IF(MOD((**79e**),(**78b**))= 0,(**78a**),"")))	(82c)

YEAR 1

Note that this is repeated for each year

Sub Total	=**(79b)**+**(80a)**+**(81a)**+**(82a)**	(83)
	VAT @ **17.5%**	(84)
	Corp Tax @ **30%**	(85)
+ Taxes	=**(83)**+((**83**)*(**84**))-((**83**)*(**85**))	(86)
PVF	=1/(1+(**73**))^(**79a**)	(87)
PV	=IF((**79a**)+1<=(**74**),(**87**)*(**86**),"")	(88)

TOTAL LCC FOR MAINTENACE COSTS

=SUM(**PV for each year of the analysis period**)	(89)

OPERATIONAL COSTS : DIRECTION #1

Note that operational costs are on an annual basis

YEAR 1

Note that this is repeated for each year

+ Taxes	=(60c)+((60c)*(84))-((60c)*(85))	(90)
PV	=IF((79a)+1<=(74),(87)*(90),"")	(91)

TOTAL LCC FOR DIRECTION #1

=(89)+(91) (92)

OPERATIONAL COSTS : DIRECTION #2

YEAR 1

+ Taxes	=(61c)+((61c)*(84))-((61c)*(85))	(93)
PV	=IF((79a)+1<=(74),(87)*(93),"")	(94)

TOTAL LCC FOR DIRECTION #2

=(89)+(94) (95)

OPERATIONAL COSTS : DIRECTION #3

YEAR 1

+ Taxes	=(62c)+((62c)*(84))-((62c)*(85))	(96)
PV	=IF((79a)+1<=(74),(87)*(96),"")	(97)

TOTAL LCC FOR DIRECTION #3

=(89)+(97) (98)

OPERATIONAL COSTS : Unobstructed houses

YEAR 1

+ Taxes	=(64c)+((64c)*(84))-((64c)*(85))	(99)
PV	=IF((79a)+1<=(74),(87)*(99),"")	(100)

TOTAL LCC FOR Unobstructed houses

=(89)+(100) (101)

OPERATIONAL COSTS : Exterior obstruction

YEAR 1

+ Taxes	=(65c)+((65c)*(84))-((65c)*(85))	(102)

PV	=IF((79a)+1<=(74),(87)*(102),"")	(103)
TOTAL LCC FOR Exterior obstruction		
	=(89)+(103)	(104)
TOTAL FOR SITE	=(92)+(95)+(98)+(101)+(104)	(105)

OPERATIONAL COSTS : OPTIMISED PASSIVE SOLAR

YEAR 1

+ Taxes	=(69c)+((69c)*(84))-((69c)*(85))	(106)
PV	=IF((79a)+1<=(74),(87)*(106),"")	(107)
TOTAL LCC FOR OPTIMISED PASSIVE SOLAR		
	=(89)+(107)	(108)

STANDARD OPTION : COST DATA AND PERIOD

Survey / Inspection	Cost	(109a)	Yrs		(109b)
Maintenance / Repair	Cost	(110a)	Yrs		(110b)
Replacement	Cost	(111a)	Yrs		(111b)
Residual	Cost	(112a)	Yrs		(112b)

MAINTENANCE, etc, COSTS

Survey / Inspection (Yr1)	=IF(((109b)=0)"",(IF(MOD((79a),(109b))=0,(109a),"")))	(113a)
Yr 2	=IF(((109b)=0)"",(IF(MOD((79c),(109b))=0,(109a),"")))	(113b)
Repeated up to, ... Yr 60	=IF(((109b)=0)"",(IF(MOD((79e),(109b))=0,(109a),"")))	(113c)
Maintenance / Repair	=IF(((110b)=0)"",(IF(MOD((79a),(110b))=0,(110a),"")))	(114a)
	=IF(((110b)=0)"",(IF(MOD((79c),(110b))=0,(110a),"")))	(114b)
	=IF(((110b)=0)"",(IF(MOD((79e),(110b))=0,(110a),"")))	(114c)
Replacement	=IF(((111b)=0)"",(IF(MOD((79a),(111b))=0,(111a),"")))	(115a)
	=IF(((111b)=0)"",(IF(MOD((79c),(111b))=0,(111a),"")))	(115b)
	=IF(((111b)=0)"",(IF(MOD((79e),(111b))=0,(111a),"")))	(115c)
Residual	=IF(((112b)=0)"",(IF(MOD((79a),(112b))=0,(112a),"")))	(116a)
	=IF(((112b)=0)"",(IF(MOD((79c),(112b))=0,(112a),"")))	(116b)
	=IF(((112b)=0)"",(IF(MOD((79e),(112b))=0,(112a),"")))	(116c)

YEAR 1

Note that this is repeated for each year

Sub-total	=(113a)+(114a)+(115a)+(116a)	(117)
+ Taxes	=(117)+((117)*(84))-((117)*(85))	(118)
PV	=IF((79a)+1<=(74),(87)*(118),"")	(119)

OPERATIONAL COSTS FOR STANDARD

Operational costs are annual

YEAR 1

+ Taxes	=(72c)+((72c)*(84))-((72c)*(85))	(120)
PV	=IF((79a)+1<=(74),(87)*(120),"")	(121)

TOTAL LCC FOR STANDARD HOUSING

=(119)+(121) (122)

CO2 EMISSIONS (tonnes)

Direction 1	=(((60b)*0.187)*(74))/1000	(123a)
0.187 is the emission factor		
Direction 2	=(((61b)*0.187)*(74))/1000	(123b)
Direction 3	=(((62b)*0.187)*(74))/1000	(123c)
Repeated for various directions		(123d)
Unobstructed	=(((64b)*0.187)*(74))/1000	(123e)
Exterior obstruction	=(((65b)*0.187)*(74))/1000	(123f)
Optimised PSD	=(((69b)*0.187)*(74))/1000	(124)
Standard housing	=(((72b)*0.187)*(74))/1000	(125)

SUMMARY (for graph)

TOTAL COST AND EMISSIONS OF PROPOSED SITE

Cost =(105)/1000
Emissions =(123a)+(123b)+(123c)+(123d)+(123e)+(123f)

TOTAL COST AND EMISSIONS OF SITE USING CURRENT METHODS OF DEVELOPMENT

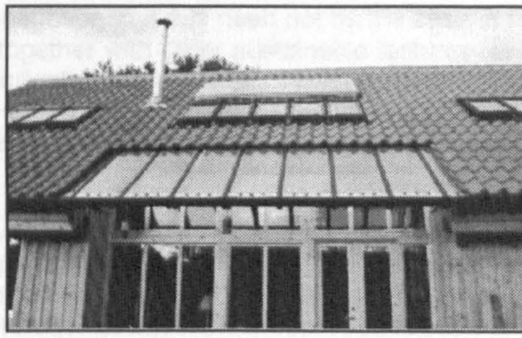
Cost =(122)/1000
Emissions =(125)

TOTAL COST AND EMISSIONS OF OPTIMISED PASSIVE SOLAR DEVELOPMENT

Costs =(108)/1000
Emissions =(124)

APPENDIX B

PERFORMANCE EVALUATION OF A CASE STUDY IN THE NORTH EAST OF SCOTLAND



A nominal '*zero heating*' house for the north-east of Scotland:

Research project reports for Aberdeen City Council Housing Department

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1: INTRODUCTION

1.1. The '*zero-heating*' family home

The 'Zero-Heating' home is a practical demonstration that this need not be the case. It has delivered very radical savings in energy use, together with other sustainable features, at an initial capital cost less than the most basic specification private sector housing by the volume builders. This has been achieved by adopting sound design principles and taking advantage of the inherent environment properties of a construction system developed to reduce material use and capital cost.

The specific aim of the project, built for a private client and completed in December 1999, was to reduce the need for dedicated heating plant to be as close as possible to zero in a simple, replicable design which can be applied to a mass market for affordable housing. The '*zero-heating*' House, despite being a single, prototypical house, has succeeded in delivering these improvements at an initial capital cost no greater than that of standard, low cost, 'spec-built' mass housing. With the 2000 Scottish Housing award winning '*zero-heating*' family home, the aim is to prove significant energy reduction performance targets can be achieved at costs less than or comparable to standard housing.

1.2. The Design

In order to achieve these aims, the design incorporated a number of technological innovations in its construction. The principal aim of this design was to ensure that, as far as possible, all the heating needs of the house can be derived from internal gains such as lighting, cooking, human body heat etc. The energy efficient specification therefore includes;

- *Super-insulation within the depth of structural timber "I" beams using recycled, newspaper insulation*
- *Passive solar design employing some thermal mass to smooth out diurnal temperature fluctuations*
- *Low E triple glazing to optimise heat loss to heat gain ratio*
- *Closely controlled mechanical ventilation with heat recovery through extractor units*
- *Solar water heating through roof-mounted panels*
- *The use of sustainable materials, including locally produced, recycled and 'waste' materials.*

Many aspects of the design are not conceptually new. Its originality lies in the conjunction of different innovations and the fact that they have not hitherto been used in the construction of housing in the UK. The main thrust of the idea for this building was the elimination of dedicated heating plant through the use of insulation 450mm thick in the roof, 300mm thick in the walls and 200mm thick in the floor. The 'Zero-Heating' family home is built using timber 'I' beams that are simultaneously quick to install and less expensive than traditional construction. Glue has also eliminated from the construction. The crucial advantage of these 'I' beams, however, lies in their increased depth, which allows extremely deep insulation to be incorporated into the structure without any cost penalty in terms of additional structure. In a highly insulated building, ventilation becomes the most important source of heat loss and the design therefore incorporates a well sealed envelope and heat recovery in a mechanical ventilation system.

Externally, the building is clad in locally purchased larch cladding with clay pantiles, both of which have expected life spans of around 60 years. Consideration of life-cycle cost also included ultimate demolition and disposal and the cladding materials have some re-sale value. The glazing is mostly south facing, with most of the north, east and west glazing eliminated. This allows daylight to enter on the south facade while reducing heat loss on the remaining facades. The windows are triple glazed, krypton filled units, rooflights are double glazed and 'low E' glass is used throughout. The floor is exposed concrete, acting as a thermal mass, with 20Omm of insulation beneath.

The interior of the building is more open than conventional, 'cellular' homes, which allows heat to circulate more effectively. Another innovation is the near elimination of dedicated circulation space by allowing all rooms to open off the central living space and balcony. As a consequence most of the interior space is two storey, which allows light to flood in for long periods of the day.

In addition to the added insulation, passive solar design, thermal mass, mechanical heat recovery fans and triple glazing, solar panels were installed to aid the water heating of the house. A wood stove is also included in the central living space as a back-up during winter, though preliminary studies suggest that internal temperatures inside the house over the year should not fall below 14'C, without the use of dedicated heating plant.

1.3. Funding

This report was funded by Aberdeen City Housing Department, which aimed to provide a life cycle cost analysis, a performance evaluation and a post occupancy evaluation of a *'zero-heating'* house for the North-East of Scotland. The reports have been commissioned to be completed a year after the occupation of the *'zero-heating'* family home.

1.4. Background[1]

Ever Since the first 'oil crisis' of the early 1970s raised awareness of energy as an issue and its excessive use in buildings as a problem, numerous attempts have been made to create houses which demand much less energy than their 'standard' contemporaries. More recently this concern to produce radical, energy efficient buildings has expanded to incorporate a whole series of other aspects of an environmental agenda in a quest for what has come to be known as 'sustainability'. Such 'cutting edge' developments have been followed, at a somewhat sedate pace, by improvements in building standards demanded by legislation.

Many of these radical homes can be characterised as 'showcase developments', which employ all manner of state-of-the-art techniques in generally expensive prestige homes designed to demonstrate what is possible. The theory is generally that a 'trickle-down' effect will ensure that the benefits ultimately reach a mass housing market. Where such one-off, demonstration developments have been transferred, perhaps in a somewhat diluted form, into the more affordable mass housing market, it has generally been accepted by all concerned that there must be a cost penalty. In order to achieve reduced energy use, improved life cycle criteria and/or enhanced sustainability, there is assumed to be an inevitable capital cost increase, however modest.

The teams at G Deveci Architects and RGU now have considerable experience in the design of quite radical, innovative affordable housing. They have always been aware that the pursuit of *'affordability'* should not be restricted to the reduction of capital cost. We should also be aware of the life cycle, energy and environmental implications of affordability.

The truly affordable house; that is the kind of house, which is affordable both to society and the individual occupier; must represent a practical, sustainable kind of development. The *'zero-heating'* house is the latest development in our thinking about affordability in housing and the demonstration project in the private sector seeks to validate the design as a model for future development.

The design for this demonstration project is a development of Scottish homes' and others previous commitment to research into affordable housing through the *'affordable rural*

1 Further information may be obtained from a previous paper entitled *'A 'zero Heating' House for the North-East of Scotland: Proposal for a Demonstration Project'*.

housing project'. Whilst the immediate output from that project has been the current 2000 homes award winning development at Kincardine O'Neil, the primary characteristics of which are cheapness, flexibility and extendibility, a number of other designs produced by the ARH project have been developed by G. Deveci Architects. These designs, though also emanating from the idea of affordability, have had a number of different types of objectives.

One of the designs developed from the generic concepts explored in the ARH project has now been built by G. Deveci Architects. This is the '*Van Midden House*', a family dwelling using lightweight composite timber 'I' beams and sheet materials, which has been built for a private client with the aid of a Scottish homes rural home ownership grant. The design employs the concept of '*buffer zones*', whilst its structure allows for large amounts for insulation, giving it exceptionally low 'U' values and low energy consumption. The house also has a series of other environmental advantages related to the materials used, the disposal of waste and the way in which the development addresses the use of the site.

The local sourcing of timber materials, to replace some of the large amounts of imported timber currently used in housing, is an important aim of the design. The Van Midden house achieves these savings at a capital cost some 30% lower than standard specification, '*off-the-shelf*' kit houses of equivalent size. Initial, ad-hoc monitoring has demonstrated a high degree of satisfaction from clients and the house has recently received a National RICS award.

Although having a series of subsidiary aims, these precedents have tended to stress capital cost reduction above other factors (*see table 1.2*). It is now suggested that, whilst there remain opportunities for further cost reduction through design refinement, other financial and environmental goals should take precedence. As a result a refined version of the Van Midden house was developed, and this proposal is concerned with looking at the monitoring and measurement of this privately financed initiative which offers a potential model for both private and social sector housing.

Whilst there are a number of precedents for such very low energy housing in Scandinavia and elsewhere, it is believed that the project will be unique within Scotland in setting such a radical agenda for reduction of energy costs.

Table 1.2 **DETAILS OF COSTS**

Comparison between Van Midden house and a rural traditional dwelling

ELEMENTS	Van Midden house, Burnorrachie farm Total Cost (£)	(£/m²)	Comparative sized Rural Traditional Total Cost (£)	(£/m²)
1 Substructure	£3,526	£28	£8,047	£63
2 Superstructure	£32,119	£310	£49,000	£386
3 Finishes				
Internal Decoration	£1,500	£12	£1,500	£12
External Decoration	£1,200	£9	-	-
4 Fittings				
Kitchen Units	£2,000	£16	£2,000	£16
Sanitary Units	£1,800	£14	£1,800	£14
5 Services				
Electrical	£3,025	£24	£3,025	£27
Mechanical	£4,491	£35	£4,520	£36
6 Builders Work	£404	£3	£640	£5
CUMULATIVE TOTALS* NOTE - Floor area is 127m²	£50,065	£451	£70,532	£559

* Totals are rounded-up

Life Cycle Cost Analysis

for the project

A nominal '*zero heating*' house for the north-east of Scotland

Report Number 1

Authors

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Edge, Dr *Martin*
Fotios, Dr *Steve*
Scott, *Jonathan* ✍

October , 1999

2 : LIFE CYCLE COST ANALYSIS: SUMMARY AND INTRODUCTION

2.1. Executive Summary

1. The *'zero heating'* house was designed to deliver radical environmental improvements over current 'standard' housing. A particular aim was to reduce the need for dedicated heating plant to be as close as possible to zero.

2. The precedents for housing with these kinds of aims have tended to be one-off, high cost designs, which have made environmental improvements at the expense of economic affordability. They are typically not replicable designs, which can be applied to a mass market for affordable housing.

3. The '*zero heating*' house, despite being a single, prototype house, aimed to deliver these improvements at an initial capital cost no greater than that of standard, low cost, 'spec-built' mass housing

4. In order to achieve this, the design incorporated a number of technological innovations in its construction

5. It was important to carry out a life-cycle cost study to ensure that the low capital cost did not compromise the maintenance, running, operation and eventual disposal costs of the house through its life-cycle. as well as to confirm the potential savings in energy running costs.

6. The life-cycle cost study contained in this report has been carried out using the best available, industry standard information. Sensitivity analysis has been carried out to ensure its robustness in the face of a wide range of possible future scenarios.

7. It should be noted however that the life-cycle cost remains a desk study and as such may contain some inevitable inaccuracies.

8. The potential for such inaccuracies and the need to ensure that, in energy terms, the house can be used in the way envisaged by the designers, is the reason for the proposed environmental monitoring exercise which will form the basis for a future report.

9. The life-cycle cost study demonstrates, to a high degree of confidence, that for all realistic scenarios over a 60 year life-span, after discounting future costs, **the '*zero heating*' house makes savings of between £10,000 and £40,000** over 'standard' 'spec-built' housing and over housing of conventional construction but the same spatial design.

10. These savings are manifested for initial capital cost, energy running cost, operation and disposal cost and residual value. Only in the area of material maintenance is there a marginal (2%) cost increase for the '*zero heating*' house.

11. In its primary aim of reducing heating costs **the '*zero heating*' house succeeds, on paper, in reducing annual heating costs to £43.40** for a gas fired heating system. **This represents an 84% saving** over current 'standard' housing designed in accordance with modern building regulations, before discounting.

12. Total energy costs for the '*zero heating*' family home, including all the energy efficient features, succeeds, on paper, in **reducing combined annual energy and maintenance bills by £300 per year** (at 2.5% discount rate). **This represents an 21% saving** over current 'standard' housing designed in accordance with modern building regulations, including discounting

13. These energy savings will be confirmed in the forthcoming environmental monitoring exercise.

14. The '*zero heating*' house is an affordable, replicable model for housing which can deliver very large environmental improvements at costs consistent with, or lower than, the cheapest housing currently on offer by our builders of mass housing.

15. Further savings may be available by moving from a one-off, prototypical construction by a small builder, to more standardised, volume production.

16. The Team of G. Deveci Architects and the Robert Gordon University is currently investigating future variants of the design, which will refine it and develop its potential advantages. In particular there is great potential to improve local and regional supply chains for the materials used in the house.

17. As the design for the '*zero heating*' house currently stands, were the ostensible savings to be replicated for the 4.4 million new homes[2] projected by the government to be needed in the United Kingdom by 2016, **annual fuel bill savings would amount to some £921 million (un-discounted)**. Whilst **the total savings made by these houses over a sixty year life would be in the order of £63 billion over a 'standard' house and up to £122 billion over a rural traditional dwelling,** assuming a discount rate of 2.5%.

2.2. Technical Summary

The following detailed conclusions were derived from the life-cycle cost study of the '*zero heating*' house:

The '*zero heating*' house is derived from Van Midden house which produced 30% capital savings compared to a typical north-east dwelling. Features added to the '*zero heating*' family home included increased fabric insulation to the floor (200mm), wall (300mm) and roof (400mm), structural changes to the depth of timber Masonite 'I' beams, triple glazing (Low-E) windows to reduce heat loss, heat recovery mechanical ventilation, passive solar design with the majority of windows facings south and a solar panel to aid the water heating. The total additional costs to the '*zero heating*' family home, compared to the Van Midden house, are approximately £5,000.

For the Life Cycle Cost Analysis three alternatives were chosen to compare whole life costs. These were the '*zero heating*' house, the standard house (traditionally built but with same spatial design as the '*zero heating*' house) and the rural traditional house (previously used to compare initial costs with the Van Midden house and typical of the modern north-east of Scotland new-build housing stock). The initial costs for these alternatives were; for the '*zero heating*' house £405/m^2; for the standard house £439/m^2; and for the rural traditional house £563/m^2, each for a floor area of 127m^2.

Using the SAP software produced by the Building Research Establishment[3], un-discounted cost savings per year were calculated. For a fair comparison between the alternatives the same heating system for each alternative was used. That is to say, if gas-fired central heating was specified for the standard house, the '*zero heating*' house had a similar heating system. This does not compromise the aim of having no dedicated heating plant in the '*zero heating*' house, but for the purposes of this desk study a heating system must be specified in order to be able to investigate theoretical levels of heating demand. This like for like comparison was also used for a different heating system, wood fire and off-peak electricity. Savings of 38% and 32% may be achieved (per year) over the typical modern house for gas-

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2 *See also* - Household Growth: where shall we live? Cm 3471. HMSO, 1996. ISBN 0-10-134712-X.

3 This software should not be used to predict annual energy consumption but may be used to compare overall energy efficiency of different dwellings.

fired central heating and a wood fire respectively. In addition, SAP ratings of 120 and 123 may be achieved compared to 72 and 61 respectively.

The Life Cycle Cost Analysis was conducted at various discount rates from 0%-30%, with the percentage saving for capital, maintenance, operation and residual remaining the same for each discount rate. In comparison with the standard house, an initial saving of 8% is achieved, while savings on operation and residual costs are 32% and 22%. Maintenance costs for the zero-heating house are 2% higher than for the standard house, due to the high replacement costs of many of the *'zero heating'* house's components. In comparison with the rural traditional dwelling, an initial capital cost saving of 28% is achieved, while savings of 32% and 58% are obtained on operation and residual costs respectively. In this case, there is also a small saving on the maintenance cost of 5%, due to the larger volume of the rural traditional building.

The risk and uncertainty of the Life Cycle Cost Analysis was determined and it was found that the result would have a high probability of accuracy. This was deduced by varying the risk of the discount rate and the cost criteria by up to 20%. It was found that because of the low initial cost, at high discount rates (5-30%) the *'zero heating'* house will be the preferred alternative and because of the lower occupancy costs, at low discount rates (0-5%) the *'zero heating'* house will also be the preferred alternative.

The lives of some materials were assessed using life cycle cost and weighted evaluation principles. Although the risk of poor cost data, maintenance frequency, etc were greater for this analysis, preliminary results show that for the wall cladding larch is the preferred alternative for almost all of the 60 year analysis period. This is due to low initial costs and average maintenance and repair costs, with the additional advantage of coming from a renewable, local source.

Similarly for roof cladding, a life cycle cost analysis was used and it was deduced that from between 55 and 65 years only, clay tiles was the preferred alternative. The weighted evaluation was used to supplement the Life Cycle Cost Analysis, so as to add a variety of non-monetary criteria. The weighted evaluation demonstrates the use of a mathematical model to assess, as a guide only, the environmental aspects of material specification. From this evaluation clay tiles were found to be the preferred alternative after 60 years, their durability being between 65-70 years. Interestingly, if capital and replacement costs were not significant to the client and could be ignored, an analysis of just the non-monetary criteria demonstrated that natural slates and shingles are equally the preferred alternatives for roof cladding.

The different aspects of the operation costs were further assessed as to where the savings were to be made, and if any area may be improved for further development. A Life Cycle Cost Analysis is particularly necessary for a building client in the area of energy saving because any return on an initial investment will only be made over the building's life (given accurate data).

An important inclusion in the design of the *'zero heating'* house was the exchange of a mechanical heat recovery unit as opposed to the standard extract fans commonly used in modern new-build houses. The analysis showed that three heat recovery units have an **additional** cost of £360, but over an entire life cycle of 60 years a **saving** of almost £7,000 may be achieved at 2.5% discount rate, a percentage saving of 18%. The payback period for the heat recovery unit was calculated at 6.3 years (at 2.5% discount rate).

The additional fabric insulation, triple glazing, heat recovery ventilation units and solar powered water heating allow for a 84% reduction in the heating CO_2 emissions between the alternatives. The use of a wood fire also complements this environmentally as the fuel is from a renewable source, termed as biomass energy.

The savings and payback on the use of the solar powered water heater were also calculated. If the solar collector is used in conjunction with a gas-fired central heating system, the payback is in excess of 75 years. Alternatively, if off-peak electricity is used, then a payback of between 40-50 years may be achieved. Savings per year are 17% and 28% respectively for gas-fired and off-peak electricity. The solar water heating is not integral to the Zero Heating design and reaps fewer rewards than other energy saving measures. Of course, there are non-monetary benefits from using this type of energy efficient design.

With all the energy saving features combined, savings of up to 21% at a discount rate of 2.5% may be obtainable, depending on the alternative, on the operational costs only. Alternatives without the solar collector were assessed, and these alternatives have a quicker overall payback period of 19-27 years due to the long payback period for the solar collector. Payback with the alternatives, which include the solar collector, will be only slightly later, between 21-28 years.

In summary, the *'zero heating'* family home will have a saving of £123/m^2 at 2.5% discount rate over sixty years compared to the standard house and £241/m^2 at 2.5% discount rate over sixty years compared to the rural traditional dwelling.

2.3. Maintenance and Life Cycle

A key factor in producing innovative affordable housing is ensuring that capital savings are not secured at the expense of life cycle characteristics. There are obvious life cycle advantages to the *'zero heating'* house, but these need to be set against the maintenance profile. This research has been completed in conjunction with a life cycle cost group at the School of Construction, Property and Surveying, which has been developing software to determine building life cycle cost models, in a project with Salford University. Any innovation involves an element of risk taking and it is incumbent upon us to learn about and minimise the risks.

Using the software created with the aid of Salford University, entitled the *Life-Cycle Cost Analysis Tool*, a basic life cycle cost analysis will be completed to provide insight, modification and flexibility of future design to the project. For further information on life cycle costing see *section 2*.

This package will be used to carry out a comparative life cycle cost study in which the total project costs over the life of the proposed *'zero heating'* house will be compared with those of houses of comparable size but of *'conventional'* construction. The comparators will be standard specification, spec' built, timber framed dwellings. The following outlines the cost that can be included in the life cycle cost analysis:

- Initial construction cost (*based on actual costs and tenders*)
- Mortgage and other borrowing costs (*based on different scenarios for future interest rates*)
- Planned maintenance costs (*predominantly from BMI, literature and manufacturers data*)
- Heating and other energy costs (*Based on SAP ratings but to be confirmed by subsequent monitoring*)
- Component and building life (*predominantly from BMI, literature and manufacturers data*)
- Demolition, disposal and material re-use (*based on material price books for demolition and actual re-sale values*)

2.4. Aims:

G. Deveci Architects are building, for a cost comparable with, or cheaper than, standard specification private sector timber framed 'kit' housing, an environmentally innovative *'zero-heating'* family home. That is, as far as possible all the heating needs of the house will be derived from internal gains such as lighting, cooking, human body heat etc. This includes heat recovery in the kitchen and bathroom extract units, superinsulation, passive solar design, solar powered water heating and Low E triple glazing to provide a minimum heat loss to heat gain ratio requiring no dedicated heating element.

2.5. Objectives:

The demonstration project offers a possible model for future housing development, but for the lessons to be learnt from it, it is important to carry out a degree of monitoring and analysis of costs-in-use. This report outlines the monetary benefits that the *'zero-heating'* family home will provide taking into account varying factors and providing a base for further energy efficient design and modifications.

2.6. Layout of report

The workings of life cycle costing are not a familiar subject and subsequently professionals from various backgrounds may not comprehend its terminology and expressions. Therefore after a section giving introduction, background, aims and objectives of this project, *Section 2* is included outlining life cycle costing from a construction industry perspective is provided. This section will provide further information and elucidation that some may find useful and which relates to the results of the life cycle cost analysis for the *'zero heating'* family home in *Section 3*.

Section 3 deals with the life cycle cost analysis of the *'zero heating'* house and it's comparatives stating the assumptions and risks entailed then providing the relevant results and conclusions. In this section sources of information are also provided with any further relevant information located in the appendices.

Finally, *Section 4* will provide a summary and conclusion of the results presented. In this section the reasons for specification of much of the building materials in the *'zero heating'* family home is also provided.

3 :Life Cycle Cost Analysis of a *'Zero Heating'* House for the North-East of Scotland

3.1 Introduction

This section will be dealing directly with the life cycle cost analysis (LCCA) for the *'zero heating'* family home and its alternatives. Prior to this LCCA it was expected that the family home located in Peterculter would perform excellently in the LCCA as it has a number of immediate advantages. These include the structure itself, a masonite structural 'I' beam, that allows large spans and depth, which subsequently allows the loft space to be used as living space but also allowing high amounts of fabric insulation (super-insulation). Fabric insulation has been popular as a means of reducing running / operation costs as it has a payback of less than seven years.

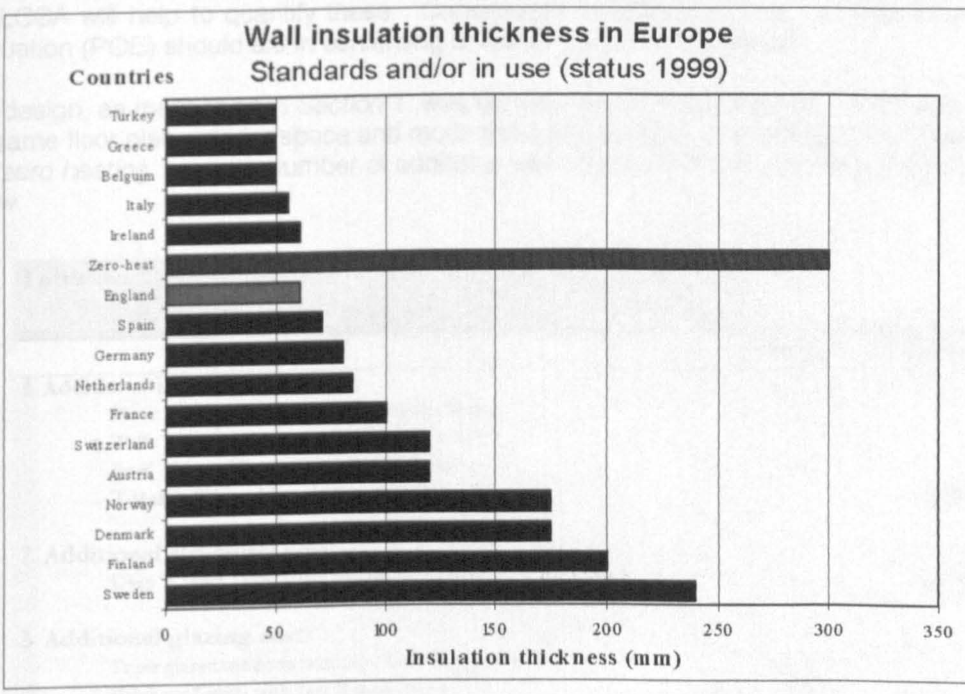
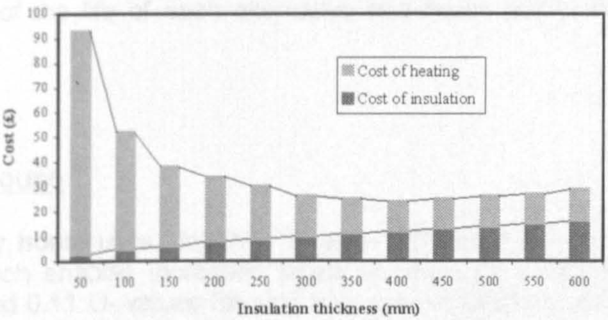


Figure 3.1: *Wall insulation thickness in various European countries*

Additionally the *'zero heating'* house also was specified with passive solar design, triple glazing (with Low E) and heat recovery mechanical units. The specification also included environmentally friendly materials (wherever possible) and locally sourced (wherever available). This means a low environmental impact and embodied energy over the life cycle, which was outside the remit of this study to measure but a brief outline is given in *Section 4*.

Although it was expected that a reduction in the whole life cost of the building was probable, the LCCA will be able to quantify this amount and also go into more depth on various points of interest. These include the life cycle of the external wall and roof cladding but most interest was given to the impact of the various 'additional' mechanical and preventative heat loss systems detailed for the house. *Figure 3*, for example, shows that the best reduction in cost over a life cycle for fabric insulation occurs between 300-450mm. Consequently the *'zero heating'* family home has 300mm wall insulation and 400mm roof insulation, therefore high life cycle reductions are expected (as compared to 150-250mm insulation for a standard dwelling).

Figure 3.2: Cost efficiency of insulation



Source:- Borer, Pat, The Whole House Book, The Centre for Alternative Technology, 1998

Operation costs of the *'zero heating'* home are similarly expected to be radically reduced and the LCCA will help to quantify these. Consequent monitoring, through a Post Occupancy Evaluation (POE) should aid in confirming or denying these calculations.

The design, as mentioned in *Section 1*, was derived from the Van Midden house and retains the same floor plan, interior space and much the same structure. To develop this design into the *'zero heating'* house a number of additions were developed that are covered in the table below.

Table 3.1

Additional costs of the 'zero heating' home (compared to Van Midden)

	Cost (£)	Totals (£)
1 Additional insulation to:-		
Floor: 200mm rigid insulation to replace 50mm	£580	
Walls: 300mm Warmcell to replace 200mm		
Roof: 400mm Warmcell to replace 300mm	£300	
Total Aditional insulation cost		**£980**
2 Additional structural cost		
Deep 'I' beam studs, joists and roof members (approx)		**£800**
3 Additional glazing cost		
Triple glazed windows with 2no. 'Low-E' glass and krypton fill	£1,000	
Velux roof lights with 2no. 'Low-E' glass panes	£150	
Total additional glazing cost		**£1,500**
4 Services		
Supply and install ventilation unit with heat recovery (25DB) 3no. Vent-Axia 150mm units to bathrooms and kitchen		**£300**
5 Solar panel		
Supply and install 4m^2 solar panel for water heating purposes		**£1,500**
CUMULATIVE TOTALS*		
NOTE:- Floor area is 127m^2		£5,080

* *Totals are rounded-up*

In order to get accurate cost information that takes into account discount rate, tax and rates the software created by a research team at R.G.U and Salford University entitled the *Life-Cycle Cost Analysis Tool* will be utilised to provide insight, modification and flexibility to the project. For running / operation costs the software from BRE standard assessment procedure will enable this project to calculate the water and space heating costs. The electricity demand will be taken from a typical 3,300kWhpa average *(source:- British Gas)*.

This section will include the identification of the alternatives used, assumptions made during the LCCA, data compilation and sourcing, LCCA of each alternative at varying discount rates, results and observations, comparison of results, evaluation of uncertainty and risk, graphical representations of the life of each alternative and finally any further impacts or conclusions.

3.2. Alternatives

3.2.1. *'Zero-Heating'* house

The *'zero heating'* family home uses Masonite 'I' beam technology for structure to allow long span and depth, which enables increased levels of cellulose insulation between its members allowing 0.10 and 0.11 U--values for roof and wall respectively and also enables the loft space to be inhabited. The building footprint and interior space is created to be cost effective with the use of solar passive design and thermal mass.

The *'zero heating'* house is clad in locally sourced larch and clay tiles with interior finishes using very little glue. It is intended that no dedicated heating plant should be used, but as an 'insurance policy' and as the client's specification a wood fire will be provided *(note that CO_2 emission from a wood fire is equal to CO_2 intake by trees).* Heat recovery ventilation units will be provided and also triple glazed windows (Low-E) and roof-lights (Low-E) provide minimum heat loss. A solar panel is also used to aid in reducing the water cost of the property

3.2.2. Standard house

Uses the same footprint and design as the *'zero heating'* family home but with a typical timber frame kit house specification that conforms directly to Building Regulations in all aspects. This includes typical double glazing, standard extract fans, no solar passive design, standard U-values and with a typical gas-fired central heating system.

3.2.3. Rural traditional house

This alternative does not use the *'zero heating'* footprint which leads to an un-economical footprint and usage of interior space. This alternative was costed by a local quantity surveying firm this building is typical of the standard north-east of Scotland property portfolio for a similar type floor area of around 127m^2. This allows for a more typical comparison with the *'zero heating'* house but there is a greater degree of risk in comparing life cycle costs and this has been accounted for. Notably it was this house which the family home was compared to where the family home achieved a remarkable capital saving of approximately 30%.

3.3 Assumptions for life cycle cost analysis

There are several assumptions that have been made in order for this LCCA to progress. The project life cycle has been stipulated as 60 years due to this being an investigation of a whole building.

The discount rates chosen take into account a variety of variations and eventualities. The software *Life-Cycle Cost Analysis Tool* allows a flexible approach to providing a sensitivity analysis of the result of changing the discount rates. As a result the discount rate ranges from 0% up to 30%, tables of all are not provided. A summary of the discount rates are given in the *table 3.3*, the current discount rate usually varies between 2.5% and 5%, but may vary between 1.5% and 8%. Option one and two will be the discount rates that will be frequently referred too but option three and four allow for an investigation of extreme discount rates. The rates and tax were accurate to the date of June 1999.

Table 3.3
Different options for sensitivity analysis

	Option One	Option Two	Option Three	Option Four
Treasury bond rate	7%	12%	3%	-
Inflation	2.8%	4%	1.5%	-
Average equity return rate	3.5%	7%	2%	-
Risk: Construction vs. equity	50%	75%	75%	-
Corporation Tax	30%	30%	30%	30%
Discount rate*	**2.50%**	**4.30%**	**0.80%**	**20%**
difference	2.00% / 2.90%	3.40% / 5.10%	0.00% / 1.50%	10% / 30%

** Note: Discount rate has a default of 5% (+/- 20%), if the above is unknown*

3.4 Data compilation

3.4.1 Initial costs

Due to the *'zero heating'* house being constructed during the analysis of the life cycle costs initial costs have been readily available. These costs have been of the form, which enable breaking down into components that enable a more accurate analysis over the life cycle of the building (i.e. structure, windows, cladding, etc). For the standard house, same floor area but different construction type, tenders were available so that comparisons could be made between the different options, therefore an accurate initial cost was available, and interestingly this produced a 7% saving on capital costs. The rural traditional type house was for a detached building in the local area costed by a local quantity surveying firm.

Initial Costs of each alternative

- *'zero heating'* house £405/m^2
- Standard house £439/m^2
- Rural traditional[4] £563/m^2

3.4.2 Maintenance costs

A variety of sources were used to understand the cost and frequency of maintenance schedules. In order to gain accurate and reliable data, preventative maintenance is assumed to be undertaken for each property. For the *'zero heating'* house manufacturers data was readily available and this was supplemented by available literature. For more specialised data, i.e. heat recovery units, and for the other alternatives other sources were utilised, the following being used.

- Kirk and Dell'isola; *Life Cycle Costing for Design Professionals*; (1995)

This provides preventative maintenance frequency and life of common building materials as well as expected energy demand for various mechanical, electrical and plumbing installations.

- Component Life Manual; E & FN Spon (1992)

This provides information on building material life, maintenance and cleaning schedules. However, this is limited to building materials that have life expectancies less than 40 years.

[4] Note:- an RICS source states that for a detached, basic domestic building of 130m^2 floor area in Scotland would average £585/m^2 (January 1999 costs).

- Spon's contractor handbook: Electrical installations (1992)
- Spon's contractor handbook: Plumbing and domestic heating (1993)
- Spon's house improvement price book; E & FN Spon (1998)
- Spon's Architects & Builders price book; E & FN Spon (1999)
- Griffith's complete building price book, Glenigan Cost Information Service (1999)
- BMI building maintenance price book; Building Maintenance Information; RICS (BCIS) (1999)
- Building Maintenance Cost Information Service: Special reports (1990-present)
- Wessex; Major Works; Ti-wessex Electronic Publishing (1999)

The above provide rates and information upon the different building, repair, replace and demolition costs of a variety of building materials. Information from these sources is sometimes of questionable accuracy therefore where actual cost information from a more reliable source is available then this was used.

3.4.3. Operation costs

Software adapted from the Standard Assessment Procedure (SAP) by the BRE was utilised to calculate the running costs for given situations, which was ideal for comparing energy efficient alternatives. In order to assess accurately the direct comparison between alternatives a number of scenarios were created, on the following page is an outline:

Table 3.4 SAP CALCULATIONS

Assessment of 'zero heating' house, using different insulation and heating options

No		SAP	£/year*
1	**Zero Heating House** Assumes 0.5 ac/h, superinsulation, triple glazed windows, gas fired heating and hot water without solar panel, mech. vent with heat recovery	116	£175
2	**Standard house** Assumes 1.5 ac/h, B'Regs u-values, double glazed windows, gas fired heating and hot water, no solar panel, mech. vent without heat recovery	72	£405
3	**Zero Heating House** Assumes 0.5 ac/h, superinsulation, triple glazed windows, wood stove heating, electric (off-peak) hot water with solar panel, mech. vent with heat recovery	120	£163
4	**Standard house** Assumes 1.5 ac/h, B'Regs u-values, double glazed windows, gas fired heating and hot water, no solar panel, mech. vent without heat recovery	61	£510
5	**Zero Heating House** Assumes 0.5 ac/h, superinsulation, triple glazed windows, gas fired heating and hot water with solar panel, mech. vent with heat recovery	123	£155
6	**Zero Heating House** Assumes 0.5 ac/h, superinsulation, triple glazed windows, wood stove heating, electric (off-peak) hot water without solar panel, mech. vent with heat recovery	108	£200

** Note that the average gas heating bill for Scotland is around £420/year; Source:- Jocklin, Christinah (1998/99) Energy efficient new housing in Scotland, dissertation for the school of the built environment, Napier University, Edinburgh*

In addition to the software used to calculate the heating costs, the operation costs were required for electricity and water rates. Any other monthly or yearly bill (i.e. home insurance, telephone bill, etc) was dependent upon type of occupant, which is to say that the bills would be the same whatever the alternative. However electricity is a major contributor to the entire operation costs therefore, though they would be the same for each alternative, given the same circumstances of use, they were also calculated. Local council advice was obtained for electricity charges and confirmed by Scottish Hydro and British Gas web sites[5].

[5] websites for British gas is:- http://www.gas.co.uk/ and website for Scottish hydro is:- http://www.hydro.co.uk/

A typical rate of electricity for this area for this size of house was given as £266 pa. Due to the *'zero heating'* having a compact footprint and interior space, reducing the need for passage / corridor space, it should be noted that the yearly electricity bill would actually be less, therefore the cost stated above favours the other alternatives.

The water rates depend upon the area and property value in order to get accurate costs. Optimistically, band G was chosen which gives the domestic charges as £198.58 for water and £151.00 for wastewater (£349.58 total) which was added to the life cycle analysis. Though the property value was an unknown in the selection of the domestic charges, the higher band of G was chosen to compensate this unknown.

More importantly, from the above costs per year it may be seen that savings of 38% and 32% comparing the *'zero heating'* house with the standard house using gas fired central heating and wood fire (with off-peak electricity) respectively, may be achieved. This is simply by adding fabric insulation to floor, wall and roof, solar powered water heating, triple glazing reducing heat losses and heat recovery mechanical units.

3.4.4. Residual costs

The following pricing sources allowed for the costing of the demolition of the property after 60 years and also for the residual value of those building materials replaced within the life span. Explained in *Section 2* is the method used for calculating the residual value, which included the demolition and consequent re-sale if applicable. Re-sale costs were obtained from primarily salvage yards costs and also web sites[6] and secondly, if appropriate, from the price books listed below:

- Spons Architects & Builders price book; E & FN Spon (1999)
- Griffiths complete building price book, Glenigan Cost Information Service (1999)
- BMI building maintenance price book; Building Maintenance Information; RICS (BCIS) (1999)
- Building Maintenance Cost Information Service: Special reports (1990-present)
- Wessex; Major Works; Tiwessex Electronic Publishing (1999)

6 A comprehensive salvage web site is:- http://www.salvo.co.uk/, which gives links to further salvage, yards nationally and internationally.

3.5 Computation of Life Cycle Costs

3.5.1 '*Zero heating*' house

Table 3.5.1:-	DETAILS OF COST (60 years) The 'Zero Heating' house				Total Floor Area -		127m²	
					Life Cycle (years):-		60	
	Whole Life Costs				Annualized method			
Discount Rate	0.80%	2.50%	5.10%	10.00%	0.80%	2.50%	5.10%	10.00%
ELEMENTS	(£/m²)	(£/m²)	(£/m²)	(£/m²)	(£/m²)	(£/m²)	(£/m²)	(£/m²)
1 Substructure	£34	£30	£29	£28	£0.71	£0.98	£1.54	£2.83
2 Superstructure								
Structure	£178	£162	£151	£144	£3.74	£5.23	£8.11	£14.44
Cladding	£65	£53	£42	£35	£1.38	£1.72	£2.27	£3.47
Glazing/doors	£206	£153	£113	£90	£4.34	£4.93	£6.09	£9.04
3 Finishes								
Internal Decoration	£23	£18	£15	£13	£0.49	£0.59	£0.80	£1.32
External Decoration	*included in superstructure costs*							
4 Fittings								
Kitchen Units	£105	£72	£48	£31	£2.20	£2.34	£2.57	£3.12
Sanitary Units	£30	£25	£22	£20	£0.64	£0.81	£1.17	£2.00
5 Services								
Electrical	£144	£101	£69	£47	£3.03	£3.27	£3.70	£4.73
Mechanical*	£378	£258	£170	£105	£7.96	£8.35	£9.12	£10.53
6 Builders Work	£30	£20	£13	£8	£0.63	£0.64	£0.67	£0.77
CUMULATIVE TOTALS**	£1,193	£892	£671	£521	£25.11	£28.86	£36.04	£52.25

* *Including domestic charges (water & wastewater) at Band G: £34958*

** *Totals are rounded up*

Table 3.5.1 **shows the summary** of the whole life costs (Present worth and annualised methods) for the '*zero heating*' family home. This table includes values for four different discount rates but the most interest lies between 2.5% and 5.1% discount rates. Note that the whole life cost decreases for the present worth method due to the fact the higher the discount rate the less the occupancy costs play a factor in the life cycle of the whole building. Using the annualised method the inverse is true. Breakdowns at each different discount rate have been created to allow for flexibility and so as to be more useful in a sensitivity analysis. The figures on the following page outline the whole life cost of the '*zero heating*' house at different discount rates.

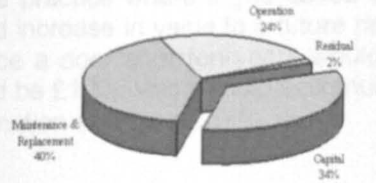


Figure 3.5.1: Whole life cost for zero heating house at 0.8% discount rate

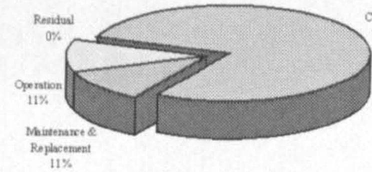


Figure 3.5.4: Whole life cost for zero heating house at 10% discount rate

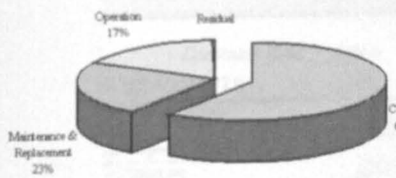


Figure 3.5.3: Whole life cost for zero heating house at 5.1% discount rate

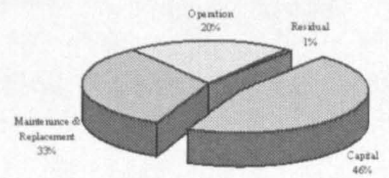


Figure 3.5.2: Whole life cost for zero heating house at 2.5% discount rate

The figures previously show more clearly the effect of the changing discount rate. For the '*zero heating*' family home the higher discount rates of between 5% and 10% are more favourable as they favour the capital cost. This is due to the 30% saving the '*zero heating*' house has initially upon the rural traditional home, therefore if the occupancy costs are kept to a minimum then the '*zero heating*' home is the better alternative. However, the current market states that the discount rate is likely to be between 2.5% and 3%, having fallen to this level over the previous five years from 7%. In this scenario *figure 3.5.2* is a more representative discount rate and if the trend continues then within the next ten years the discount rate should have fallen to between 0.5% and 1.5% discount rates, though this may be unlikely. For the purposes of this study concentration upon the discount rate of 2.5% has been deemed adequate though where costs are likely to fluctuate reference to other relevant discount rates are made.

The following table gives the life cycle cost breakdown of the '*zero heating*' family home at 2.5% discount rate. This allows a perusal of some of the costs in comparison to *table 3.5.1* and *figure 3.5.2*.

Table 3.5.2:- DETAILS OF COST (60 years)
The 'Zero Heating' house

Total Floor Area:- 127m²
Discount Rate:- 2.5%

ELEMENTS	Total Cost (£)	Capital (£)	Capital (£/m²)	Maintenance & Replacement (£)	Maintenance & Replacement (£/m²)	Operation (£)	Operation (£/m²)	Residual (£)	Residual (£/m²)
1 Substructure	£3,853	£3,556	£28.00	£88	£0.69	-	-	£209	£1.65
2 Superstructure									
Structure	£20,525	£18,051	£142.13	£2,300	£18.11	-	-	£174	£1.37
Cladding	£6,734	£4,053	£31.91	£2,785	£21.93	-	-	-£104	-£0.82
Glazing/doors	£19,370	£10,046	£79.10	£9,331	£73.47	-	-	-£7	-£0.06
3 Finishes									
Internal Decoration	£2,300	£1,524	£12.00	£598	£4.71	-	-	£178	£1.40
External Decoration	*included in superstructure costs*								
4 Fittings									
Kitchen Units	£9,193	£2,425	£19.09	£6,592	£51.91	-	-	£176	£1.39
Sanitary Units	£3,190	£2,473	£19.47	£682	£5.37	-	-	£35	£0.28
5 Services									
Electrical	£12,823	£2,904	£22.87	£2,560	£20.16	£7,277	£57.30	£82	£0.65
Mechanical*	£32,785	£6,033	£47.50	£10,686	£84.14	£15,912	£125.29	£154	£1.21
6 Builders Work	£2,520	£404	£3.18	£2,021	£15.91	-	-	£95	£0.75
CUMULATIVE TOTALS**	**£113,293**	£51,469	£405.27	£37,643	£296.40	£23,189	£182.59	£992	£7.81
Equivalent totals with no discount rate***	£484,158	£219,953		£160,868		£99,098		£4,239	

* *Including domestic charges (water & wastewater) at Band C £340.58*
** *Totals are rounded up*
*** *Discount rate at sixty years is 0.234 (single present worth at 2.5% discount rate)*

The table on the previous page also allows the consideration of costs without discounting, demonstrating that costs may be reduced by around a quarter by its introduction. This is due to the practice where if you saved an amount of money at the present time, that amount would increase in value to a future period where it is valued as a greater amount. That is, to replace a door after ten years would cost £200. At a discount of 5.1%, the present value would be £120, which would accumulate up until the tenth year to produce £200. For further information see *section 2*.

3.5.2 Standard House

Table 3.5.3:-	DETAILS OF COST (60 years) Standard house				Total Floor Area:-		127m²	
					Life Cycle (years):-		60	
	Whole Life Costs				**Annualized method**			
Discount Rate	0.80%	2.50%	5.10%	10.00%	0.80%	2.50%	5.10%	10.00%
ELEMENTS	(£/m²)	(£/m²)	(£/m²)	(£/m²)	(£/m²)	(£/m²)	(£/m²)	(£/m²)
1 Substructure	£52	£47	£44	£44	£1.08	£1.51	£2.38	£4.37
2 Superstructure								
Structure	£202	£189	£181	£176	£4.25	£6.13	£9.72	£17.69
Cladding	£114	£80	£58	£47	£2.40	£2.58	£3.11	£4.74
Glazing/doors	£138	£104	£79	£64	£2.91	£3.36	£4.23	£6.42
3 Finishes								
Internal Decoration	£23	£18	£15	£13	£0.49	£0.59	£0.80	£1.32
External Decoration	*included in superstructure costs*							
4 Fittings								
Kitchen Units	£101	£72	£48	£31	£2.13	£2.34	£2.57	£3.12
Sanitary Units	£30	£25	£22	£20	£0.64	£0.81	£1.17	£2.00
5 Services								
Electrical	£144	£101	£69	£47	£3.03	£3.27	£3.70	£4.73
Mechanical*	£521	£347	£215	£126	£10.97	£11.22	£11.56	£12.67
6 Builders Work	£47	£31	£21	£12	£1.00	£1.02	£1.10	£1.23
CUMULATIVE TOTALS**	£1,373	£1,015	£751	£581	£28.90	£32.82	£40.35	£58.30

* *Including domestic charges (water & wastewater) at Band G £349.38*

** *Totals are rounded up*

***Table 3.5.3* summarises the** whole life costs for four different discount rates similarly to the *table 3.5.1* which summarises for the '*zero heating*' house, and as such may be used to compare. A casual comparison will show that the whole life costs have a limit, that is to say the difference between each alternative at 0.8% discount rate is greater than at 10% discount rate. This required further investigation, and indeed at higher discount rates of 20% and 30% the two alternatives became more comparable. However, at 30% discount rate the '*zero heating*' family home remained the preferred alternative and anything over 30% discount rate is very extreme and consequently unlikely but the '*zero heating*' family home would remain the preferred alternative.

In summary, in all the discount rates used (0-30%) the '*zero heating*' family home is the preferred alternative to the standard house. Further investigation of the whole life cost of the standard house at different discount rates is given in the figures on the following page.

Figure 3.5.5: Whole life cost for Standard house at 0.8% discount rate

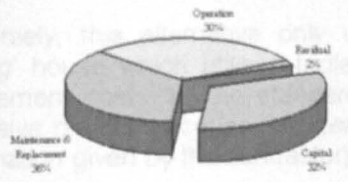


Figure 3.5.6: Whole life cost of standard house at 2.5% discount rate

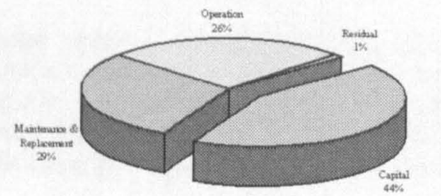


Figure 3.5.7: Whole life cost for standard house at 5.1% discount rate

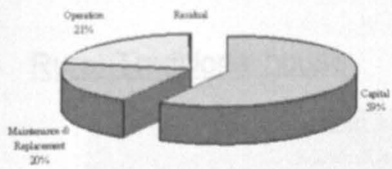
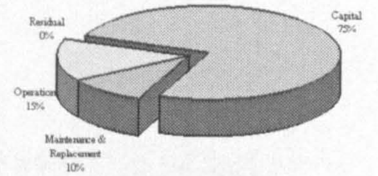


Figure 3.5.8: Whole life cost for standard house at 10% discount rate



From *figures 3.5.5-8* we may compare these to *figures 3.5.1-4* briefly. Important points from this comparison are the higher capital percentage for the '*zero heating*' house. This is primarily due to the occupancy costs (the costs excluding the capital costs) being lower than for the standard house. In addition to this the '*zero heating*' family home has a 7% saving upon capital costs. In summary, the standard house is more expensive than the '*zero heating*' house comparing capital and occupancy costs. A more thorough comparison is made later in this section.

Following is a table that shows the cost breakdown of the standard house at 2.5% discount rate. This table is shown for the reason previously stated for the '*zero heating*' family home.

Table 3.5.4:- DETAILS OF COST (60 years) Standard house (same plan) Total Floor Area:- 127m² Discount Rate:- 2.5%

ELEMENTS	Total Cost (£)	Capital (£)	(£/m²)	Maintenance & Replacement (£)	(£/m²)	Operation (£)	(£/m²)	Residual (£)	(£/m²)
1 Substructure	£5,925	£5,500	£43.31	£103	£0.81	-	-	£322	£2.54
2 Superstructure									
Structure	£24,062	£22,167	£174.54	£1,847	£14.54	-	-	£48	£0.38
Cladding	£10,126	£5,619	£44.24	£4,262	£33.56	-	-	£245	£1.93
Glazing/doors	£13,209	£7,440	£58.58	£5,805	£45.71	-	-	-£36	-£0.28
3 Finishes									
Internal Decoration	£2,300	£1,524	£12.00	£598	£4.71	-	-	£178	£1.40
External Decoration	none								
4 Fittings									
Kitchen Units	£9,193	£2,425	£19.09	£6,592	£51.91	-	-	£176	£1.39
Sanitary Units	£3,190	£2,473	£19.47	£682	£5.37	-	-	£35	£0.28
5 Services									
Electrical	£12,823	£2,904	£22.87	£2,560	£20.16	£7,277	£57.30	£82	£0.65
Mechanical*	£43,541	£4,570	£35.98	£11,985	£94.37	£26,777	£210.84	£209	£1.65
6 Builders Work	£3,993	£640	£5.04	£3,203	£25.22	-	-	£150	£1.18
CUMULATIVE TOTALS**	**£128,362**	£55,262	£435.13	£37,637	£296.35	£34,054	£268.14	£1,409	£11.09
Equivalent totals with no discount rate***	£548,556	£236,162		£160,842		£145,530		£6,021	

* Including domestic charges (water & wastewater) at Band G £349.38

** Totals are rounded up

*** Discount rate at sixty years is 0.234 (single present worth at 2.5% discount rate)

For the standard house the major capital cost changes occur with the cladding and the foundations, with the major changes for the occupancy costs being the same and in addition the operation costs are more expensive. In this alternative concrete block and render is used as opposed to timber, and concrete tile replace clay tiles respectively, all of which increase the initial cost of this element.

Conversely, this alternative only uses standard double glazing compared to the '*zero heating*' house which utilises triple glazed low-E windows resulting in lower capital and replacement costs for the standard house. The capital cost of the foundation is more expensive directly because the '*zero heating*' alternative was costed from completed work (information given by the contractor) and this alternative uses average figures for this type of dwelling.

In summary, the capital cost is almost identical therefore more emphasis may be placed on the differences produced by the occupancy costs when comparing these alternatives later in this section.

3.5.3 Rural Traditional house

Table 3.5.5:-	**DETAILS OF COST (60 years)** **Standard house**				Total Floor Area - 127m^2 Life Cycle (years):- 60			
	Whole Life Costs				**Annualized method**			
Discount Rate	0.80%	2.50%	5.10%	10.00%	0.80%	2.50%	5.10%	10.00%
ELEMENTS	(£/m^2)	(£/m^2)	(£/m^2)	(£/m^2)	(£/m^2)	(£/m^2)	(£/m^2)	(£/m^2)
1 Substructure	£74	£68	£64	£63	£1.57	£2.18	£3.45	£6.34
2 Superstructure								
Structure	£310	£292	£279	£276	£6.53	£9.45	£15.00	£27.67
Cladding	£153	£111	£86	£72	£3.22	£3.60	£4.65	£7.19
Glazing/doors	£87	£69	£55	£47	£1.83	£2.23	£2.96	£4.69
3 Finishes								
Internal Decoration	£23	£18	£15	£13	£0.49	£0.59	£0.80	£1.32
External Decoration	*none*							
4 Fittings								
Kitchen Units	£105	£72	£48	£31	£2.20	£2.34	£2.57	£3.12
Sanitary Units	£30	£25	£22	£20	£0.64	£0.81	£1.17	£2.00
5 Services								
Electrical	£144	£101	£69	£47	£3.03	£3.27	£3.70	£4.73
Mechanical*	£523	£345	£213	£123	£11.00	£11.16	£11.42	£12.33
6 Builders Work	£48	£32	£20	£12	£1.01	£1.03	£1.08	£1.24
CUMULATIVE TOTALS**	£1,497	£1,133	£871	£704	£31.52	£36.66	£46.79	£70.64

* *Including domestic charges (water & wastewater) at Band G £54938*

** *Totals are rounded up*

The rural traditional dwelling has the most expensive capital cost of all the alternatives but has a very similar occupancy cost to the standard house. This is due to both alternatives having a similar specification, however the rural traditional building is also the more expensive in terms of occupancy cost. This is due to both the '*zero heating*' family home and the standard house having more cost efficient footprints and interior spaces.

In summary, both the '*zero heating*' and the standard house are more cost effective than this alternative. The following figures show the breakdown of whole life costs for the rural traditional dwelling.

Figure 3.5.9: Whole life cost for traditional house at 0.8% discount rate

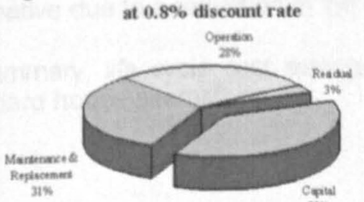


Figure 3.5.10: Whole life costs for a traditional dwelling at 2.5% discount rate

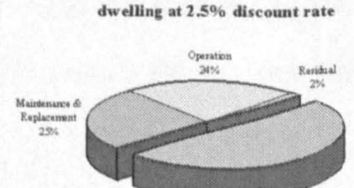


Figure 3.5.11: Whole life cost for traditional house at 5.1% discount rate

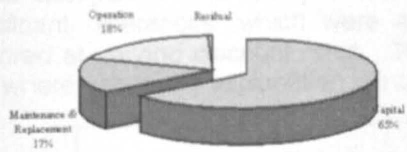
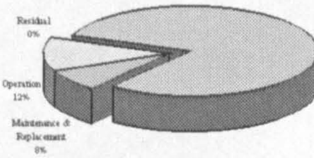


Figure 3.5.12: Whole life cost for traditional house at 10% discount rate



From the figures above and on the previous page we may deduce that the capital cost forms the major cost item for the rural traditional dwelling. It should be noted that the rural traditional dwelling also has more expensive occupancy costs so comparing these figures with figures 3.5.1-4 would be misleading. Nevertheless at 2.5% discount rate, the current discount rate at the present time, the occupancy costs will still cover up to half the whole life costs of a building highlighting the importance of life cycle costing as an essential tool where accurate or predictable information is readily available.

Table 3.5.6 shows the breakdown of costs for the rural traditional dwelling highlighting once again the significance of the occupancy costs compared to the capital costs.

Table 3.5.6:- DETAILS OF COST (60 years) Comparative sized rural traditional — Total Floor Area:- 127m² — Discount Rate:- 2.5%

ELEMENTS	Total Cost (£)	Capital (£)	Capital (£/m²)	Maintenance & Replacement (£)	Maintenance & Replacement (£/m²)	Operation (£)	Operation (£/m²)	Residual (£)	Residual (£/m²)
1 Substructure	£8,573	£8,001	£63.00	£103	£0.81	-	-	£469	£3.69
2 Superstructure									
Structure	£37,114	£34,798	£274.00	£1,847	£14.54	-	-	£469	£3.69
Cladding	£14,125	£8,626	£67.92	£4,984	£39.24	-	-	£515	£4.06
Glazing/doors	£8,759	£5,575	£43.90	£3,226	£25.40	-	-	-£42	-£0.33
3 Finishes									
Internal Decoration	£2,300	£1,524	£12.00	£598	£4.71	-	-	£178	£1.40
External Decoration	*none*								
4 Fittings									
Kitchen Units	£9,193	£2,425	£19.09	£6,592	£51.91	-	-	£176	£1.39
Sanitary Units	£3,190	£2,473	£19.47	£682	£5.37	-	-	£35	£0.28
5 Services									
Electrical	£12,823	£2,904	£22.87	£2,560	£20.16	£7,277	£57.30	£82	£0.65
Mechanical*	£43,791	£4,572	£36.00	£12,123	£95.46	£26,777	£210.84	£319	£2.51
6 Builders Work	£4,032	£640	£5.04	£3,242	£25.53	-	-	£150	£1.18
CUMULATIVE TOTALS**	**£143,900**	£71,538	£563.29	£35,957	£283.13	£34,054	£268.14	£2,351	£18.51
Equivalent totals with no discount rate***	£614,957	£305,718		£153,662		£145,530		£10,047	

* Including domestic charges (water & wastewater) at Band G £349.38

** Totals are rounded up

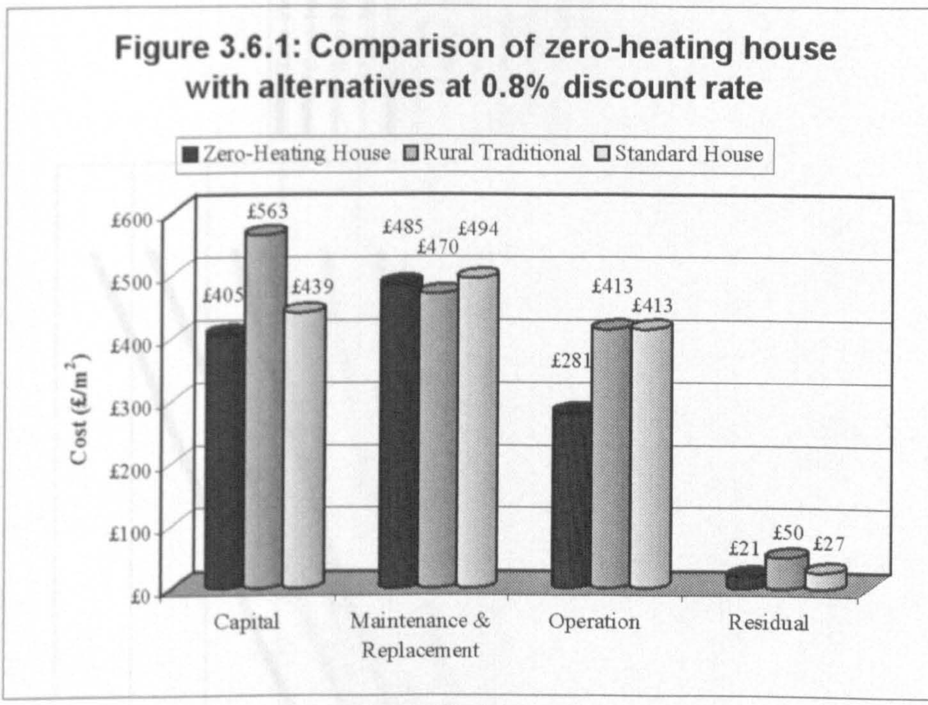
*** Discount rate at sixty years is 0.234 (single present worth at 2.5% discount rate)

For similar reasons for the standard house alternative, there are some significant changes in the cost of the rural traditional dwelling. The substructure cost has increased due to the change in the footprint of this alternative and the increase in the superstructure mass. The structure itself is more expensive due to not being able to utilise the loft space as the '*zero heating*' has benefited from the use of the Masonite 'I' beam, which leads to increased cost of the cladding to this alternative. The glazing is significantly less expensive for this alternative due to a reduction in the window to floor ratio as their is no solar passive design.

In summary, life cycle cost savings of 25-30% can be created for the '*zero heating*' and standard house alternatives.

3.6 Differences between alternatives

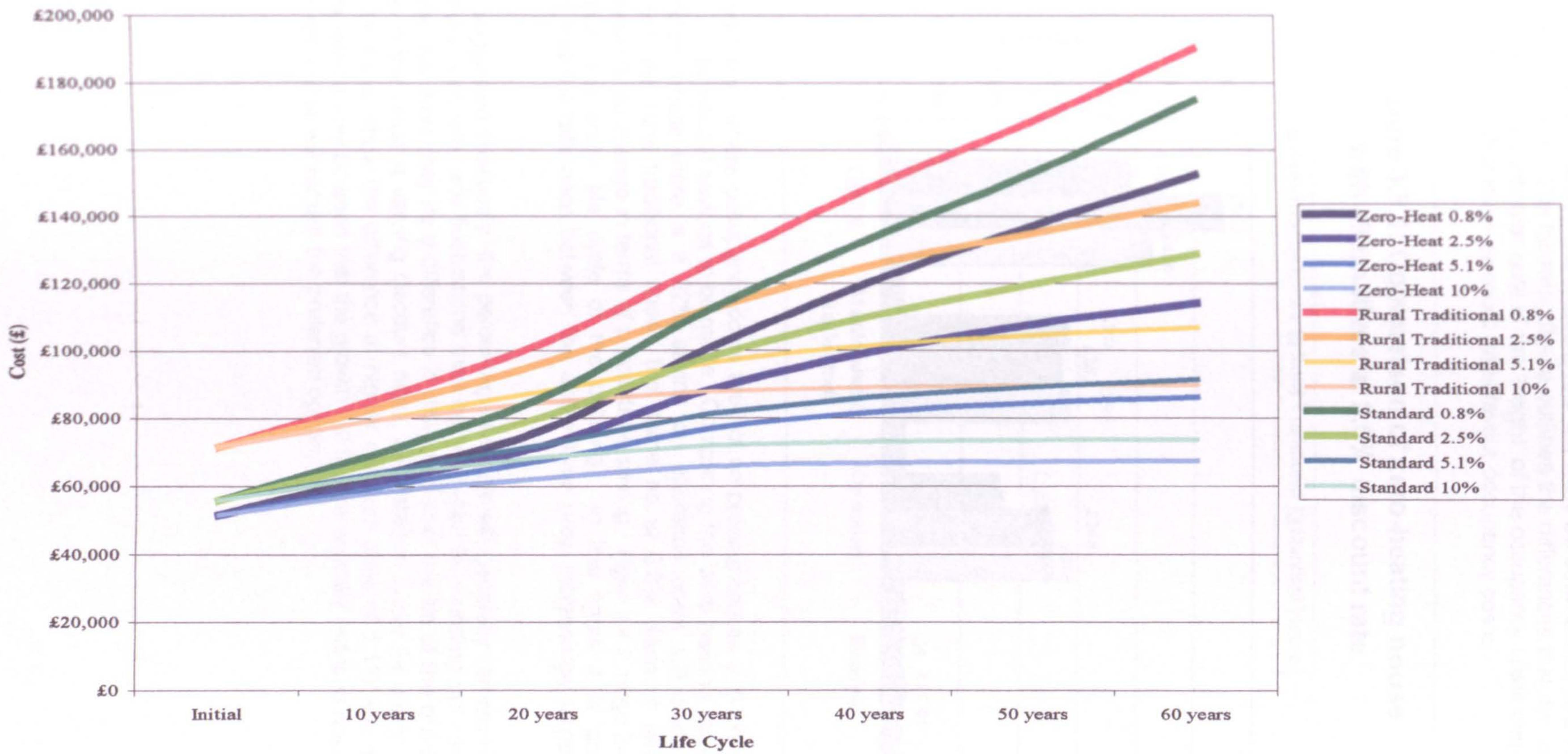
In *3.5 Computation of life cycle costs* when the alternatives where compared there where significant differences, which were anticipated, therefore the differences will be further explored at varying discount rates. The following tables will be comparing the alternatives and where necessary explanation will be given as to why the differences actually occur.



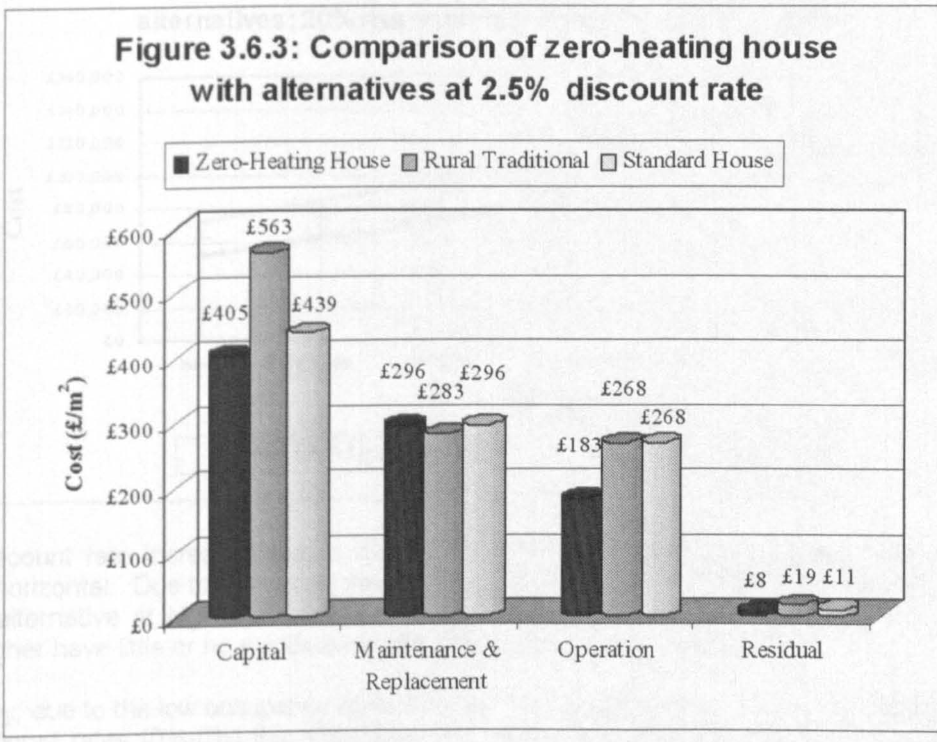
At 0.8% discount rate where the effect of occupancy costs are more substantial there are immediate contrasts between the alternatives. The difference between the standard and '*zero heating*' house initially are only minimal as are the costs for maintenance & replacement and residual costs. A significant saving is, however, made by the operation costs. Due to the introduction of super-insulation, triple glazing and heat recovery the '*zero heating*' family home makes a 32% saving over the entire life of the building. In *figure 3.6.1* the comparison between the '*zero heating*' and the rural traditional homes is also represented. In this comparison there are more significant gains to be obtained providing savings of 28%, 32% and 58% created on the capital, operation and residual costs. This is due to the rural traditional dwelling restricting liveable loft space with an uneconomic footprint and interior space. This makes the rural traditional more expensive initially but also makes occupancy costs more expensive through greater volume, greater heat loss and no additional fabric insulation. However the '*zero heating*' family home makes a small loss on the maintenance and replacement costs of around 2% as it is quite expensive for the '*zero heating*' family home to maintain the high quality, which enables the house to have low heat loss.

The *figure 3.6.2* (following page) shows the predicted life of each alternative and shows clearly that the '*zero heating*' family home is the better (economically) alternative of the three. Comparing the '*zero heating*' family home with the standard house where the initial costs are almost identical it is shown that at the discount rate of between 0.8%, the difference between the two alternatives will gradually grow greater.

Figure 3.6.2: Comparison of alternatives at 0.8%, 2.5%, 5.1% and 10% discount rates



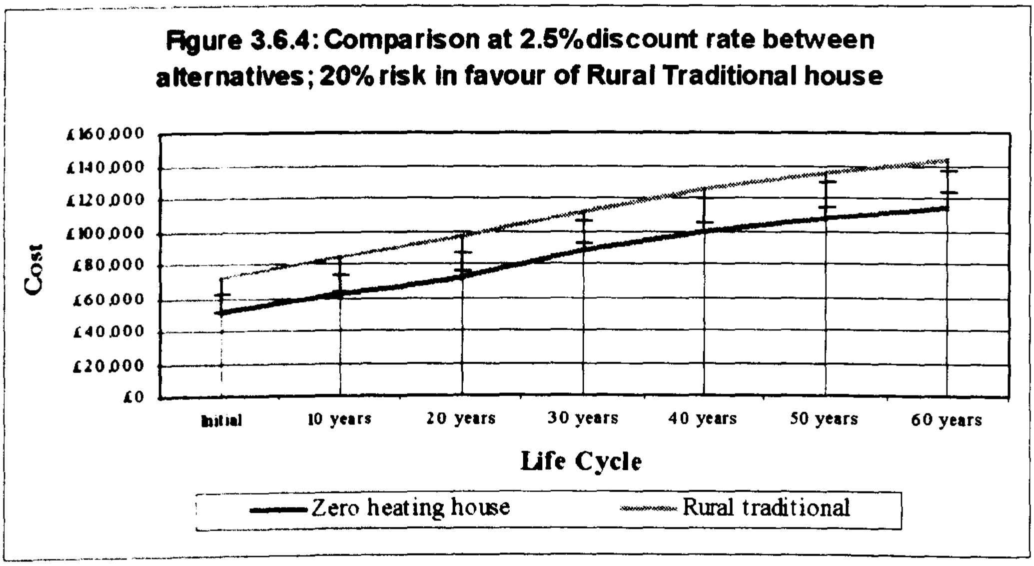
It is unlikely, as has been stated previously, that the discount rate will reach as low as 0.8% discount rate and that a more suitable discount rate will likely be between 2.5% and 5% and may reach as high as 10%. The following figure outlines the differences that are created at 2.5% discount rate. Take particular note of the 'height' of the occupancy costs compared to *figure 3.6.1*, remembering that lower discount rates favour occupancy costs.



At 2.5% discount rate, where occupancy costs are not so pronounced as at 0.8% discount rate there are still significant savings to be made. Comparing the 'zero heating' family home with the standard house there is a 32% saving on operation costs still created while comparison with the rural traditional shows the same as at 0.8% discount rate. This therefore represents no change in terms of percentage saving. *Figure 3.6.2*, page 24, shows this saving over the entire life cycle of the building. In this figure it is graphically demonstrated that the difference between the alternatives grow increasingly larger at this discount rate.

As has been suggested previously, the percentage savings will generally remain the same whatever the discount rate, any fluctuations may be attributed to 'rounding up'. However, *figure 3.6.2* show that there may be a difference in the *growth* over the life of the building, due to the change in the value at varying discount rates, as stated in *Section 2.4* under discount rates. *Figures 3.6.2* also show the difference at higher discount rates of 5.1% and 10%. At these discount rates it may be seen that the growth will be dramatically reduced however the '*zero heating*' alternative will remain the preferred option.

These graphs also highlight the importance of the capital costs of the '*zero heating*' family home, as they are so significant that even given a **twenty** percent risk factor this alternative will still prove to be cost effective (*see figure 3.6.4*).



As the discount rate increases, up to 10% in *figure 3.6.2*, the life cycle curve gradually becomes horizontal. Due to the capital saving, the '*zero heating*' family home will remain the preferred alternative at higher discount rates also. Occupancy costs at discount rates at 10% or higher have little or no significance after the first twenty to thirty years.

In summary, due to the low occupancy costs that the '*zero heating*' family home may achieve at low discount rates (0%-5%) this alternative will be the preferred alternative. Due to the initial capital saving of around 28%, at higher discount rates (greater than 5% up to 30% in this study) the '*zero heating*' family home will remain the preferred alternative. To further confirm this and to assess the risk associated with the costs *3.7 Risk and Uncertainty* will calculate the variables.

3.7 <u>Risk and Uncertainty</u>

The following table outlines the calculation used to assess the risk associated with the life cycle analysis of the three alternatives. It must be noted, however, that the risk will be small due to the accurate capital costs that were obtained which gave such a high saving of 28%. That is to say, if the risk of the occupancy costs were high it would be unlikely to effect the final outcome.

The confidence index is used to assess the '*confidence*' of the alternatives (high versus low). As stated previously if the risk is high there will only be a negligible effect to the conclusion. The outcome of this table may either be high, medium or low confidence. The discount rate that was chosen for this calculation was 4.3% as this represented a compromise between the higher discount rates, which favour low capital costs, and the lower discount rates, which favour the occupancy costs.

Table 3.7.1	LIFE CYCLE COST ANALYSIS (Present Worth Method)										
CONFIDENCE INDEX (CI) COMPUTATION											
Project/Location:	'*Zero heating*' family home, Peterculter										
Description:-											
Risk -	10%										
Project Life Cycle :-	60 years	ESTIMATES RANGES			DIFFERENCES IN EST.					PRESENT WORTH	
Discount Rate :-	4.30%						DELTA				
Present Time :-	Design	LOW	HIGH	BEST	LOW SIDE	HIGH SIDE	%	ok	BEST	DELTA	DELTA^2
***Zero heating*' house**											
Initial Cost (£/m^2)		£364.74	£445.80	£405.27	£40.53	£40.53	0%	ok	£405.27	£40.53	1,642
Maintenance & Operation Costs (£/m^2)		£284.06	£347.18	£315.62	£31.56	£31.56	0%	ok	£315.62	£31.56	996
Residual Cost (£/m^2)		£2.39	£2.92	£2.65	£0.27	£0.27	0%	ok	£2.65	£0.27	0
Totals									**£723.54**		
Rural Traditional											
Initial Cost (£/m^2)		£506.96	£619.62	£563.29	£56.33	£56.33	0%	ok	£563.29	£56.33	3,173
Maintenance & Operation Costs (£/m^2)		£326.44	£398.98	£362.71	£36.27	£36.27	0%	ok	£362.71	£36.27	1,316
Residual Cost (£/m^2)		£5.88	£7.18	£6.53	£0.65	£0.65	0%	ok	£6.53	£0.65	0
Totals									**£932.53**		
	Note = If high and low 90% estimates > 25%, then							*Difference*	**£208.99**	*Sum*	**7,128**
	use sensitivity analysis									*(Sum)^1/2*	**84.4253**

Confidence Index = $\frac{\text{PW(High) - PW(Low)}}{\text{(PW Diff(High)^2 + PWDiff(Low)^2)^1/2}}$ = $\frac{208.99}{84.43}$ = **2.475442 (HIGH)**

Confidence Ass.
Low: CI < 0.14
Med: 0.15<CI<0.24
High: CI>0.24

As given in the bottom box of this calculation the confidence index is high, which is more a reflection in the difference between the capital costs than the occupancy costs for the reason stated previously and a result of 2.48 is considerable.

Table 3.7.2 shows the confidence between the '*zero heating*' family home and the standard house. In this case the capital cost is almost identical therefore it is more a straightforward analysis of the occupancy costs. Once again the confidence for this comparison is high (1.14) and therefore the risk, though greater, is once again minimal.

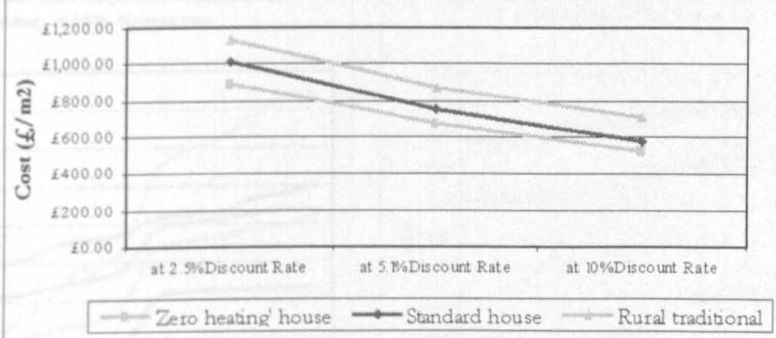
Table 3.7.2	LIFE CYCLE COST ANALYSIS (Present Worth Method)										
CONFIDENCE INDEX (CI) COMPUTATION											
Project/Location:	'*Zero heating*' family home, Peterculter										
Description:-											
Risk -	10%										
Project Life Cycle :-	60 years	ESTIMATES RANGES			DIFFERENCES IN EST.					PRESENT WORTH	
Discount Rate :-	4.30%						DELTA				
Present Time :-	Design	LOW	HIGH	BEST	LOW SIDE	HIGH SIDE	%	ok	BEST	DELTA	DELTA^2
***Zero heating*' house**											
Initial Cost (£/m^2)		£364.74	£445.80	£405.27	£40.53	£40.53	0%	ok	£405.27	£40.53	1,642
Maintenance & Operation Costs (£/m^2)		£284.06	£347.18	£315.62	£31.56	£31.56	0%	ok	£315.62	£31.56	996
Residual Cost (£/m^2)		£2.39	£2.92	£2.65	£0.27	£0.27	0%	ok	£2.65	£0.27	0
Totals									**£723.54**		
Standard house											
Initial Cost (£/m^2)		£395.05	£482.83	£438.94	£43.89	£43.89	0%	ok	£438.94	£43.89	1,927
Maintenance & Operation Costs (£/m^2)		£331.89	£405.65	£368.77	£36.88	£36.88	0%	ok	£368.77	£36.88	1,360
Residual Cost (£/m^2)		£3.53	£4.31	£3.92	£0.39	£0.39	0%	ok	£3.92	£0.39	0
Totals									**£811.63**		
	Note = If high and low 90% estimates > 25%, then							*Difference*	**£88.09**	*Sum*	**5,925**
	use sensitivity analysis									*(Sum)^1/2*	**76.9767**

Confidence Index = $\frac{\text{PW(High) - PW(Low)}}{\text{(PW Diff(High)^2 + PWDiff(Low)^2)^1/2}}$ = $\frac{88.09}{76.98}$ = **1.144372 (HIGH)**

Confidence Ass.
Low: CI < 0.14
Med: 0.15<CI<0.24
High: CI>0.24

To confirm the opinion created from the inclusion of the *tables 3.7.1* and *3.7.2*, which gave very good results for the confidence of each alternative, the following figure graphically represents the total life cycle costs at 2.5%, 5.1% and 10% discount rates. It shows that at each of these discount rates the '*zero heating*' house is the preferred alternative and due to its economical footprint and interior space the standard house takes second place.

Figure 3.7: Sensitivity Analysis at different discount rates



In summary, the confidence index in *table 3.7.1* and *3.7.2* together with the sensitivity analysis performed the results of which are given in *figure 3.7*, suggest there is little risk associated with the costs produced. From this and section *3.5 Computation of Life Cycle Costs*, it is assumed that the '*zero heating*' house is the preferred alternative. To assess the impact of the specification and energy saving the following parts of this section will discover the effects and payback achieved for the '*zero heating*' family home.

3.8 Lives of materials

Due to the flexibility of the software *Life-Cycle Cost Analysis Tool* used to produce the life cycle analysis, an analysis of the external cladding was conducted. This provided interesting insights as to the life cycle of many commonly specified materials for external wall cladding and roof cladding. The discount rates chosen to represent the different materials were 0.8%, 2.5% and 4.3% discount rates as these values were easily obtainable from the previously conducted life cycle analysis of the '*zero heating*' family home, the standard house and the rural traditional house. The life cycle analysis proved to be a useful addition to this study with interesting conclusions upon common building materials.

In the tables on the following page larch cladding is the better alternative through the entire 60 year life cycle of the building. This is primarily due because larch does not need staining or painting at regular intervals like the whitewood cladding. More common alternatives of block and brick have better occupancy / life costs than larch cladding, however their initial high cost prohibits these alternatives from being preferable economically. There is the case where given a longer life cycle the brick and block alternatives would be the preferable alternative, however this would be beyond 100 years.

At higher discount rates (greater than 4.3%) the larch cladding could be replaced four times (over 200 years) and probably more before economically it becomes less viable than the brick or block alternatives. Therefore it may be assumed there is an aesthetical advantage to using brick and block rather than an economic advantage. The coated metal alternative is an example only because it is dependent upon the type of coating this alternative has varying lives. In this case a life cycle of 30 years has been used (the average value from previously conducted LCCA's has been between 20-35 years).

Figure 3.8.1: Life cycle comparison of external wall claddings at 0.8% discount rate

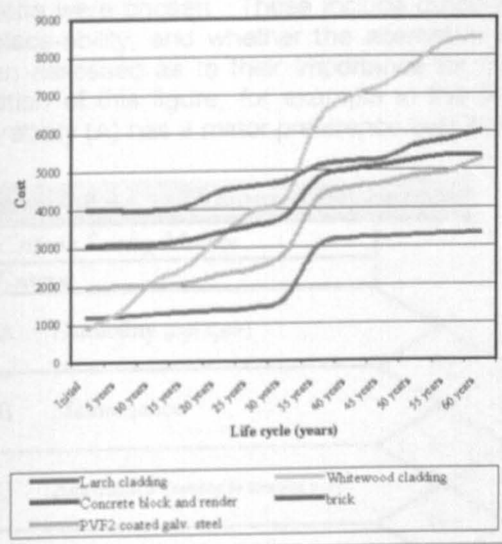
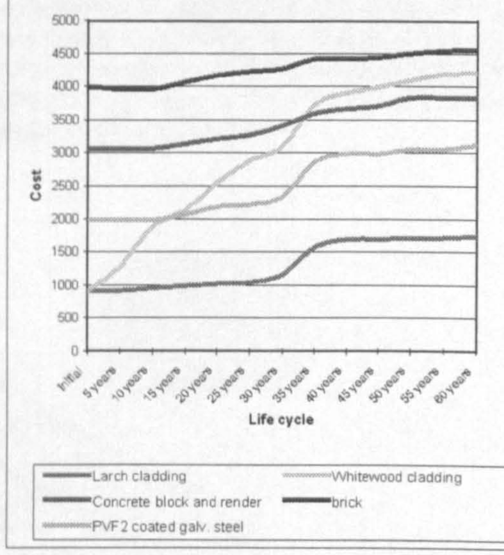
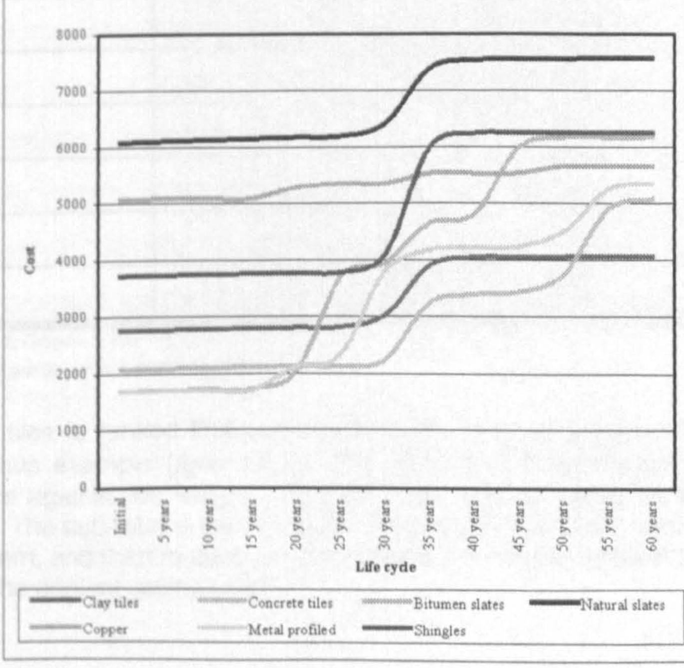


Figure 3.8.2: Life cycle comparison of external wall claddings at 4.3% discount rate



For roof cladding, the copper development association produced a life cycle cost analysis of different roof claddings, which proves interesting for the purposes of this study. *Figure 3.8.3* shows the life cycle of varying roof claddings over 60 years and demonstrates that for a small period of time clay rooftiles are the best alternative. In the original study conducted by the CDA the life cycle was conducted over 120 years and demonstrated that copper and stainless steel where the best options for roof cladding.

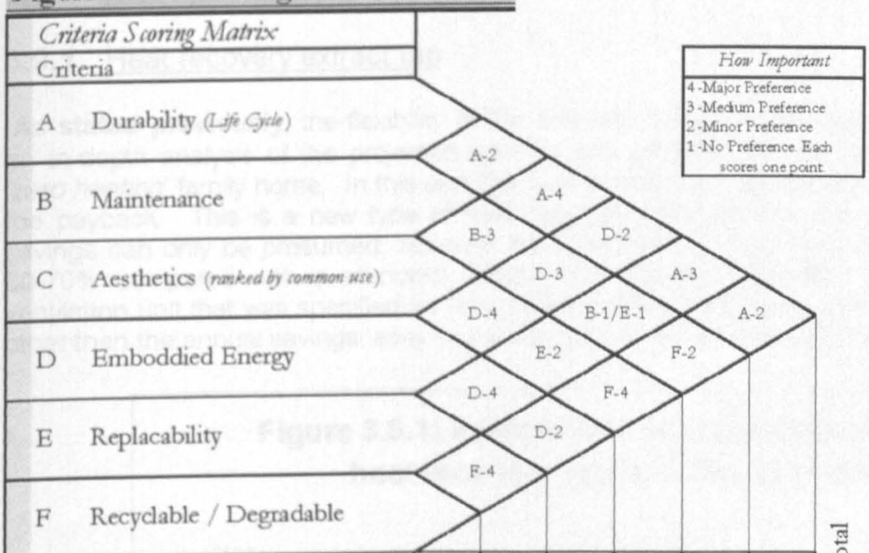
Figure 3.8.3: Life cycle comparison of roof cladding at 2.5% discount rate



From *figure 3.8.3* clay roof tiles are the best alternative between 55 and 65 years. This is due to the life cycle of clay roof tiles being 65 years enabling this alternative, for a brief period, being the best alternative. Clay roof tiles provide quite a low capital cost with average life span occupancy cost schedule. Therefore for the purposes of this study, which is intended to last 60 years, clay roof-tiles are the best alternative.

In addition to using *figure 3.8.3* as a material specification tool, *figure 3.8.4* gives a weighted evaluation for each alternative. As described in *Section 2.6.6*, a weighted evaluation can provide a basic mathematical assessment of different alternatives. In the case of roof cladding, in order to assess the environmental aspects of the roof cladding, seven different criteria were chosen. These include durability, maintenance, aesthetics, embodied energy, replace-ability, and whether the alternative is recyclable / degradable. These criteria are then assessed as to their importance for this type of cladding. This forms the triangular section of this figure, for example in the first box A is given a value of 2, which means Durability (A) has a minor preference over Maintenance (B) and so on.

Figure 3.8.4 Weighted Evaluation



Analysis Matrix	A	B	C	D	E	F	Sub-total	Unit cost multiplier	Lives (60 year life cycle)	Total	Ranking
Raw Score	10	3	15	0	4	11					
Alternatives — Weight of Imp (0-10)	7	3	10	1	4	8					
1	3*	3	3	2	3	3					
Clay tiles	21	9	30	2	12	24	98	1.00	1	98.0	1
2	4	3	4	1	3	3					
Concrete tiles	28	9	40	1	12	24	114	0.86	2	196	6
3	5	2	5	4	5	5					
Bitumen Slates	35	6	50	4	20	40	155	0.48	3	223	7
4	2	3	2	1	3	1					
Natural slates	14	9	20	1	12	8	64	2.29	1	147	3
5	1	4	5	3	1	1					
Copper	7	12	50	3	4	8	84	1.91	1	160	4
6	4	3	5	3	3	4					
Metal profiled	28	9	50	3	12	32	134	0.52	2	139	2
7	1	3	1	3	3	3					
Shingles	7	9	10	3	12	24	65	1.5	2	195	5**

* Excellent - 1; Very Good - 2; Good - 3; Fair - 4; Poor - 5

** *If locally sourced timber used with 60 year life cycle (i.e. Larch) ranking is 2*

From *figure 3.8.4* clay tiles is ranked first compared to the other alternatives for the same reasons as the previous example (*figure 3.8.3*). The calculation is achieved by multiplying values of performance against the weight of performance and subsequently adding these values up (sub-total). The sub-total is then multiplied by the unit cost price, with the clay tiles being the base cost item, and then multiply by the number of times the material is replaced in 60 years (1 signifies the original capital cost).

Although this method is subjective, relying on information that is not always accurate and in some cases, such as aesthetics, variable. However it is a useful tool to assess, prior to specification, as to the performance of various materials compared to others and to express it in such a fashion that demonstrates which is best, which is second best and so on. From *figure 3.8.4*, it is easy to select, for instance if capital and replacement costs were not an issue, natural slates would be the ideal choice with shingles (preferably cedar, larch or other durable timber) a close second best. On the basis of ignoring costs, clay tiles is only the fourth best. However when initial and replacement costs are included then clay tiles is the preferred choice.

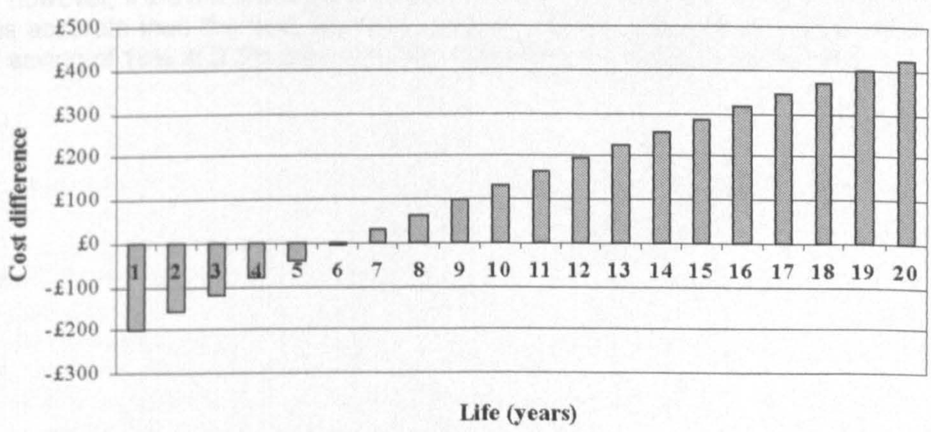
Note that maintenance costs in this figure are not included but are weighted as part of the criteria scoring matrix where the alternative with the lowest maintenance costs, for this example copper, is weighted the highest 1, with subsequent alternatives being valued from this derived result.

3.9 Energy life cycle

3.9.1 Heat recovery extract fan

As stated previously, the flexibility of the software *Life-Cycle Cost Analysis Tool* has enabled an in-depth analysis of the projected savings and payback that can be accrued from the '*zero heating*' family home. In this part the heat recovery extract fan will be analysed to find the payback. This is a new type of heat recovery unit therefore the electrical costs and savings can only be presumed, however the manufacturer states that an annual saving of 60-70% compared with a standard extract fan may be achieved. The heat recovery ventilation unit that was specified for this project was the Vent-Axia HR150 that also boasts, other than the annual savings, easy installation, quiet performance and longer life.

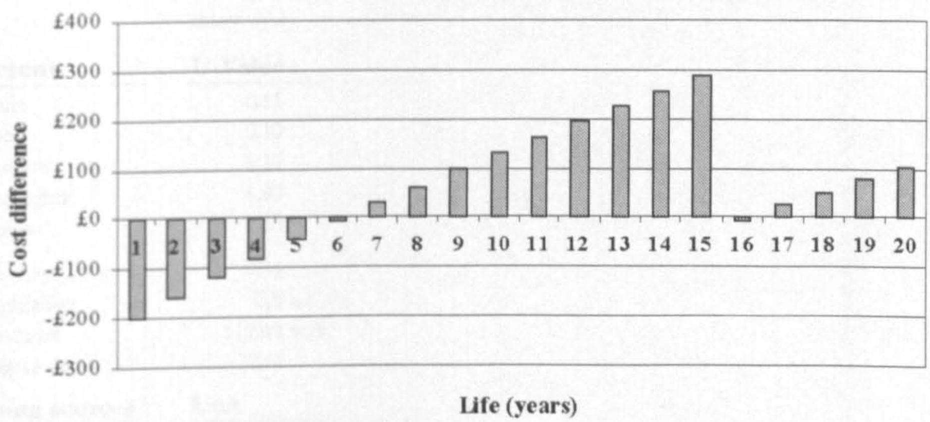
Figure 3.9.1: Payback period for extract fan with heat recovery at 2.5% discount rate



BMI sources stated that the life of an extract fan with heat recovery unit would be around 15 years and a standard extract fan was slightly longer 20 years. The manufacture stated that a longer life is expected from the new heat recovery unit therefore, the Vent-Axia HR150 will have the same life span of 20 years. The purpose of the following graph is to ascertain where the payback is achieved (at 2.5% discount rate), the payback being represented by the crossing over of each alternative (the x-axis represents zero capital gain or loss). Analysis shows that the payback will be achieved within the first twenty years, and the following graph is a representation of this summation.

From *figure 3.9.1* (previous page) we may ascertain that payback is achieved between 6 and 7 years, most likely in the early part of the sixth year. However, to conclude that the Vent-Axia HR150 is cost effective despite the 15 year life cycle as stated from BMI sources, the following graphs is represented. To clarify, the life cycle of the extract fan with heat recovery has been reduced from 20 years (from manufacturers sources) to 15 years (public and BMI sources). The standard extract fan's 20 year life cycle remains the same.

Figure 3.9.2: Payback period for extract fan with heat recovery at 2.5% discount rate



Due to the life cycle of the heat recovery unit, in this example, being 15 years the heat recovery unit is briefly not economic before achieving payback within the 16 year. It should also be noted that since the heat recovery unit requires more regular removal, disposal and subsequent installation additional costs for such work will created through builders work and overheads.

In summary, however, if the manufacturer's statement of 60-70% annual saving of the bill for these units is accurate then the heat recovery units will have a payback of 7 years and a total life cost saving of 18% at 2.5% discount rate compared to a standard extract fan.

3.9.2 Space heating and Water costs

ENERGY EFFICIENCY

Building Research Establishment S.A.P. (Standard Assessment Procedure)

House:-	Zero Heating House
Option No:-	1
SAP Rating:-	116
Description:-	Assumes 0.5 ac/h, superinsulation, triple glazed windows, gas fired heating and hot water without solar panel, mech. vent with heat recovery

Element	U-Value
Walls	0.11
Roof	0.10
Windows	1.10
Rooflights	1.80
Doors	1.10
Window/floor	18%
Ventilation	0.5 a.c./hr
Heat loss	119.65 w/k
Degree days	719

Heating sources	Unit
Useful Gains	1008 W (Solar + Casual)
Heating system	2170 kWh
Water heating	6552 kWh
diff from Option 2	11513 kWh
Boiler efficiency	80%

Gas heating	Cost (£/p.a.)
Space heating	£43.40
Water heating	£131.04 *(incl. pumps/fan/standing charge)*

CO_2 emissions:- **1.394** tonnes per year

Other than the original capital cost saving the main aim of the '*zero heating*' family home was to reduce operation costs. As stated previously this has been achieved but the difference between the alternatives is to be taken a step further. The tool used to produce the costs was adapted from the SAP software created by the BRE. *Table 3.4* shows the conclusions from the software and the following descriptive outline of each option. To allow for a fair comparison between each alternative, they were paired. That is to say the standard house / rural traditional has a gas fired central heating system, then this is paired with a '*zero heating*' house with a gas fired system, likewise with a wood stove. In terms of simplicity, for this part only, the standard house and the rural traditional house are the same alternative in favour of the standard house.

ENERGY EFFICIENCY

Building Research Establishment S.A.P. (Standard Assessment Procedure)

House:-	Standard house
Option No:-	2
SAP Rating:-	72
Description:-	Assumes 1.5 ac/h, B'Regs u-values, double glazed windows, gas fired heating and hot water, no solar panel, mech. vent without heat recovery

Element	**U-Value**
Walls	0.45
Roof	0.25
Windows	3.30
Rooflights	3.30
Doors	3.30
Window/floor	18%
Ventilation	1.5 a.c./hr
Heat loss	332.96 w/k
Degree days	1630

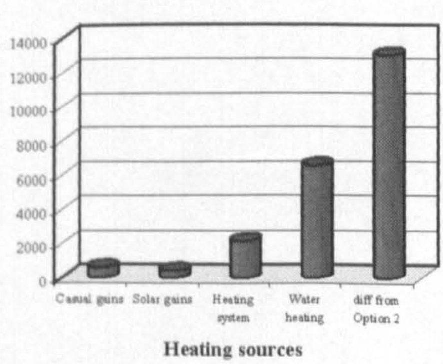
Heating sources	**Unit**
Useful Gains	1530 W (Solar + Casual)
Heating system	13683 kWh
Water heating	6552 kWh
Boiler efficiency	80%

Gas heating	**Cost (£/p.a.)**
Space heating	£273.66
Water heating	£131.04 *(incl. pumps/fan/standing charge)*

CO_2 emissions:-	**3.460** tonnes per year

Options one and two are for comparisons between gas fired central heating systems. They show, for option one, a remarkable reduction in CO_2 emissions compared to option two, a difference of 2.562 tonnes per year. The differences are graphically represented in the following table, bearing in mind this is a direct comparison between super-insulation, triple glazing and heat recovery air units. In *figure 3.9.1* and *3.9.2* solar gains are particularly low due to the triple glazed (Low-E) glazing.

Figure 3.9.3: Heating supply in kWh/p.a. to zero heat house



Option three and four highlight the difference between two wood stove alternatives. As an extra addition in the '*zero heating*' house a solar panel for the water heating is included, the payback for which is discussed later.

ENERGY EFFICIENCY

Building Research Establishment S.A.P. (Standard Assessment Procedure)

House:-	Zero Heating House
Option:-	3
SAP Rating:-	120
Description:-	Assumes 0.5 ac/h, superinsulation, triple glazed windows, wood stove heating, electric (off-peak) hot water with solar panel, mech. vent with heat recovery

Element	U-Value
Walls	0.11
Roof	0.10
Windows	1.10
Rooflights	1.80
Doors	1.10
Window/floor	18%
Ventilation	0.5 a.c./hr
Heat loss	119.65 w/k
Degree days	896

Heating sources	Unit
Useful Gains	1004 W (Solar + Casual)
Heating system	2774 kWh
Water heating	4921 kWh
diff from Option 4	18338 kWh
Boiler efficiency	60%

Wood heating	Cost (£/p.a.)
Space heating	£64.86
Water heating	£98.42 *(incl. pumps/fan/standing charge)*

CO_2 emissions:- **1.128** tonnes per year

In this comparison of option three (above) and option four (following page) there is a CO_2 emission reduction of 3.834 tonnes per year. This is a significant but in terms of wood stove fires it is negligible as any CO_2 emitted from wood burning is consumed by living trees. Additionally, the solar powered water heater gives a yearly saving of £36.46, for an initial capital cost of around £1,500.

ENERGY EFFICIENCY

Building Research Establishment S.A.P. (Standard Assessment Procedure)

House:-	Standard house
Option No:-	4
SAP Rating:-	61
Description:-	Assumes 1.5 ac/h, B'Regs u-values, double glazed windows, wood stove heating with electric (off-peak) hot water, no solar panel, mech. vent without heat recovery

Element	U-Value
Walls	0.45
Roof	0.25
Windows	3.30
Rooflights	3.30
Doors	3.30
Window/floor	18%
Ventilation	0.5 a.c./hr
Heat loss	332.96 w/k
Degree days	1861

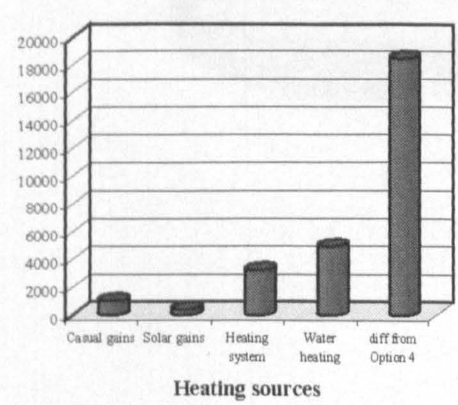
Heating sources	Unit
Useful Gains	1551 W (Solar + Casual)
Heating system	18743 kWh
Water heating	6744 kWh
Boiler efficiency	60%

Gas heating	Cost (£/p.a.)
Space heating	£374.85
Water heating	£134.88 *(incl. pumps/fan/standing charge)*

CO_2 emissions:- **3.125** tonnes per year

Figure 3.9.2 graphically represents the difference between options three and four with similar result to *figure 3.9.1*. In this case the total cost per annum is significantly different, aided by the solar panel. Therefore a further two option of the '*zero heating*' family home were added with the same heating systems but including or excluding the solar powered water heater.

Figure 3.9.4: Heating supply in kWh/p.a. to zero heat house



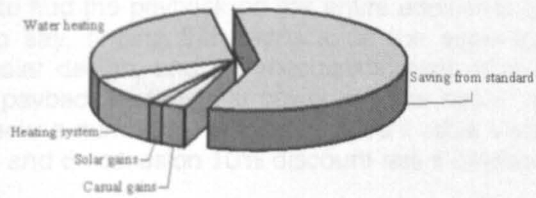


Figure 3.9.5: Heating gains (kWh per year) gas fired

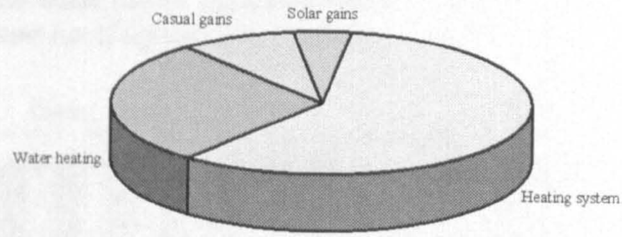


Figure 3.9.6: Heat gains (kWh per year) gas fired

Figures 3.9.3 and *3.9.4* (options one and two) show the heating costs and proportion of heat gains for the two alternatives. The upper one is the '*zero heating*' family home showing a significant saving by using super-insulation and preventing heat loss through triple glazing and mechanical heat recovery. In *figure 3.9.5,* which includes solar water heating, it may be seen that there is a significant reduction in the proportion of the water-heating segment compared to *figure 3.9.3.* The effects of super-insulation, passive solar design, triple glazing and heat recovery units on energy consumption may clearly be seen. The following figures highlight options three and four.

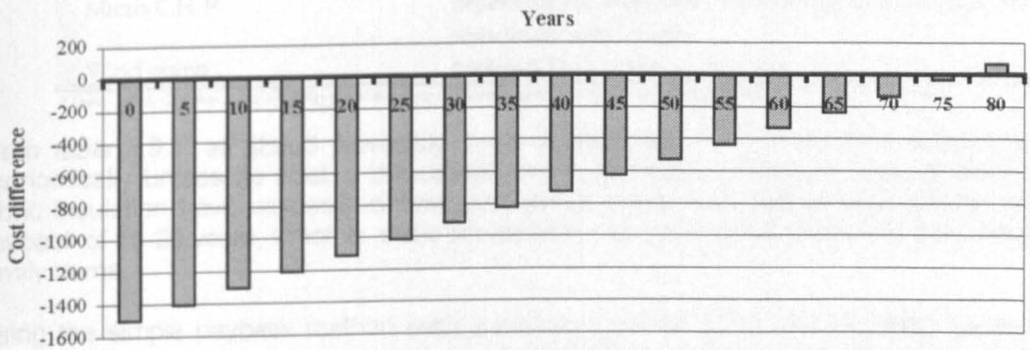
figure 3.9.7: Heat gains (kWh per year) gas fired

Figure 3.9.8: Heat gains (kWh per year) gas fired

3.9.3 Payback

Payback has previously been demonstrated for the mechanical heat recovery. Here it is intended to find the payback on the entire additional cost of the '*zero heating*' family home. That is to say, finding the payback on the super-insulation, triple glazing, solar power, passive solar design, and the mechanical heat recovery combined. It is also intended to show the payback on the solar powered water heater, if there is any to be made. In gaining the payback, a number of different discount rates were utilised which included 0.8%, 2.5% and 4.3% and on occasion 10% discount rate if deemed applicable.

Figure 3.9.9: Payback on the solar panel, based on both alternatives having Gas-fired back-up heating systems



From *table 3.9.2*, it may be seen that payback on a solar collector may be anywhere between 5 years and 100+ years. *Figure 3.9.9* shows the payback which the solar collector on the '*zero heating*' house will achieve, but this is a *minimum* value. A 4m^2 solar collector was specified to supplement the water heating to the '*zero heating*' family home with a capital cost of £1500. The cost per year was found by using the software, which calculated the water heating cost as well as the space heating costs. This allows a direct comparison of the yearly total water heating costs for the four options of a '*zero heating*' house.

From *figure 3.9.9* the payback is undistinguished, though comparing it with *table 3.9.1* it may be described as average. The payback is not very attractive to the private client, though this is a comparison between gas-fired back-up systems, where as in reality the comparison should be between electric (off-peak) heating and gas-fired heating. For this analysis, to be non-discriminatory, it was deemed that if we wanted a straight comparison of just the solar collector, then we would have to 'specify' the same back-up heating system. Analyses of gas-fired and electric (off-peak) systems were undertaken.

Alternating the discount rate shows that the solar collector used to supplement the water heating is not ideal at any discount rate. At 0.8% payback may be achieved between thirty and thirty-five years but this discount rate where energy is the cost criteria is unlikely, more realistic discount rates being between 5% and 8%. At these discount rates, including 10% discount rate, payback may not be achieved within the 60-year life cycle. It is anticipated that between 5% and 7% discount rates the solar panel becomes unfeasible. This was confirmed by the sensitivity analysis, where at 10% discount rate the alternative without a solar panel was the preferred option after 60 years, although at all discount rates. For option two, with gas fired heating, this alternative was only preferable at 0.8% discount rate.

Though the solar panel does not give ideal payback, and at higher discount rates, it is not the preferred alternative, it does give good yearly savings. Savings of 17% and 28% per year may be achieved on the gas-fired and electric (off-peak) alternatives, respectively. This would mean, that if capital costs were reduced, then solar collectors would become more feasible.

From the following table we can now contrast the result of the '*zero heating*' house with some expected payback rates.

Table 3.9.1

*Typical payback periods for energy saving measures compared to normal practice**

Energy saving measure	Simple payback period
Compact flourescent lighting	under 4 years
Condensing boilers	under 4 years
Increased fabric insulation	at best between 5.5-7 years
Solar collectors	water and space heating in between 4.7-112 years and 3-12 years respectively
Passive solar design	between 15.4-25 years
C.H.P. *(for more than one dwelling)*	under 2 years
Micro C.H.P.	depending on 'consistent' use possibly under 4 years, but realistically a lot longer
Wind pump	between 8-10 years

* *Source:- Jocklin, Christmah (1998/99) Energy efficient new housing in Scotland, dissertation for the school of the built environment, Napier University, Edinburgh*

From *table 3.9.1*, as stated previously, there is still room for improvement without being economically unfeasible (that is the capital cost is too high). Features such as additional fabric insulation have paybacks of less than seven years and passive solar design has a payback of 15-25 years, which is a little similar to the payback achieved by the '*zero heating*' family home.

Using the simple payback method (with a discount rate of 2.5%) the following figure was created to highlight the *minimum* period when payback is achieved. It is the minimum value here that is important as the simple payback method, though easy to use can suffer from some inaccuracies. To compliment this *figure 3.9.7* is also given to graphically demonstrate the payback.

Figure 3.9.10: Payback on all energy efficient design features in the 'zero-heating' family home

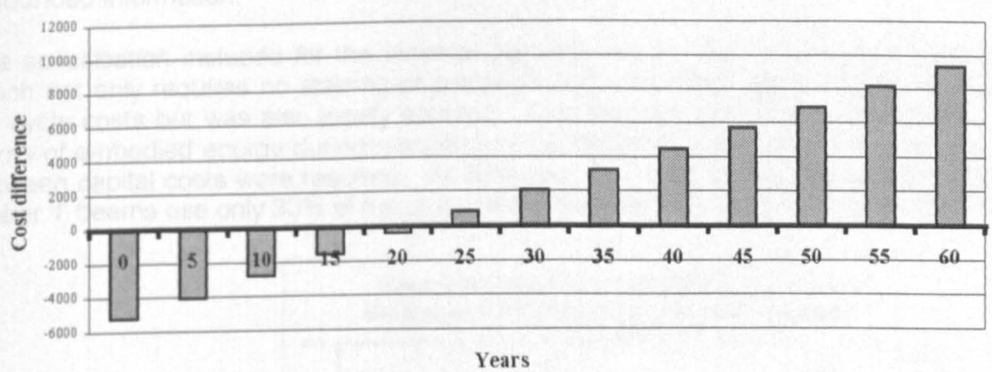


Figure 3.9.10 suggests relatively quick payback periods, but on reflection there is still some 'room for improvement' (see *table 3.9.1*). Six different scenarios were used to calculate the payback figures illustrated in the graph above, and this included alternating heating systems, life cycles, and changing various other variables. The quickest payback was 17 years and 8 months, and the longest payback was 27 years and 6 months. The average values of these paybacks were calculated, and it was these figures, which were used to construct this graph. To clarify, the average payback period for a variety of scenario would be 21 years and 2 months.

Varying the discount rate to ascertain the effect this would have on the payback period proved that, the lower the discount rate, the sooner the payback, and vice versa. At 0.8% the payback is only slighty earlier between 20 and 21 years but at 4.3% discount rate the paybacks are a little later. The payback at this discount rate for is 27 to an unsatisfactory 37. At 10% discount rate there is still a payback within the 60 years. In short, if the discount rate remains less than 10% there is a payback within 60 years, however the higher the discount rate, the later the payback. The most preferable discount rate would be one around 4% or less.

In summary, the overall payback for the '*zero heating*' family home is very good and is to be expected to be between twenty and thirty years. For the solar panel the payback is at best average and not very attractive to private clients (unless combined with space heating, (*see table 3.9.2*).

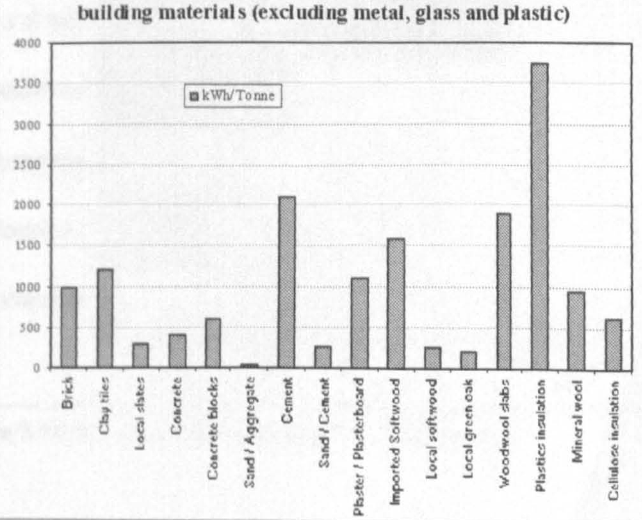
3.10 Emissions and Embodied Energy

Analysis of the embodied energy of the '*zero heating*' home was not part of the remit of this study, but embodied energy has a major part to play in the life cycle of an energy efficient building, such as the '*zero heating*' house. As a result, a small section is provided that highlights the benefits of the '*zero heating*' family home over conventional construction. Also note that a full-embodied energy analysis needs to be conducted before the specification of the building takes place, and is also a significant study area in itself. Therefore normally an embodied energy study would be conducted separately from a life cycle cost study and is essential before construction.

Over the life cycle of a building, the CO_2 emissions are also an important consideration for any design. The '*zero heating*' house exhausts considerably less CO_2 emissions every year than its nearest alternative through the use of 'no heating'. Despite some CO_2 emissions through a wood fire, it has been stated that any wood burned can be taken back by living trees. This achievement is not at the cost of additional CO_2 specification initially. All the building materials for the project were previously risk assessed for their embodied energy during the building materials life, but admittedly this is an area the project was restricted to unfounded information.

The specification included for the external cladding coming from a renewal source (larch) which not only requires no staining or painting which can have high embodied energy and life cycle costs but was also locally sourced. Clay tiles are one of the least unpleasant in terms of embodied energy during manufacture, transport and life but in this case a balance between capital costs were required. As little glue was used as possible and the Masonite timber 'I' beams use only 30% of the glue and timber used in traditional timber techniques.

Figure 3.10.1: Embodied energy figures for common building materials (excluding metal, glass and plastic)



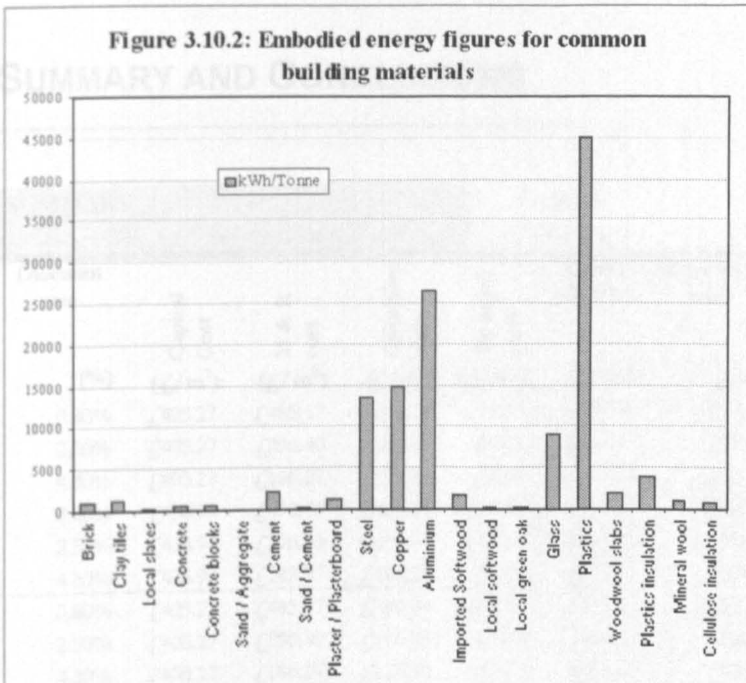


Figure 3.10.2: Embodied energy figures for common building materials

Figure 3.10.2 outlines the embodied energy of some common building materials. The elements relevant to the '*zero heating*' family home are Clay tiles, Imported and local softwood and cellulose insulation. *Figure 3.10.1* is a descriptive of the first excluding metal, glass and plastic as these provide the highest embodied energy values. When interpolating these figures care must be taken, as the standard unit is kWh/tonne and in this case, for example, for the same area of concrete blocks compared to softwood, concrete blocks have greater mass/m^2.

Embodied energy for building materials is found by calculating all the resources throughout the building materials life. This includes the provision of raw material, processing and manufacture into building products, provision of recycled materials, transport and packaging, construction and maintenance, and demolition. It may also include the calculation of heat loss, provision of fuel and electricity generation if the building material is used in such a manner (i.e. u-value, insulation). An example showing the embodied energy for Warmcel insulation, the type used for the '*zero-heat*' house, is shown below.

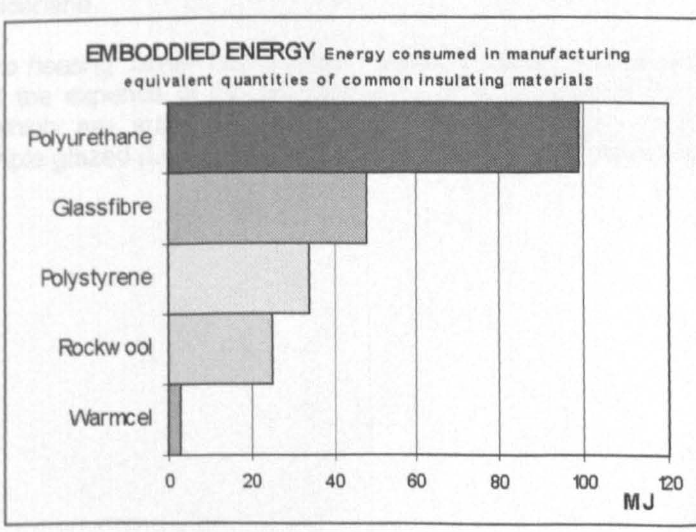


Figure 3.10.3: *Embodied energy of common building insulants*

4 : SUMMARY AND CONCLUSIONS

Table 4.1 **SUMMARY**

Payback on zero heating house at 0.8%, 2.5% and 4.3% discount rates

Life cycle:- 60 years

Floor area:- 127 m²

Cost item	Discount rate	Capital Cost	M & R cost	Operation costs	Residual costs	Total PVF**	Annualized costs	Saving
Unit	(%)	(£/m²)	(£/m²)	(£/m²)	(£/m²)	(£/m2)	(£/m²)	(£/m²)
Zero heating house	0.80%	£405.27	£485.17	£281.34	£21.23	£787.73	£25.11	£179.78
	2.50%	£405.27	£296.40	£182.59	£7.81	£486.80	£28.86	£122.46
	4.30%	£405.27	£186.27	£129.35	£2.65	£318.27	£33.82	£88.10
Standard house*	0.80%	£438.94	£493.72	£413.17	£26.94	£933.83	£28.90	n/a
	2.50%	£438.94	£296.35	£268.14	£11.09	£575.59	£32.82	n/a
	4.30%	£438.94	£183.57	£185.20	£3.92	£372.69	£37.93	n/a
Zero heating house	0.80%	£405.27	£485.17	£281.34	£21.23	£787.73	£25.11	£304.11
	2.50%	£405.27	£296.40	£182.59	£7.81	£486.80	£28.86	£241.00
	4.30%	£405.27	£186.27	£129.35	£2.65	£318.27	£33.82	£208.99
Rural traditional	0.80%	£563.29	£470.20	£413.17	£50.46	£933.82	£31.52	n/a
	2.50%	£563.29	£283.13	£268.14	£18.51	£569.78	£36.66	n/a
	4.30%	£563.29	£177.51	£185.20	£6.53	£369.24	£43.58	n/a

* *Same floor plan as zero heating house but using a standard timber frame and block structure.*

** *Costs excluding capital costs*

Table 4.1 gives a concise summary of the whole life costs for the three alternatives. It may be seen that savings of 10% can be made using super-insulation and other similar energy savings features when the capital cost is similar. It may also be seen that savings of 20% can be made compared to a basic dwelling (rural traditional alternative) which form the bulk of the north east of Scotland stock. Payback on the '*zero heating*' house may be obtained between 20 and 30 years well before the end of the building's life cycle of 60 years.

Through a rigorous risk assessment procedure which varied discount rates, life cycle, cost criteria, etc, it was discovered that considerable savings were achieved by the '*zero heating*' family home through initial capital gains and through occupancy gains. From a 0% discount rate up to 30% discount rate the '*zero heating*' family home proved to be economically viable under every variable scenario.

In summary, the '*zero heating*' family home makes some dramatic capital and occupancy cost gains but not at the expense of the environment. This is achieved by a number of different methods, which are super-insulation, passive solar design, mechanical heat recovery ventilation, triple glazed (Low-E) glazing and solar collector for water heating.

The full specification of the '*zero heating*' family home is as follows:

ENERGY EFFICIENCY

SAP Rating:- 120

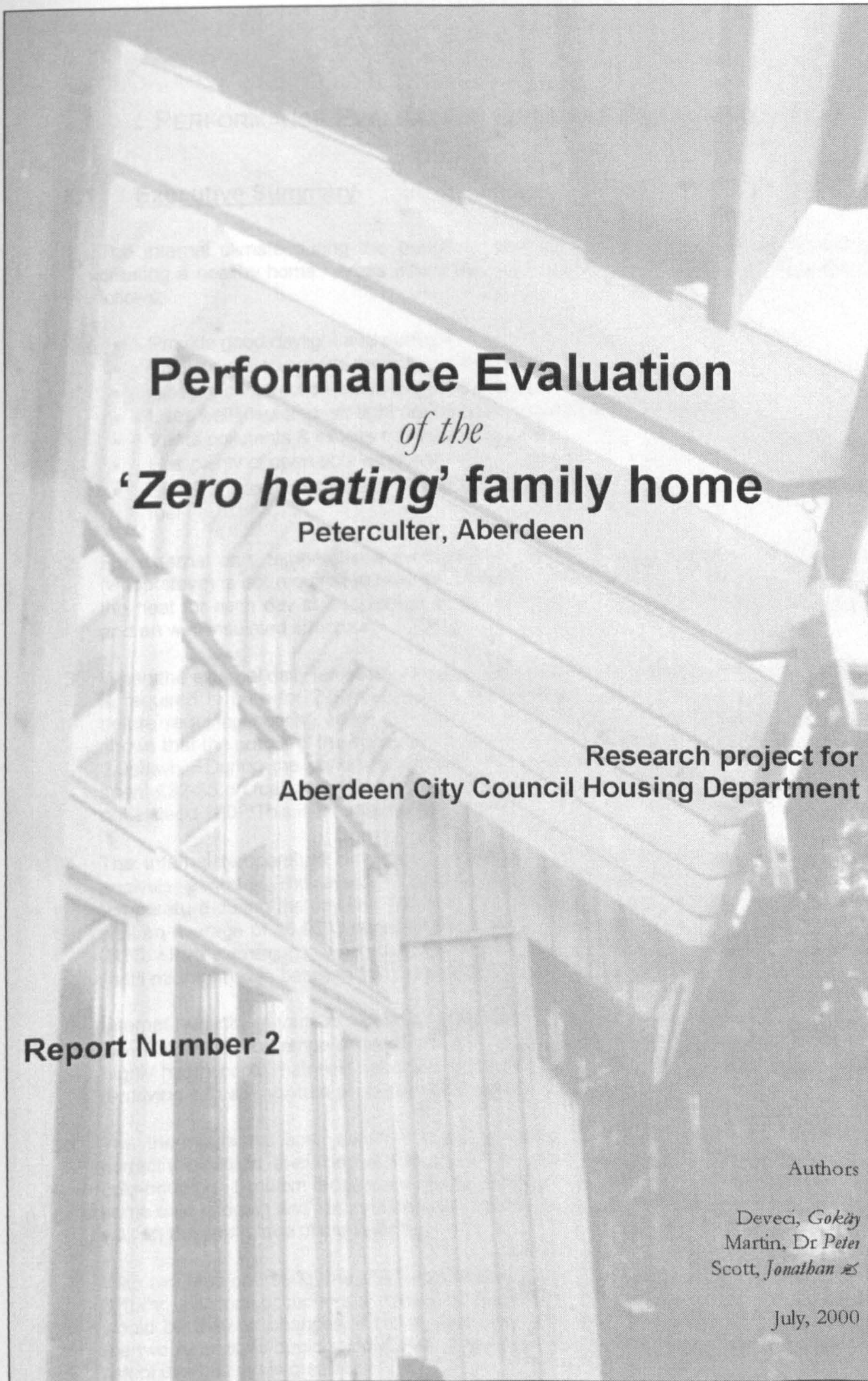
Description:- Assumes 0.5 ac/h, superinsulation, triple glazed windows, wood stove heating, electric (off-peak) hot water with solar panel, mech. vent with heat recovery

Element	U-Value	Element	U-Value
Walls	0.11	Windows	1.10
Roof	0.10	Rooflights	1.80
Floor	0.25	Doors	1.10
Ventilation	0.5 a.c./hr		
Heat loss	119.65 w/k		

Heating sources	Units	Heating sources	per year (kWh)
Useful Gains	1008 W	*Heating system*	2774
Boiler efficiency	60%	*Water heating*	4921

Wood heating	Cost (£/p.a.)
Space heating	**£64.86**
Water heating	**£98.42** *(incl pumps/fan/standing charge)*

CO_2 emissions:- **1.128** *tonnes per year*



Performance Evaluation
of the
'*Zero heating*' family home

Peterculter, Aberdeen

Research project for
Aberdeen City Council Housing Department

Report Number 2

Authors

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Martin, Dr *Peter*
Scott, *Jonathan* ✉

July, 2000

5 : Performance Evaluation: Summary and Introduction

5.1 Executive Summary

1. The internal climate during the period of analysis fulfils the entire requirements for creating a healthy home. Areas where the '*zero heating*' family home succeeds are as follows;

   - Provide good daylight and sunlight
   - Insulate well to provide thermal comfort
   - Air-tight construction which avoids draughts
   - Uses well-insulated, air-tight construction to avoid condensation
   - Vents pollutants & excess moisture at source
   - Has plenty of open-able windows
   - Easily understood secondary heating element, which is radiant, and uses bio-mass fuel

2. For external daily temperatures averaging above 5°C, the secondary heating element (wood stove) is not required to heat the building. The '*zero heating*' family home retains the heat for each day at an average of between 17-18°C through passive solar design and an well-insulated structure.

3. When the external daily temperature averages below 5°C the secondary heating element is required to burn for 2-3 hours which will then heat the house for around 24 hours before requiring heating again. Calculation of the heating in the '*zero-heating*' house shows that the output of the stove for the period of analysis is 40Kwh, providing a cost of 2.9p/kwh. During the period of analysis, the family in the '*zero-heating*' family home spent £32-35 on fuel, and if this is transposed for the entire year, the cost of fuel should not exceed £60. This is for space heating only.

4. The internal temperature did not fall below 14°C in any of the locations during the analysis period. The average temperature at night is 16.5°C and the average temperature during the day is 17.75°C during the day for the living room. The bedroom was an average of 16.95°C during the day, with a minimum of 14°C and a maximum of 21°C. In the evenings, when the building is fully occupied, the average temperature (until midnight) was between 18.5°C and 20°C.

5. Internal humidity in various locations all fall within the recommended comfort zones (*see table 1.3*). All rooms range between 41-49%. It appears that humidity is controlled by the highly hygroscopic materials specified (such as timber, cellulose insulation, etc) and by removing excess moisture at source (bathrooms, kitchen).

6. The thermographic scan confirms that the building has been well built in that it is correctly insulated, the windows and doors are air-tight and that there is little evidence of cold-bridging. Problem areas identified by the scan were service inlets where there was some cold bridging and the joint between the concrete floor and the glazed timber frame wall on the south face of the building.

7. With two fans operating, the mechanical ventilation could achieve an air change rate of 0.15/hr. For four occupants a minimum, baseline fresh air requirement for this house would be 0.49 air changes. If the system was balanced with natural ventilation forces, the two fans alone could supply 30% of the total, even in very still conditions when the risk of overheating is greatest.

8. The ventilation system is capable of recovering 70% of the exhaust air's heat content. In full operational mode each unit extracted 0.017 kg/s of stale air replacing it with 0.013 kg/s of fresh air.

5.2 Audit Introduction

This project aims to carry out a performance evaluation of a *'zero-heating'* house for the North-East of Scotland. The site for the *'zero-heating'* house is located at Peterculter (near Aberdeen) and this part of the project entails analysing the environmental aspects of the zero-heat design. The performance evaluation will include the following;

- External temperatures for the period January to April
- Internal dry and radiant temperatures for the period January to April
- Internal and external humidity for the period January to April
- External weather characteristics such as wind speed, wind direction, pressure, wind-chill, dew point, rainfall and conditions
- Survey using Thermography
- Analysis of the mechanical heat recovery units in a lab situation
- Air infiltration test

A Future report will document the post-occupancy evaluation exercise, which will further add to the performance evaluation and allow for accurate recommendations.

5.3 Aim of the Performance Evaluation

The aim of the *'zero-heating'* family home was to provide energy efficient and healthy home. Energy efficiency was achieved by adding fabric insulation, creating an air tight construction, triple glazing, passive solar design with thermal mass in the ground floor, re-arranging the internal layout and access, mechanical (heat recovery) ventilation and solar power water heating.

In order to test whether the building efficiency principles highlighted above were successful a performance evaluation has been carried out which will assess the different principles. In addition to this the performance evaluation will also detail whether the *'zero heating'* family home is a healthy home.

The following table outlines the typical performance values that are hoped to achieved with the *'zero heating'* family home.

Table 5.3: Recommended ranges

Place in Building	Activity	Comfort Temp.	Min	Max
Bedroom	Sleeping	18°C	15°C	21°C
Living	Sitting	20°C	17.5°C	22.5°C
	Light Work	16°C	13°C	19°C
	Heavy Work	10°C	6°C	14°C
Kitchen	Light Work	as above	-	-
	Heavy Work	as above	-	-
Bathroom	Bathing	27°C	26°C	28°C
Humidity	Relative humidity makes little difference to the comfort of a person not engaged in strenuous activity. It is important to keep humidity below **70%** (to prevent mould, etc) and above **40%** (otherwise too dry). An ideal range is between **40-50%**			

5.4 Performance Evaluation

A performance evaluation is a structured analysis of whole or part of a building(s). In this analysis the performance evaluation will provide vital information for the Robert Gordon University, G. Deveci Architects and Aberdeen City Housing Department.

Firstly it will aid the teams at RGU and G. Deveci Architects by allowing an insight into the actual performance of a building after construction, enabling future variants of this design to become superior.

Secondly it will aid the Aberdeen City Housing Department in proving that affordable housing can also be highly energy efficient, especially when combined with the previous report entitled, "*Life Cycle Cost Analysis for the project; A nominal 'zero heating' house for the north-east of Scotland*".

The main aim that this report hopes to achieve is to examine the '*zero-heating*' family home, in terms of it's energy efficiency, and demonstrate that the design features within the building comply with building regulations.

5.5 Methodology

5.5.1 Introduction

With the aid of the funding provided by the Aberdeen City Housing Department a four month data logging was considered the best alternative. The four months chosen were January to April, notoriously the coldest months of the year. Most of the equipment was readily available and given by the Robert Gordon University who provided the technical assistance. More specialised equipment for, for example, the air infiltration was provided by the Building Research Establishment. A flexible methodology was required so that as much information was gathered as possible without having to disturb the clients who had recently moved into the property. The performance evaluation strategy is outlined as follows.

5.5.2 Preliminaries

A meeting between the researchers at the Robert Gordon University was undertaken in order to establish a strategy for implementing the performance evaluation. In order to achieve the objectives established with the Aberdeen City Housing Department the following evaluation techniques were chosen.

- Record the external temperatures for the period January to April
- Record the internal dry and radiant temperatures for the period January to April
- Record the internal and external humidity for the period January to April
- Record other external weather characteristics such as wind speed, wind direction, pressure, wind-chill, dew point, rainfall and conditions
- Thermographic scan of building
- Testing of the mechanical heat recovery units in a lab situation
- Air infiltration test

Recording the internal dry, radiant temperatures and the humidity was seen as critically important. Also important was to run these tests under a series of different scenarios. For example, for one week the mechanical ventilation was switched off, the next it was switched on. The aim of recording is to find if there is a critical point where the secondary heating (the wood stove) became essential.

5.5.3 Survey

A survey was conducted in order to establish the best place for recording the internal dry and radiant temperatures and also the humidity. Regular visits to the site were undertaken to chronicle the external temperatures, humidity, wind speed, etc. The following areas were agreed upon:

- A downstairs bedroom
- One data-logging device on the left hand side of the balcony in the living space and one on the right hand side
- In the kitchen
- At a high level in the living space i.e. the ridge
- A bathroom

6 : Performance Evaluation of a *'Zero Heating'* House for the North-East of Scotland

6.1 Condensation risk

To assess the effect of the additional fabric insulation and the air-tightness of the construction, a condensation risk analysis was conducted. This assessed the wall and roof construction, calculating the interface temperature and the dew-point temperature through each structural element.

6.1.1 Wall construction

U-value, wall construction

Construction Type

Element:	Timber framed wall
Exposure:	Normal
Internal surface emissivity	High
External surface emissivity	High
Building Use	BS5250 dry/moist occupancy

Construction

	Thickness °C	Thermal Conductivity °C	Thermal resistance kPa	Vapour resistivity kPa	Vapour Resistance g/m^2
1 Outside Surface Resistance	-	-	0.060	-	-
2 Larch cladding	22.00	0.125	0.176	0.00	0.00
3 ventilated cavity	50.00	-	0.180	-	0.00
4 Panelvent	9.20	0.080	0.115	159.78	1.47
5 Warmcel 500 (45kg)	47.00	0.036	1.306	9.30	0.44
6 Warmcel 500 (45kg)	203.00	0.036	5.639	9.30	1.89
7 Warmcel 500 (45kg)	47.00	0.036	1.306	9.30	0.44
8 Plasterboard	12.50	0.167	0.075	45.00	0.56
9 Gyproc drywall sealer	-	-	-	-	15.00
10 Inside surface resistance	-	-	0.120	-	-

U-Value

0.11 W/m^{2}K

(Based on the proportional area calculation method for determining U-values of structures containing repeating thermal bridges)

Table 7.1.1a details the wall construction for the '*zero-heating*' family home. The following *table 7.1.1b* outlines the temperatures created in the construction within certain parameters.

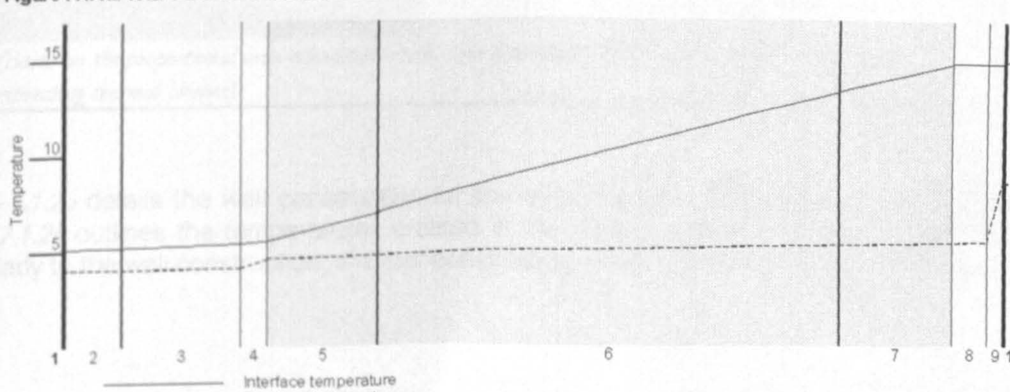
Table 7.1.1b: Winter Condensation Risk Analysis

Internal RH	65.00%
External RH	95.00%

	Interface Temp. °C	Dewpoint Temp. °C	Vapour resistance kPa	Saturated VP kPa	Winter Buildup g/m²	Annual Buildup g/m³	Conden-sation
1 Outside Surface Resistance	5.0	4.3	0.83	0.87	0.0	0.0	No
2 Larch cladding	5.1	4.3	0.83	0.88	0.0	0.0	No
3 ventilated cavity	5.3	4.3	0.83	0.89	0.0	0.0	No
4 Panelvent	5.5	4.3	0.83	0.90	0.0	0.0	No
5 Warmcel 500 (45kg)	5.6	4.6	0.85	0.91	0.0	0.0	No
6 Warmcel 500 (45kg)	7.0	4.7	0.86	1.00	0.0	0.0	No
7 Warmcel 500 (45kg)	13.3	5.2	0.88	1.53	0.0	0.0	No
8 Plasterboard	14.8	5.3	0.89	1.68	0.0	0.0	No
9 Gyproc drywall sealer	14.9	5.4	0.90	1.69	0.0	0.0	No
10 Inside surface resistance	14.9	8.5	1.11	1.69	0.0	0.0	No
	15.0	8.5	1.11	1.70	0.0	0.0	No

From *table 7.1.1b* the analysis concludes that there is no condensation risk for this wall construction. *Figure 7.1.1a* portrays the wall construction graphically, detailing the interface and dew-point temperatures likely to occur.

Figure 7.1.1a: Wall construction demonstration



6.1.2 Roof construction

U-value, roof construction

Construction Type

Element:	Warm pitched roof
Exposure:	Normal
Internal surface emissivity	High
External surface emissivity	High
Building Use	BS5250 dry/moist occupancy

Construction

		Thickness	Thermal Conductivity	Thermal resistance	Vapour resistivity	Vapour Resistance
		°C	°C	kPa	kPa	g/m^2
1	Outside Surface Resistance	-	-	0.040	-	-
2	Tiling	18.00	0.833	0.022	0.00	0.00
3	ventilated cavity	50.00	-	0.180	-	0.00
4	Tyvek HD plus	-	-	-	-	0.20
5	Panelvent	9.20	0.080	0.115	159.78	1.47
6	Warmcel 500 (45kg)	400.00	0.036	11.111	9.30	3.72
7	BSK 410 - Building paper	-	-	-		42.00
8	Softwood dry	18.00	0.125	0.144	100.00	1.80
9	Varnish	-	-	-	-	10.00
10	Inside surface resistance	-	-	0.100	-	-

U-Value

0.10 W/m^{2}K

(Based on the proportional area calculation method for determining U-values of structures containing repeating thermal bridges)

Table 7.1.2a details the wall construction for the '*zero-heating*' family home. The following *table 7.1.2b* outlines the temperatures created in the construction within certain parameters. Similarly to the wall construction, the roof construction does not have a risk of condensation.

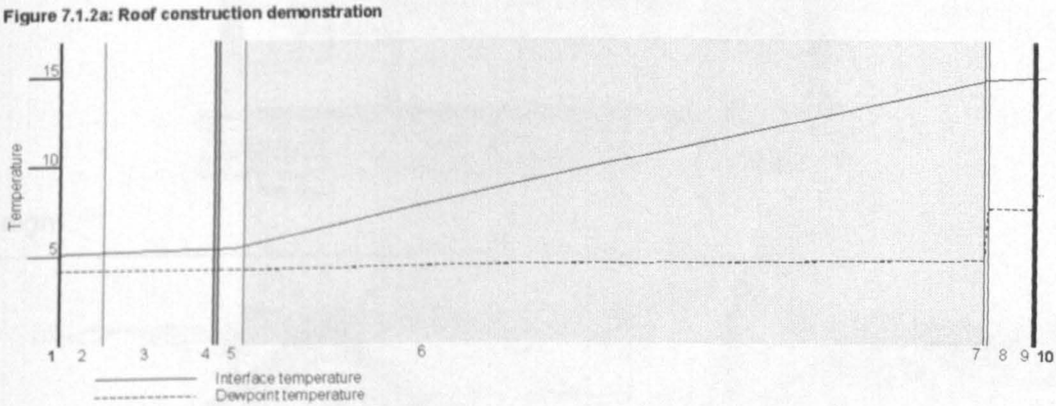
Table 7.1.2b: Winter Condensation Risk Analysis

Internal RH 65.00%
External RH 95.00%

		Interface Temp. °C	Dewpoint Temp. °C	Vapour resistance kPa	Saturated VP kPa	Winter Buildup g/m^2	Annual Buildup g/m^3	Conden-sation
1	Outside Surface Resistance	5.0	4.3	0.83	0.87	0.0	0.0	No
2	Tiling	5.0	4.3	0.83	0.87	0.0	0.0	No
3	ventilated cavity	5.1	4.3	0.83	0.88	0.0	0.0	No
4	Tyvek HD plus	5.2	4.3	0.83	0.88	0.0	0.0	No
5	Panelvent	5.2	4.3	0.83	0.88	0.0	0.0	No
6	Warmcel 500 (45kg)	5.3	4.4	0.84	0.89	0.0	0.0	No
7	BSK 410 - Building paper	14.8	4.7	0.85	1.68	0.0	0.0	No
8	Softwood dry	14.8	7.7	1.05	1.68	0.0	0.0	No
9	Varnish	14.9	7.8	1.06	1.70	0.0	0.0	No
10	Inside surface resistance	14.9	8.5	1.11	1.70	0.0	0.0	No
		15.0	8.5	1.11	1.70	0.0	0.0	No

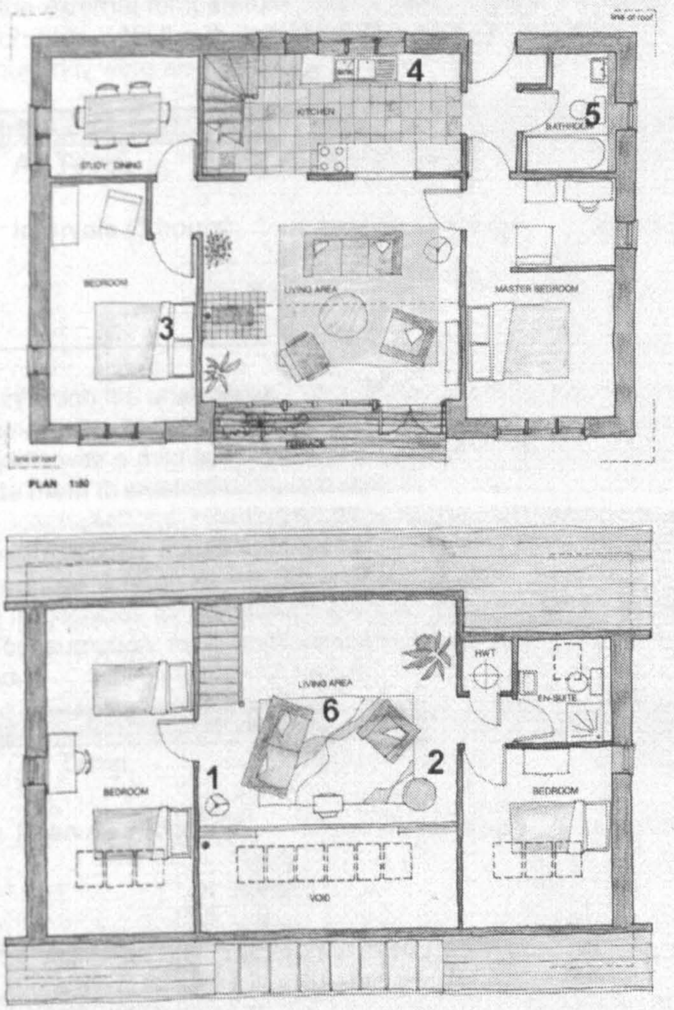
Figure 7.1.2 details the passage of interface and dew-point temperatures through the roof construction.

Figure 7.1.2a: Roof construction demonstration

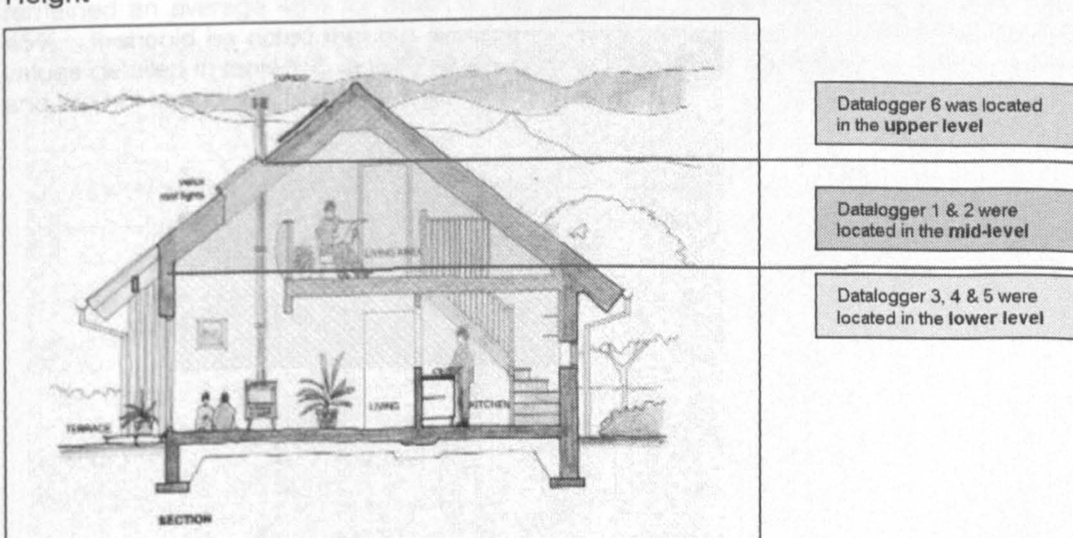


6.2 Location of Dataloggers

Position



Height



Key:-

1 - Located at first floor level on balcony above the stove
2 - Located on the opposite side of 1 at the same height
3 - Ground floor bedroom at head height
4 - Kitchen wall unit
5 - Bathroom at cill level
6 - High level above first floor

6.3 Balcony Temperature and Humidity (option 2: opposite side of option 1)

Table 7.1a details the external temperature and humidity figures for the site. These figures will be used to compare with the averages of the internal dataloggers. Daily figures for temperature and humidity were also taken

Table 7.3a: External data			(Phase 2)
Name	Air Temp.	Radiant Temp.	Humidity (%)
LogMode	Intervals (3 hours)	Intervals (3 hours)	Intervals (3 hours)
Min	-4	n/a	49
Average	**4.6**	**n/a**	**72.5**
Max	15	n/a	100

During the period in which the analysis was undertaken there was varying temperature levels from lows of -4 up to 15. At the beginning and end of this phase there were cold spells however in the middle was a mild spell which can be used to compare frequencies of use of the stove and relate them to external temperatures.

The following *table 7.1b* outlines the internal temperatures and humidity figures for the project. The site above the stove was chosen in order to exaggerate the temperature and humidity figures so that the frequencies for the stove could be obtained. This was required in order to calculate the fuel consumption, number of times the stove was used and the length of time the stove was used.

Table 7.3b: Logger placed above Stove			
Name	Air Temp.	Radiant Temp.	Humidity (%)
MeasType			
LogMode	Intervals (30mins)	Intervals (30mins)	Intervals (30mins)
Min	14.3	14.3	31.2
Average	**18.3**	**18.1**	**48.0**
Max	27.4	31.9	67.1

Comparing the figures from *table 7.1b* to *table 7.1a* it may be seen that the '*zero heating*' family home kept an average 18°C for external average of less than 5°C. Similarly the humidity remained an average 48% for much of the period of analysis, with the anticipated aim of 45%. It should be noted that the average for each measurement is comparable to those values detailed in table 1.3, in that the occupants of this room are neither too warm nor cold, and are not too dry suggesting a healthy environment.

Figure 7.3a: Comparison of Internal and External Temperatures

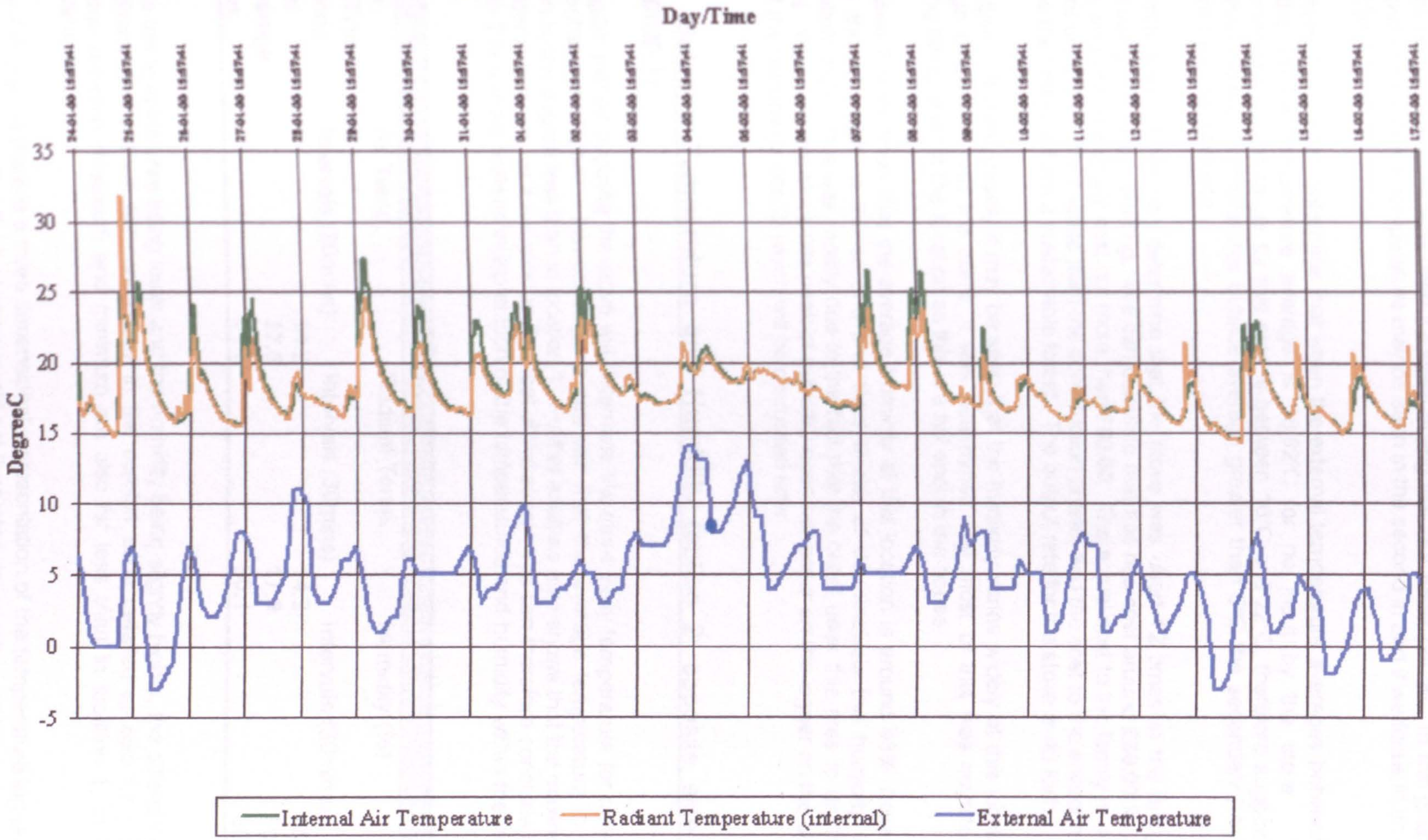


Figure 7.3a shows the daily cycle over the whole of the analysis period. From this it may be determined that the stove was used 12 times during this four week period. In this graph a mild spell in the external temperature may be seen in the second in and if we focus in on this week (*figure 7.3b*).

From *figure 7.3a* we can determine that when the external temperature averages between 6-7°C, the internal temperature average is 18.62°C for no input by the stove. The recommended comfort range for this area is between 16°C and 22°C, therefore suggesting that when external temperatures outside average greater than 5°C the secondary heating element becomes obsolete.

Also from *figure 7.3a* we can determine that the stove was used 12 times in the analysis period using 10kg each burning. We can calculate that this has cost around **£30.00** for this period, suggesting a yearly cost not more than **£60.00**. The actual cost to the family is nil as they are using the timber waste from the construction phase, and the cost to the environment is nil as the timber is from a sustainable forest. The output rate for the stove is 40 Kwh.

From *figure 7.3b* (next pages) it may be seen that the humidity varies widely at this location. Through discussion with the client, it was determined that most of this was caused by washing being dried at this location as this is a hot spot in the house.

From *table 7.3b* we know that the average humidity at this location is around 48%, however during the mild spell in the second and third weeks of the analysis the humidity was particularly high. This was mostly due to the fact that the client uses this area to dry their clothes. We know this since this peak of humidity does not occur on the logger on the other side of the balcony (option 2) which will be discussed later.

6.4 <u>Balcony Temperature and Humidity</u> <u>(option 2: opposite side of option 1)</u>

The logger placed opposite the stove will determine the more likely temperature for most of this central living space. Immediately we can see that the average temperature in this location is one degree less than in location 1. Further analysis also shows that the maximum is greater in location, as it will pick up the heat of the stove. We can therefore conclude that location 2 is a more realistic interpretation of the temperatures and humidity within the living space.

Table 7.4: Logger placed opposite to stove			
Name	Air Temp.	Radiant Temp.	Humidity (%)
MeasType			
LogMode	Intervals (30mins)	Intervals (30mins)	Intervals (30mins)
Min	14.2	14.2	40.6
Average	**17.8**	**17.9**	**50.0**
Max	24.2	30.1	60.3

Despite the temperatures being lower and the humidity being slightly higher, the difference is insignificant and still will fall contentedly in the comfort zone detailed in *table 6.1*. The variations between maximum and minimum are also far less than in location 1, in fact remarkably so.

In *figure 7.4c* (*page 58*) there is a three dimensional representation of the temperature logged at this location. It shows that the temperature did not fluctuate very much at all for vast periods of time, favouring to remain between the values of 15-20 which are well within the comfort zones.

Figure 7.3b: Internal Humidity for Option 1

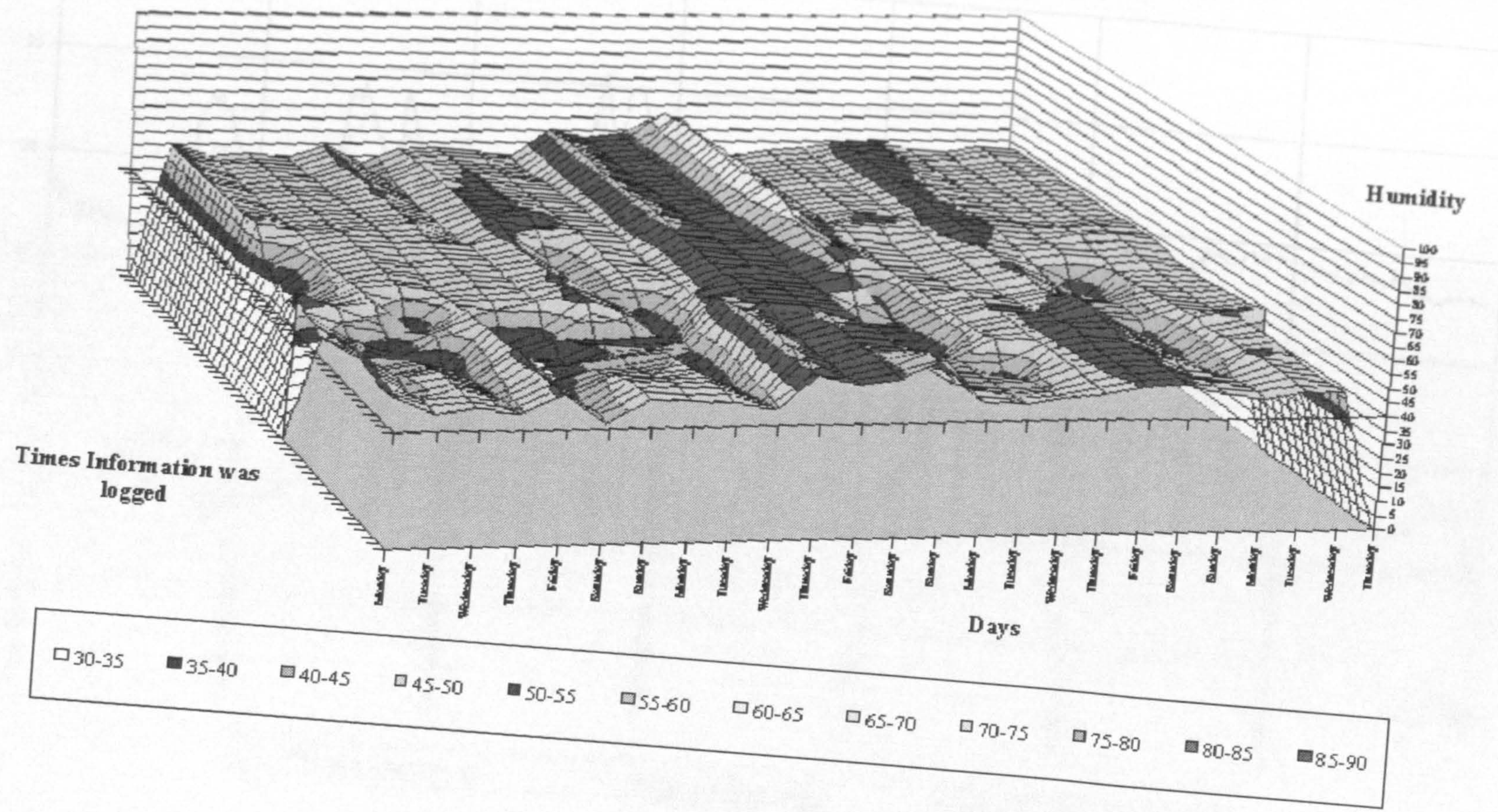


Figure 7.4a: Comparison of External and Internal Temperature in the Zero-Heat House (week 2)

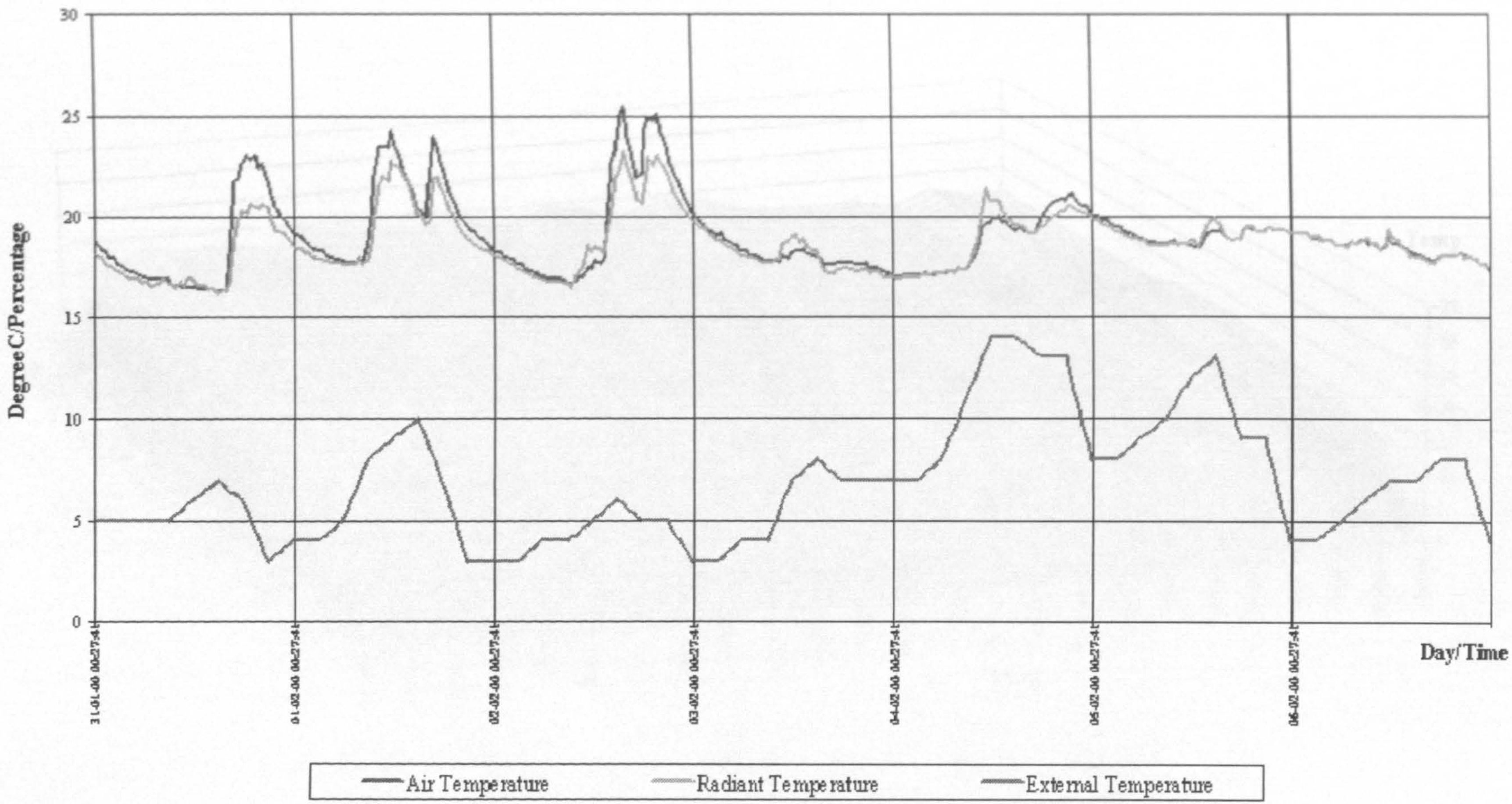
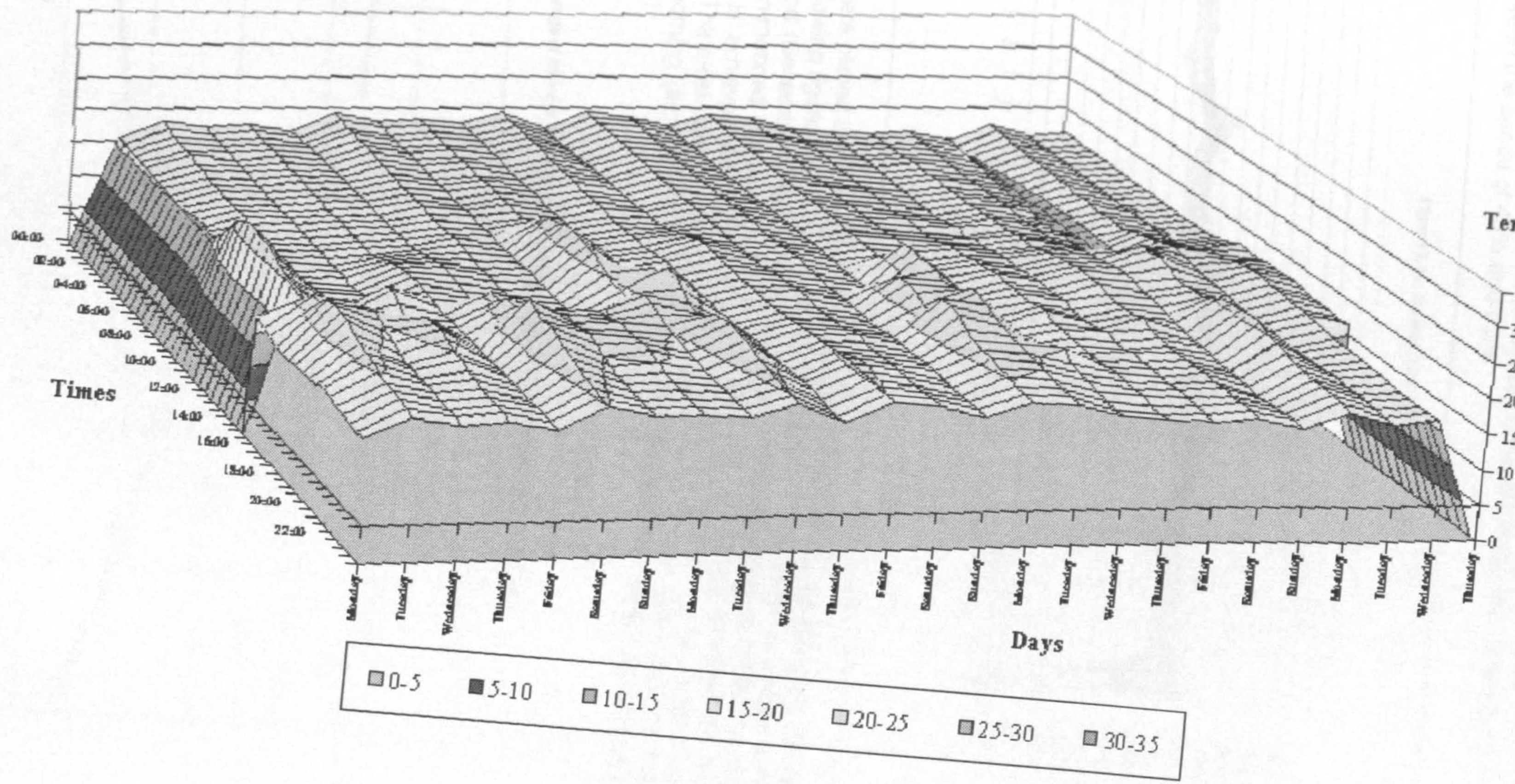
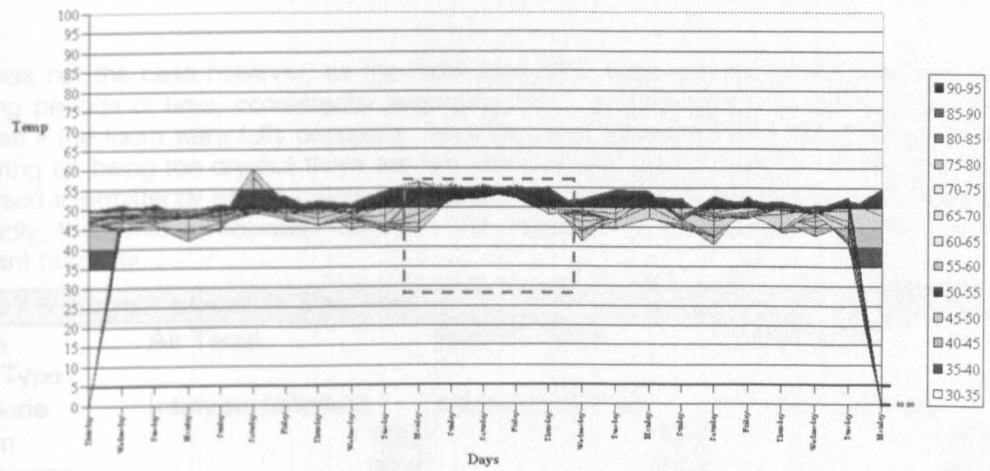


Figure 7.4b: Internal Temperature



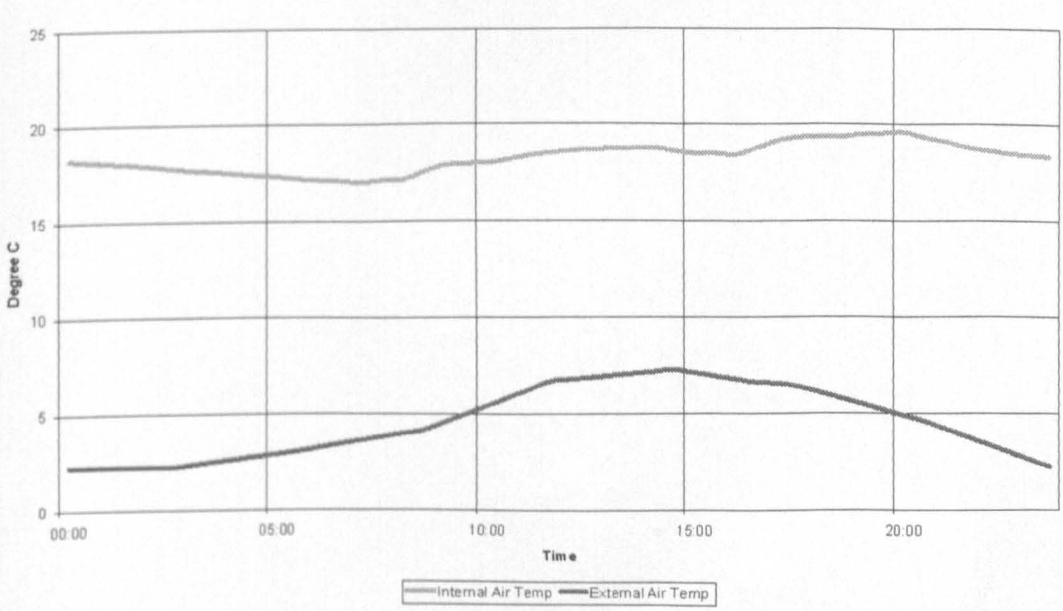
Similarly with the humidity the fluctuations are minimal, and as discussed previously, during the mild spell in weeks 2 and 3, the humidity does not peak at all but remains at almost a constant level at 55%. This is well within the comfort zones detailed in table 1.3. *Figure 7.4c* shows that the humidity remains at a remarkably constant level, the majority of the time remaining between the bands of 45% and 55%.

Figure 2.2b: Internal Humidity max and min



From the data loggers placed in the central living space a daily average temperature can be calculated. The following figure details the consistent temperature periods in this space over a three month period (December 1999 – February 2000). The temperature for this space falls within the recommended range of 15-21 without significant secondary heating from the wood stove. This is achieved with the external temperature regularly falling below five degree C at night. The most common period where the wood stove was used was the first period during the morning (around 7-8:30 o'clock) and in the evening (when the children returned from school).

Daily Average of Internal and External Air Temperature in the Main Living Space (2.2c)



6.5 Bedroom Temperature and Humidity (option 3)

Since the bedroom's only primary heating is the air-tightness and fabric insulation, the heat build-up and loss variations were expected to be minimal. It was also the case that the room chosen only had occupants for part of the analysis period per day. From discussions with the client, it was found that the room was used irregularly and generally in the early evening during the week and intermittently at weekends. Since this was the case it was expected that this room would get very cold (about 10°C) due to the lack of a heating source for the room.

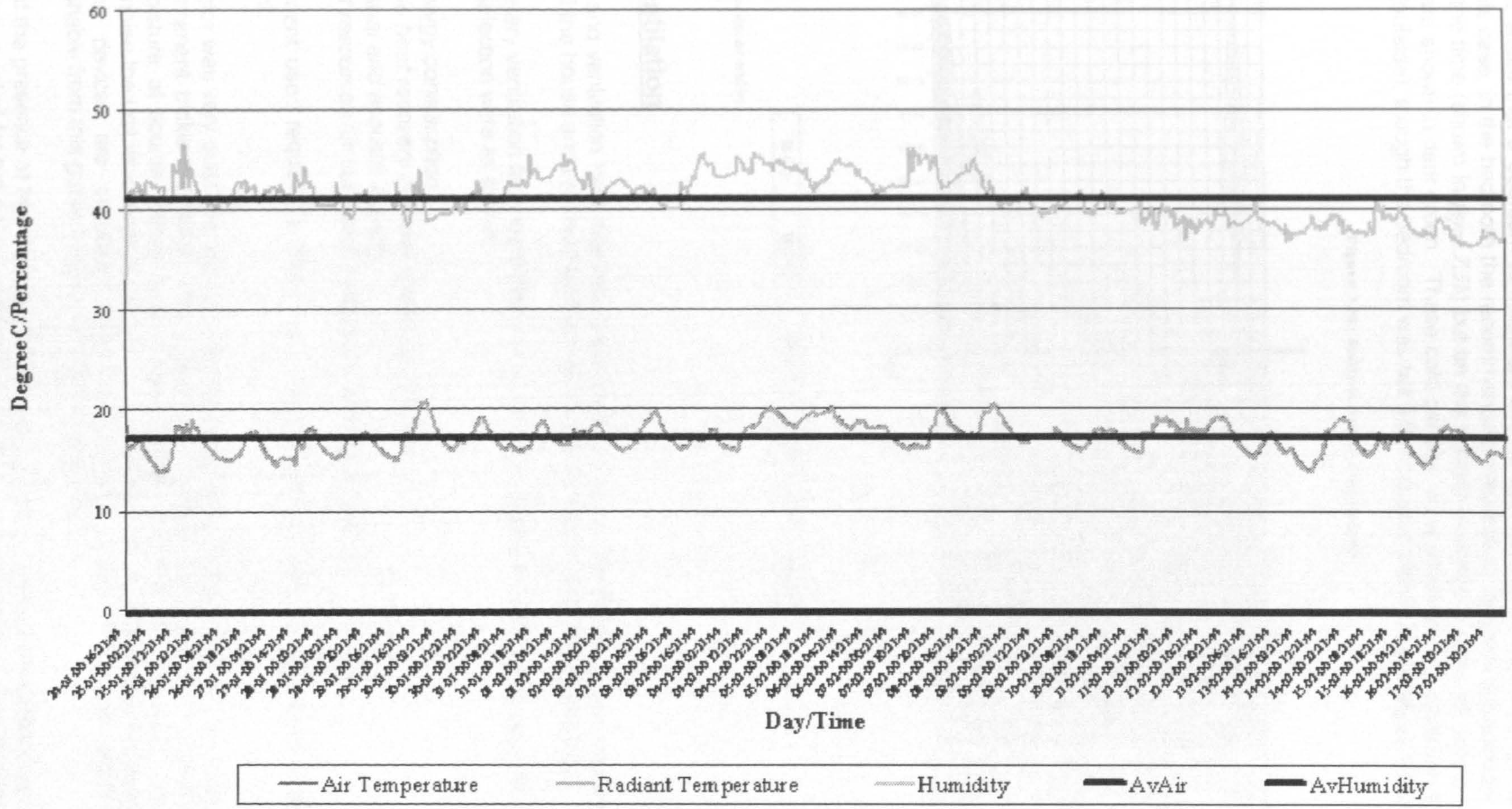
This was not the case however, as the room kept what heat was produced extremely well, for long periods of time, consistently averaging 17°C, a value which would rise by 1 or 2 degrees if the room were fully occupied. Note also that the rooms average 41% and this is bordering on being too dry but there are two reasons why this is unlikely. Firstly, the room was used intermittently and if it were used regularly the humidity would rise by at least 5%. Secondly, the variation between minimum and maximum is 2.24, suggesting that this is a constant humidity.

Table 7.5: Logger placed in Bedroom

Name	Air Temp.	Radiant Temp.	Humidity (%)
MeasType			
LogMode	Intervals (30mins)	Intervals (30mins)	Intervals (30mins)
Min	13.8	13.7	36.2
Average	**17.1**	**17.0**	**41.1**
Max	20.9	20.8	46.5

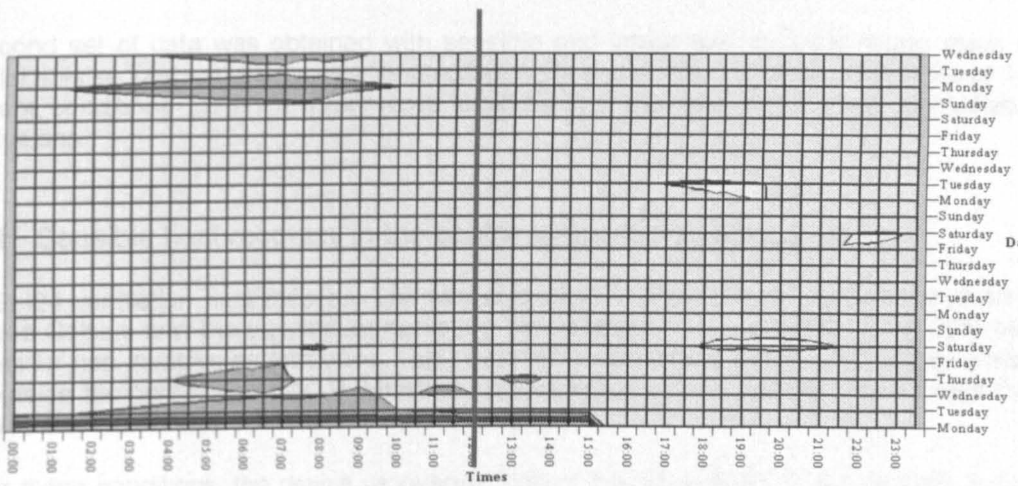
From *figure 7.5a* (*next page*) we can see the constant fluctuations in the bedroom clearly, the room did not respond to the external temperatures suggesting that the room will not react to the summer sun. That is to say the bedrooms should remain cool throughout the summer.

Figure 7.5a: Temperature and Humidity Analysis of the Bedroom



In *table 7.5* it states that a bedroom temperature should fall within the comfort range of 15-21°C. In this case, in the bedroom the recommended temperature range is obtained for the majority of the time (shown in *figure 7.5b*) but on the coldest mornings it does fall below 15°C and these are shown in dark green. These cold periods occur when the temperature drops below 1°C (outside), though the bedroom was not fully occupied during the analysis period.

Figure 7.5b: Daily internal temperature



Note: - The red line denotes midday

6.6 Ventilation

Ventilation and ventilation heat recovery were predicted to be key factors in the successful operation of the house and provision for this was an integral part of the design strategy.

Two proprietary ventilation fans were installed in the main areas of moisture generation. The criteria for selection were as follows:

- *Low energy consumption*
- *Tangible heat recovery in prime operating conditions*
- *Low visual and acoustic impact*
- *Modest resources for purchase, installation and maintenance*

The equipment used required a 24Volt DC supply making it safe to operate in a moist environment.

The DC motor was very quiet and efficient and operated at two speeds, a tick-over speed to ensure permanent trickle ventilation, and a high speed triggered by elevated humidity to remove moisture at source. Firmly located in a kitchen or bathroom to negate system generated noise the unit would operate below the background noise level and with negligible impact. The devices are consistent with contemporary extract fans and would be indistinguishable from this genre to all but the expert observer.

Detection of the presence of high humidity levels was effective, robust and reproducible and some capacity existed for tuning the operation of the device to the bespoke requirements of the household.

The fans operate with an ingenious impeller which provides exhaust from one half of the duct whilst simultaneously supplying fresh air via the other half. Heat exchange is across the surface dividing the duct and is of augmented area.

Tests were carried out under laboratory conditions to determine the heat exchange efficiency and the capacity of the unit for moisture removal with latent heat recovery.

A typical set of conditions was simulated to find the sensible heat recovery efficiency.

A second set of data was obtained with sensible and latent heat removal taking place in parallel; this second set of data was less reproducible and would require tighter control of the ambient conditions (in an environmental chamber for example) to produce publishable conclusions.

6.6.1 Sensible heat recovery in the centre range of operating conditions

The EH24 ventilation heat recovery unit was subjected to a temperature difference of 10.0 degrees Celsius and the equilibrium operating temperatures were recorded using infra red images for non invasive performance. The inside temperature was set to 20.0 degree whilst the outside temperature was 10.0. Moisture content either side of the device was kept the same to restrict the number of variables in the test.

Under these conditions, the device recovered 70% of the exhaust air's heat content. In full operational mode the unit extracted 0.017 kg/s of stale air replacing it with 0.013 kg/s of fresh air. This gives the dwelling a slight negative pressure; this is typical of a low impact extract system; for the purposes of data analysis air movement was taken as the mean of these two figures at 0.015 kg/s.

With two fans operating, the mechanical ventilation could achieve an air change rate of 0.15/hr. For four occupants a minimum, baseline fresh air requirement for this house would be 0.49 air changes. If the system was balanced with natural ventilation forces, the two fans alone could supply 30% of the total, even in very still conditions when the risk of overheating is greatest.

A figure of 71% of the exhaust heat equates to a performance under the above conditions where 100W of heat energy is recovered and 40W exhausted. This is akin to the introduction of one more person's body heat into the house.

When moisture levels were greater inside than out there was a greater amount of heat recovered but the size of this extra saving is not quoted, as the test data is unreliable.

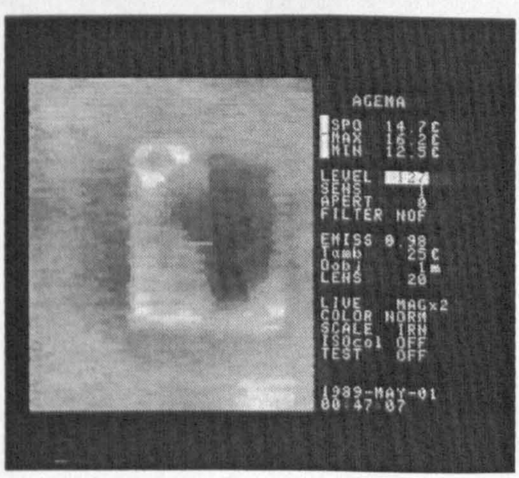


Figure 2.5.1: *Internal view of the vent blowing cold air into the room (blue).*

6.7 Thermographic Scanning

For establishing the performance of the construction of the '*zero-heat*' project it was critical to use thermographic scanning. Thermographic scanning will enable analysis of the construction of the building, the detailing therein and also information regarding the positive/negative effectiveness of the installed insulation. In this case thermographic scanning establishes the temperature of the internal and external surfaces. With the information this provides areas may be established which require improvement or slightly better detailing to provide more air-tight or better insulated joints and construction. With this in mind four areas were established for improvement, these are detailed as follows,

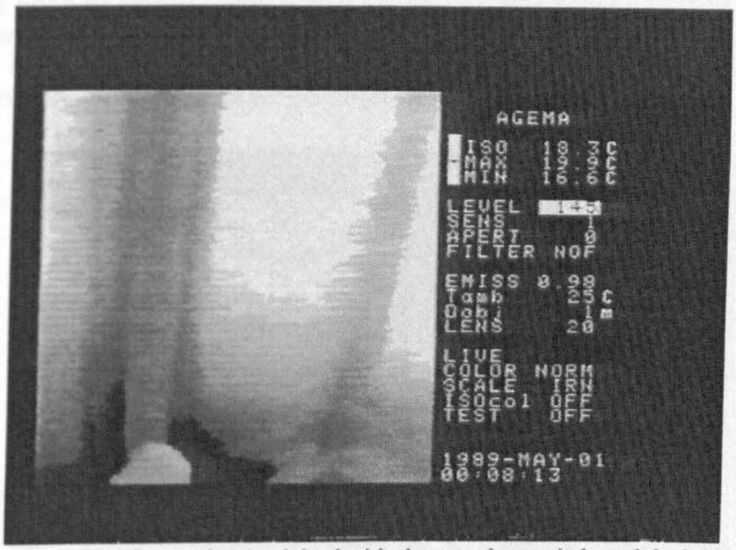


Figure 2.6b: *Internal view of the double door on the south face of the building*

The internal doors provide an area for improvement. Although the black and dark purple areas show the colder areas (the opposite of external pictures) the difference is not all that great. The white areas are influenced by the fact that the scanning was conducted during a sunny day, meaning that the colours exaggerate actual deficiencies. That aside, there is evidence that the bottom of the south facing glazing, and in particular the double door's, are not as air-tight as they could be. This was anticipated in the design stage and was given particular consideration, though further research and development is required. One solution could be the use of a more pliable sealant between the joint of concrete and timber.

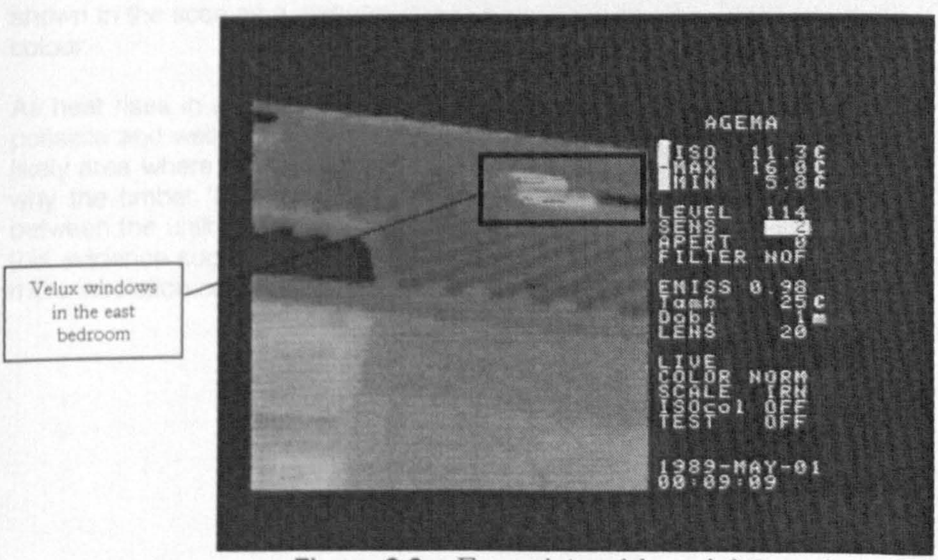


Figure 2.6c: *External view of the south-facing roof*

As this is an external view, the brighter colours denote the areas of heat loss. As stated previously, this was a particularly sunny day so the brighter colours illustrated in the bottom left of this picture are actually the reflections of the warmth of the sun. Clearly seen are the eaves of the building and underneath the light pink colour describes the 'shadow' of the eaves. The uniform orange colour is where the sun reflects from the cladding.

The interesting point of *figure 2.6c* is that one of three windows in the east bedroom is open for ventilation. This shows bright areas which depict heat loss and may be compared to window next to this (the dark blue patch). Although windows in this area are useful to reduce excess heat in the building, there is very little quality control and it there is no control over when the window should be open or closed. The '*zero-heat*' project was designed to be air-tight and therefore open windows such as the one shown would eliminate the air-tightness of the building and also allow pollutants into the building, which would effect asthmatics. In this case an extract fan with a temperature sensor may be more useful.

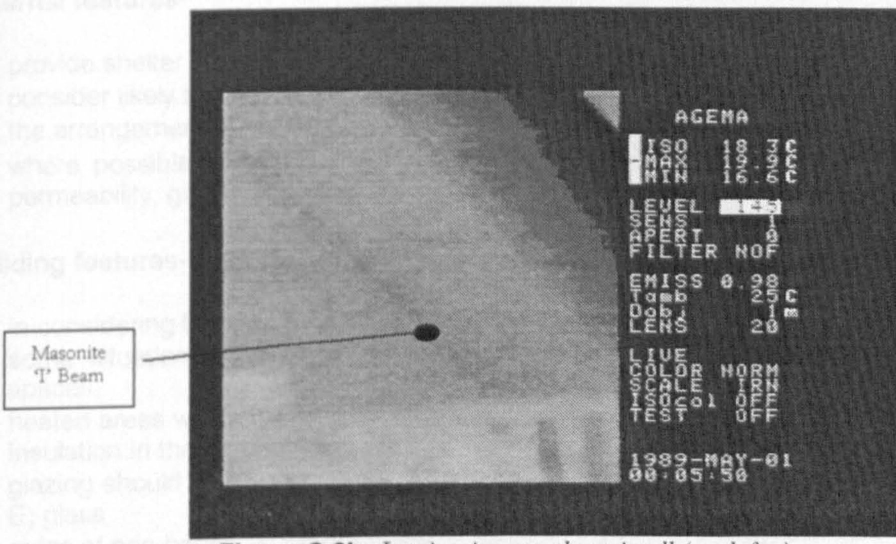


Figure 2.6b: *Interior view over the stairwell (north face)*

This is another interior scan, the darker colours depicting heat loss areas. As this is on the north face the colours are once again exaggerating the heat loss. Actual difference between the surface of the window and the interior faces is just over 3°C, an insignificant difference. What is interesting in this scan is that you can ascertain the line of the Masonite 'I' beams, shown in the scan as a diagonal line of dark orange/purple within the normal uniform orange colour.

As heat rises in any given building, it becomes critical that the roof must be as air-tight as possible and well-insulated as the heat will settle in the roof. As such, the roof is the most likely area where the thermographic scan will pick out any problem areas. This is probably why the timber 'I' beam may be seen in the roof compared to the wall. The difference between the uniform orange of the roof and the yellow of the wall also may be depicted. All this evidence suggests the insulation is working very well, although it may be the case that more insulation could be located in the roof.

7 : RECOMMENDATIONS

7.1 Recommendations

7.1.1 Identification of Problems

With the predicted growth in the house building sector over the next decade it is important that Designers exert maximum pressure to ensure that new homes realise the highest standards of energy efficient design. The following are recommendations for minimising the use of energy;

External features-

- provide shelter from prevailing winds in winter;
- consider likely air flow patterns when designing site layout and door positions;
- the arrangement of building groups should be designed to reduce wind pressures;
- where possible provide non-solid shelter-belts (trees, shrubs, fences) with about 40% permeability, give best protection.

Building features-

- in considering the plan a compact building shape reduces heat loss areas;
- some situations may allow for the protection afforded by earth-berming and buffer spaces;
- heated areas within the dwelling should be isolated from un-heated spaces by providing insulation in the partitions between such spaces;
- glazing should be the equivalent of triple-glazed through the use of low emisstivity (Low E) glass;
- areas of non-beneficial windows should be minimized;
- window frames should be selected which optimize energy efficiency;
- the detailing of joints in the building fabric can have a significant impact on energy efficiency;
- potential cold bridges should be eliminated;
- fabric insulation which is significantly better than the minimum required by regulation is strongly recommended;
- air tightness to about 4 air changes per hour at 50 Pascal's pressure in association with heat recovery ventilation is recommended;
- care should be taken in the design of which should be isolated from main occupied area; at the same time account should be taken of probable air flow patterns.

Passive solar heat gain

External considerations

- the main facade of a dwelling should face close to south (+/- 30° approximately);
- the spacing between dwellings should be sufficient to avoid over-shading;
- where possible contours should be exploited either to maximize solar gain or minimize adverse effects;
- areas with particular overheating risk should be considered when planning building layout and form;
- the provision of deciduous trees and shrubs will offer summer shade whilst allowing penetration by winter sun.

The built form

- the internal layout should place rooms on appropriate sides of the building either to benefit from solar heat gain or to avoid it where necessary;
- shading (externally if possible) should be installed for window posing overheating risk;
- the effect on heat gain of window frames and glazing bars can be significant;
- in the design and positioning of windows the effect of solar gain must be considered in conjunction with daylight design;
- as a general rule it is desirable to maximize south facing windows and minimize north facing windows;
- high thermal mass construction levels out the peaks and troughs of temperature;
- internal surfaces should maximise solar heat absorption, for example, heat absorbing floor areas should not be covered by carpet;
- conservatory or other buffer space can be used to preheat incoming ventilation air.

Systems

- environmental considerations should be a priority when making the choice of fuel;
- high efficiency heating systems should be installed, for example condensing boilers;
- space heating and hot water systems should be appropriately sized;
- in wet central heating systems thermostatic radiator valves are essential;
- controls, programmers, and thermostats should be appropriate to the task and correctly positioned and their operation easily understood by occupants;
- the heating system should be geared to the thermal response of the building fabric and occupancy pattern of the dwelling;
- hot water storage cisterns and the distribution system should be effectively insulated;
- where there is a high standard of air tightness a heat recovery ventilation system is essential;
- ventilation of utility areas, bathrooms and kitchens should be considered with respect to condensation;
- the venting of hot air in summer should be considered;
- the environmental benefits of conservatories are cancelled out if they are centrally heated.

7.1.2 Problems identified by performance evaluation:

Following problems need to be addressed in the '*zero-heating*' family home

- The recording of temperatures shows a temperature difference between the lower level and the ceiling level (higher temp.) in the double height space. Consideration should be given to the layout design of two-storey houses. ie. Locate bedrooms in downstairs and living room upstairs if possible and desirable. Change traditionally accepted layout principles. Or adapt a natural or environmentally friendly way of circulating warm air towards the lower, cooler levels in the house.

- Client's presumption of fresh air intake is only possible by opening the window and the mechanical heat recovering vent should be switched off. Client is aware of energy efficient principles and environmental sound designs but is unsure how to operate these agendas. A user manual is possibly the answer, provided to the client at the end of construction or alternatively or as an addition, a fuller involvement in the design process is required. Although the client is aware of the theory behind the design of the '*zero-heating*' house, putting the theory into practice has proved a problem despite their being **less** mechanical or electrical equipment than is typical in an ordinary house. It is hoped that more information will be provided during the post occupancy evaluation on this topic.

- Analysis with the thermographic camera depicts that there is some cold bridging at the service points and with the detail of the sole plate. As regards the service points, greater quality of workmanship could provide less cold bridging, but some cold bridging at this point is inevitable. The sole plate, around the glazing on the south facade requires more insulation or a raised step of concrete (for the glazed area only) as condensation becomes a risk at low temperatures. Careful insulation of the lintel above the glazed area on the south facade needs further consideration also, though this area still exceeds current standards.

- For future buildings, extensive use of hygroscopic materials, such as timber, will be utilised as this type of building material have controlled the humidity in the 'zero-heating' family home effectively. The client has also commented on the 'clean' air in the building despite the building being air-tight, possibly produced by the use of these materials.

- The mechanical ventilation with heat recovery has proved to confirm what the manufacturer claimed. Future houses are recommended this system, with the possible introduction of a ventilation system with heat recovery in the upper storey of the living space where datalogger 6 was located.

- The bathroom was unable to benefit from passive solar design as much as the rest of the building as it was separately insulated. Currently the client is using an electric towel dryer to heat the bathroom, but this is not environmentally friendly as we would wish. Recommendations for future variants should be to introduce a way that the bathroom could benefit from the passive solar design, either by way of natural ventilation (ducts) or through hot air systems.

Further recommendations will be given after the completion of the post occupancy evaluation, which is to be conducted.

Post Occupancy Evaluation

for the project

A nominal '*zero heating*' house for the north-east of Scotland

Report Number 3

Authors

Deveci, *Gokäy*
Buda, Dr *Gerry*
Scott, *Jonathan* ✍

September , 2000

8: INTRODUCTION AND EXECUTIVE SUMMARY

8.1 Executive Summary

1. The passive solar design with the triple glazing, super-insulation, glazing orientation, thermal mass, etc seems to work and the family are generally happy with this aspect of the house. The family noted a few problems however, these are noted below:-

    - The lower floors get too cold sometimes yet on the first floor it remains warm almost all the time, despite windows constantly remaining open.

    - The ground floor rooms, especially the kitchen and dining area, gets too dark in the evenings, the family feeling dedicated lighting sources and less of an overhang would benefit this situation.

    - In the winter the home provides excellent heating with only little input from the secondary-heating source. The family noted, however, that in summer the house remains "too cool" despite the outside temperature being high.

    - On the second floor, the depth, shape and size of the windows restrict all round views and also some members of the family find this type of window "not comfortable".

    - The family finds the thermal mass, which is bare concrete, unpleasant and intend to replace it with a timber floor. This would make the thermal mass ineffective though the family feels that the bare concrete is too cold and colourless.

2. The family is not sure about the open plan living area. Though they both feel that the area is ideal for entertaining and as a congregation space they still feel that a more semi-private or dedicated living room would be preferable, some members of the family feeling that the area could get too crowded and noisy.

3. There was not much dedicated storage space in the main bedroom or kitchen.

4. Many of the ground floor rooms come in for criticism but the upper floor spaces, which are the landing space and bedrooms, come in for just as many compliments. The upper storey, the family find, provides excellent accommodation for the purpose intended. In particular the lighting and ease of ventilation come in for particular praise.

8.2 Post Occupancy Evaluation

Although the '*zero-heating*' family home is a single, stand alone dwelling, the practice based research team at the Robert Gordon University is striving towards the mass housing market. We also believe that the 'zero-heating' home is not the final product, but a staging post for a variety of research opportunities and further development. We want to improve buildings through better understanding of their performance in use, and more care with their design and management With this in mind, a post occupancy evaluation was conducted after the family had lived in the dwelling for eight months through the coldest and hottest periods of the Scottish year

The idea of a POE is to compare the reality of a building in use from the theory. Although the architect and the client had set out the agenda for this development at an early stage, there is little or no information on how a development of this nature performs from a user aspect.

Based on the results of the POE, a scope can be drawn up to improve the outcome of the actual building and future ones. In addition, a POE demonstrates a commitment to users.

It is difficult for developers, architects and in this case researchers to get feedback on speculative projects, designers do benefit provided that they have good feedback. Occupiers in a one off project receive incremental gains and internal standards and organisational development; whereas occupiers having a series of projects benefit for future projects

In the case of this dwelling, particular interest is given to the energy-efficient measures taken to make this dwelling a 'zero-heat' house, therefore issues of thermal comfort are important. Also the design is different from a standard house, therefore questions related to movement and usability was important.

8.3 Layout of report

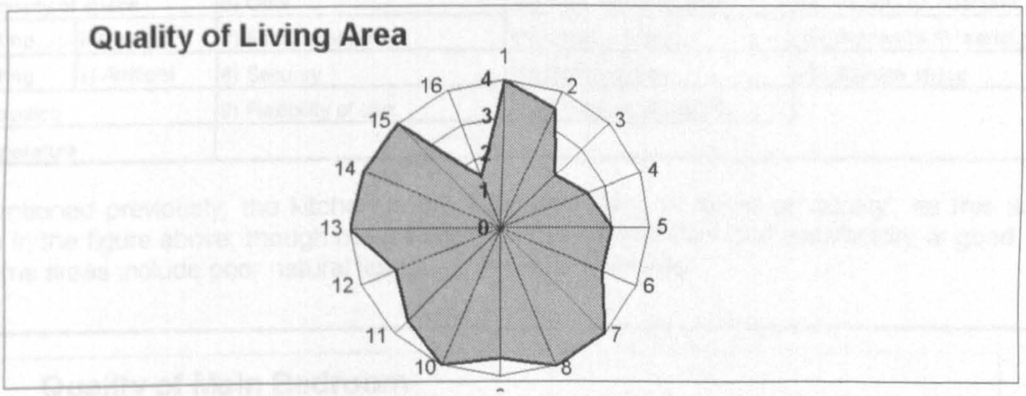
The report will mirror the arrangement of the questions in the POE (see appendices). The report will tackle each room / space individually concluding with a section asking queries of the building holistically.

9: POST OCCUPANCY EVALUATION

9.1 The 'zero-heating' family home: General comments

> *"I thought it would be helpful to write in the things we are not 100% happy with and have doubts about; we've tried to be honest. But basically it is a wonderful house and we are very happy with it ..."*

The rooms in the house that were the most popular and had the greatest 'quality' to the family were those rooms in the upper stories, none of which had any significantly derogatory remarks. The poorest room, in terms of quality, was the kitchen, the most popular being the

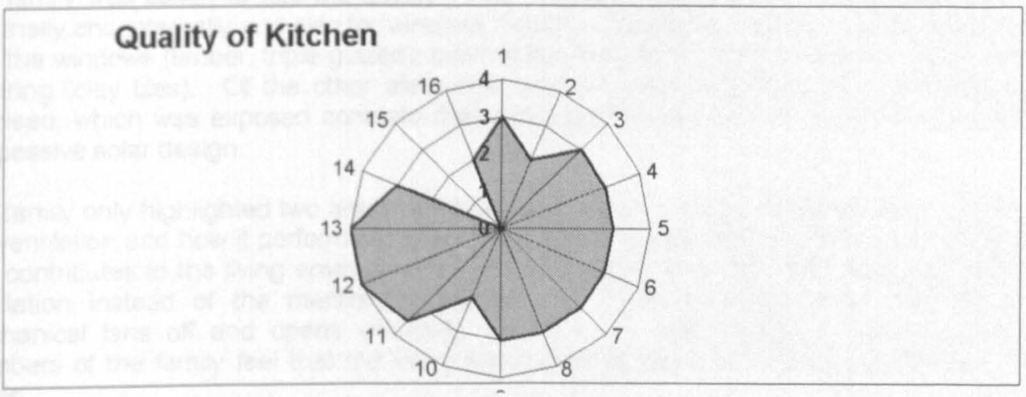


4 Excellent		3 Good	2 Moderate	1 Poor
1) Adequacy of space		6) Odor	10) View to the outside	14) Access to Telecoms
2) Lighting	i) Natural	7) Esthetic appeal	11) Visual privacy	15) Access to TV aerial port
3) Lighting	ii) Artificial	8) Security	12) Ceiling height	16) Storage space
4) Accoustics		9) Flexibility of use	13) Access to el. outlets	
5) Temperature				

upper storey bedrooms.

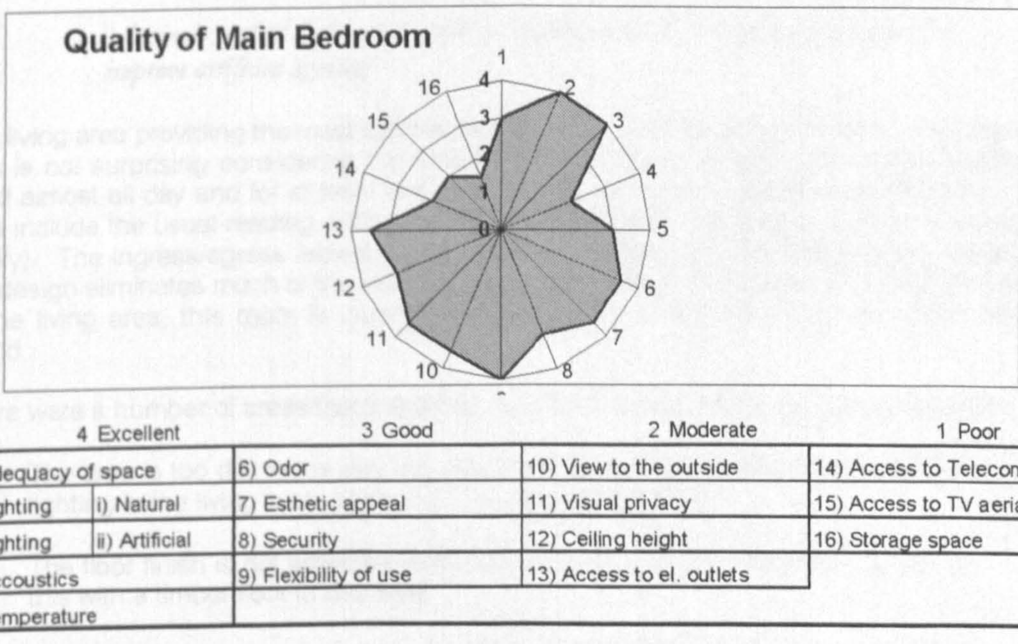
As may be seen by the above figure, there are only four areas where there are any potential problems in this space, in terms of 'quality'. There is no criteria, which the family finds 'poor', there are some aspects that the family find only 'good' or satisfactory, these are a lack of storage space followed by poor artificial lighting, acoustics and to some degree temperature and Odour.

In general, the family finds this space a pleasant environment in which they are happy with. In addition, the landing area, which is used as a more secluded version of the living area offers greater appeal than this space.



4 Excellent	3 Good	2 Moderate	1 Poor
1) Adequacy of space	6) Odor	10) View to the outside	14) Access to Telecoms
2) Lighting i) Natural	7) Esthetic appeal	11) Visual privacy	15) Access to TV aerial port
3) Lighting ii) Artificial	8) Security	12) Ceiling height	16) Storage space
4) Accoustics	9) Flexibility of use	13) Access to el. outlets	
5) Temperature			

As mentioned previously, the kitchen is the least preferred, in terms of 'quality', as this is shown in the figure above, though most aspects of the kitchen they find satisfactory or good, problems areas include poor natural light and view to the outside.



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4) Accoustics	9) Flexibility of use	13) Access to el. outlets	
5) Temperature			

The main bedroom was one of the most favoured spaces in the home, as is indicated in the figure above. The only derogatory aspects of the main bedroom was that it performed slightly poor acoustically, and that it had poor connection to electrical, telephone and TV outlets.

Questions were also asked of the bathroom, but this was another room where fault was hard to find. The family felt that acoustically the bathroom was of only moderate quality, but of the other criteria the bathroom performed either good or excellent.

The family was asked to rate the quality of the materials specified for fittings, finishes both externally and internally and also for windows / doors. The family was particularly impressed with the windows (timber, triple glazed), internal first floor finish (timber) and the exterior roof covering (clay tiles). Of the other elements, only the internal ground floor covering was criticised, which was exposed concrete that was specified as thermal mass to compliment the passive solar design.

The family only highlighted two areas of moderate concern. Firstly, the family was critical of the ventilation and how it performed, which they ranked highly as one of their main priorities that contributes to the living environment. This is probably why they frequently use natural ventilation instead of the mechanical alternative. The family frequently switches the mechanical fans off and opens windows, which is not best practice. Secondly, some members of the family feel that the living area offers to great a proximity to others in the house.

9.2 Living Area

> "*We might put a screen behind the sofa by the stove, to create a cosier space ..... it is a good area, but we would benefit from an additional sitting area ...*"
>
> "*In winter the insulation system, etc seems to work very well, as the house never gets terribly cold. However we have found the inside of the house sometimes too cool in summer, when it has been very warm outside.*"
>
> "*A single central light source and/or lighting over the dining table would improve artificial lighting.*"

The living area providing the most comments / suggestions than any other room in the home. This is not surprising considering the amount of activities completed in the room, which is used almost all day and for at least one third of an entire week. Activities performed in this area include the usual reading, sitting, eating, ingress/egress and playing (as this is a young family). The ingress/egress aspect of the activities is particularly interesting since, because the design eliminates much of the usual corridors in the home and access to rooms is mainly of the living area, this room is used as a thoroughfare much more than any other home would.

There were a number of areas that the family detailed that they would like to change/alter:-

- The area is too dull in the evening, leading to the requirement of further artificial lighting in the living area, particularly over the dining table.
- The floor finish is not attractive (bare concrete) and they would prefer replacing this with a timber floor in due time.
- There is a difference of opinion as to the acoustics in the room, some feel that the acoustics are poor, specifically when cooking. Similarly some feel that occasionally the area gets too stuffy during the day and that the air quality suffers.
- The area does get cold occasionally, but this is adequately supplemented by firing the stove. In the winter the family are pleased with the building performance but in the summer the house can feel to cool after being out during a warm day. There is a feeling that the overhang and/or the glazing restrict too much daylight during the summer. (*see also comments on landing*).

- The family feels this area is ideal for the purposes they require and for entertaining guests, as a focal point for family activity and features such as the double height space, wall and ceiling finishes are attractive. The family also feels, however, that they would benefit from a separate and enclosed sitting area.

9.3 Kitchen

> *"[We are] Confident this will be an adequate and attractive space once we can install a purpose-built kitchen suite."*

> *"Larger windows on the north wall would solve the light problem."*

In the design the kitchen was sited on the north wall in order to allow bedrooms and the living area to face south. In passive solar design it is also advisable to only put the minimal amount of glazing on the north, east and west facades in order to minimise heat loss. However, the family major concern in the kitchen is that it often is too dark and there is poor natural light.

There were a number of areas that the family detailed that they would like to change/alter:-

- There is not enough storage space provided in the kitchen.
- The kitchen is probably the worst for getting cold in the building, possibly aided by the 'darkness' of the room.
- A member of the family commented that the heat recovering mechanical extract fan was too noisy, though in the performance evaluation this proved not to be the case.
- An extractor fan for cooker would be beneficial to remove cooking odours.

9.4 Landing

"A very pleasant space ..."

The landing was designed so that heating from the south facing windows could rise to the second storey thus to heat this area as well as the ground floor. As such it had no designated purpose but the family has used this for a number of activities such as clothes drying, playing, reading and overflow sleeping area. It is proposed that the landing will become a more secluded living area as compared to the comments made about the main living area.

There were a number of areas that the family detailed that they would like to change/alter:-

- The main aspect / comment in this area is that it can quickly overheat if the secondary heating is on. This is overcome easily however by opening a window on the upper storey, which is open most of the time, which incidentally is not energy-efficient best practice. As such the family comments that after the heating has been switched on either in the morning or the evening, and the window is left open, it can lead to it getting cold in the early mornings.
- The family enjoys the fact that this space has not got a designated activity and that it is flexible.
- The family also comments that the lighting, particularly during the day, is very pleasant.

- The space is also regularly used for sleeping and therefore may benefit with an area semi-designated for sleeping.

9.5 Bedroom

> *"We prefer to have windows open therefore the bedroom is cool and well-ventilated."*
>
> *"If you were buildings another house you could think about the effect of the very thick walls and roof on the windows."*

In order to reduce costs the upper storey was situated within the roof space. Although this has a number of benefits, it does restrict head height and usable floor space.

There were a number of areas that the family detailed that they would like to change/alter:-

- Generally the family feel that the upper storey bedrooms are ideal. The main bedroom is possibly too small for the purpose intended, but this is due for the additional wish for an en suite.

- There is some feeling that the thickness of the roof and walls restrict the views from the windows and also find the depth to be uncomfortable.

- The ground floor rooms sometimes get too cold, however the upper storey bedrooms don't. In addition they provide very good daylight and ventilation.

- There is some feeling that noise pervades from the living area.

- There is not enough storage but there is scope to build cupboards into the lower end of the pitched roof.

9.6 Bathroom

There were a number of areas that the family detailed that they would like to change/alter:-

- The family found nothing radically wrong with the features of the bathroom though the arrangement of the appliances was questioned. If the bathroom door was left open you can see the WC.

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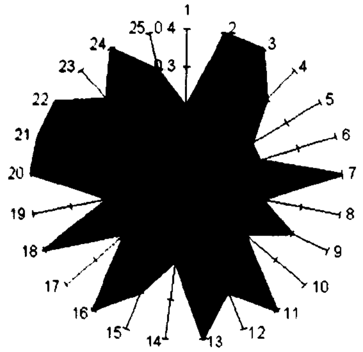
Scottish Homes

Housing Quality Assessment Program

EXECUTIVE SUMMARY

PERFORMANCE CATEGORY RATINGS:
USER-DEFINED



0 4 = EXCELLENT 0 3 = GOOD 0 2 = SATISFACTORY 0 1 = UNSATISFACTORY 0 = NULL ASSESSMENT

Performance Categories Key

INTERNAL DESIGN
1 Space Standards
2 Functionality of Internal Space
3 Accessibility and Flexibility
4 Relationship with External Space

EXTERNAL DESIGN
5 Private Gardens
6 Boundaries
7 Communal Space
8 Balanced Use of Space
9 Accessibility
10 Maintenance

ARCH. QUALITY:
11 Design Concept
12 Materials
13 Sense of Place

SECURE DESIGN:
14 Defensible Space (1)
15 Defensible Space (2)
16 Physical Security
17 Lighting

SUSTAINABILITY
18 Project Delivery
19 Social Value
20 Site Development
21 Energy Strategy
22 Environmental Systems
23 Resource Conservation
24 Healthy Buildings
25 Maintenance and Adaptability

Executive Summary

This software is used to assess housing estates at the design, construction or post-construction phases. Despite the 'zero-heating' house being a one-off project, in key areas the housing quality assessment shows that this home exceeds many aspects of common best practice

In particular, the 'zero-heating' house offers 'excellent' advantage over other building designs in the 'internal design', 'arch quality' and 'sustainability' aspects When thus type of housing is considered in a mass-housing situation, I am sure that the housing will benefit holistically

Association: Private Owner

Project: Zero Heating Family Home

Method of Procurement: Traditional: Design Team

HAG Level (£): None

Number of Units: 1

Form of Assessment: Standard (Benchmark)

Development Stage: Post-Completion Review

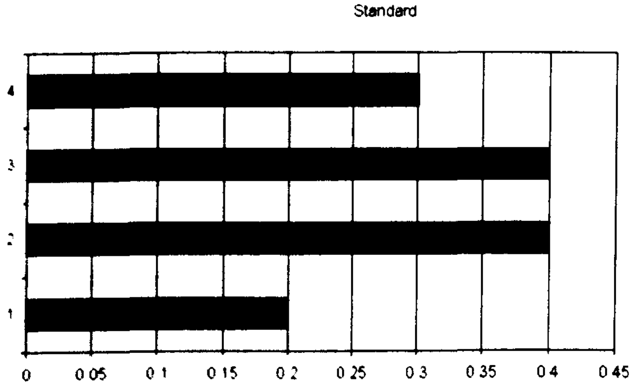
Assessor: Jonathan R Scott

Date: 20/05/2000

Scottish Homes

Housing Quality Assessment Program

REPORT: INTERNAL DESIGN



Default Performance Rating for INTERNAL DESIGN Quality Dimension =

Very Good

Performance Categories Key

1. **Space Standards**
2. **Functionality of Internal Space**
3. **Accessibility and Flexibility**
4. **Relationship with External Space**

Category Ratings Key

0.4 = EXCELLENT
0.3 = GOOD
0.2 = SATISFACTORY
0.1 = UNSATISFACTORY
0 = NULL ASSESSMENT

Summary

The 'zero-heating' home's functionality of internal space and accessibility & flexibility both rate excellent in this assessment. The space standards are good, though some aspects highlighted in the Post Occupancy Evaluation surmise that space is short in the Main bedroom and Kitchen. There is also a shortage of storage space, though there is flexibility in the design ti incorporate this.

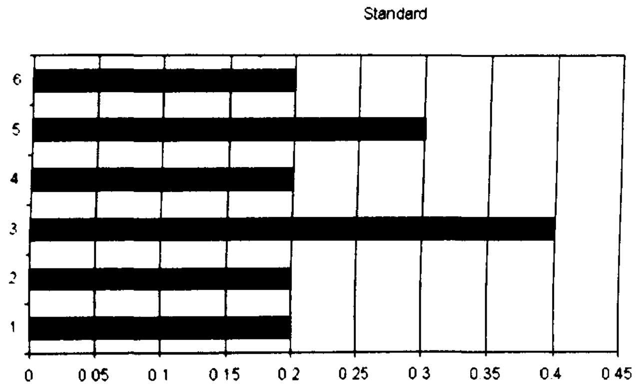
In this design aspect the 'zero-heating' home suffers chiefly from the relationship with external space. Here the 'zero-heating' house only gains a satisfactory rating due to site restrictions.

Association: Private Owner	Project: Zero Heating Family Home
Method of Procurement: Traditional: Design Team	HAG Level (£): None
Number of Units: 1	
Form of Assessment: Standard (Benchmark)	Development Stage: Post-Completion Review
Assessor: Jonathan R Scott	Date: 20/05/2000

Scottish Homes

Housing Quality Assessment Program

REPORT: EXTERNAL DESIGN



Default Performance Rating for EXTERNAL DESIGN Quality Dimension =

Quite Good

Performance Categories Key

1. **Private Gardens**
2. **Boundaries**
3. **Communal Space**
4. **Balanced Use of Space**
5. **Accessibility**
6. **Maintenance**

Category Ratings Key

0.4 = EXCELLENT
0.3 = GOOD
0.2 = SATISFACTORY
0.1 = UNSATISFACTORY
0 = NULL ASSESSMENT

Summary

Due to the 'zero heat' design being a one-off prototype dwelling and the site being restrictive, the ratings above reflect this. In addition the materials chosen for the 'zero-heat' home do not reflect the local environment. The resulting rating of 'quite good' therefore does not reflect this development as it should.

Of the Perfromance Categories listed above the 'communal space' aspect is rated as excellent, due mainly to the internal design and orientation on site.

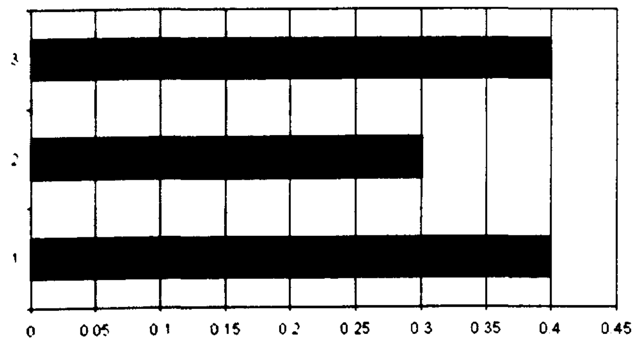
Association: Private Owner	Project: Zero Heating Family Home
Method of Procurement: Traditional: Design Team	HAG Level (£): None
Number of Units: 1	
Form of Assessment: Standard (Benchmark)	Development Stage: Post-Completion Review
Assessor: Jonathan R Scott	Date: 20/05/2000

Scottish Homes

Housing Quality Assessment Program

REPORT: ARCHITECTURAL QUALITY

Standard



Default Performance Rating for ARCHITECTURAL QUALITY Quality Dimension =

Very Good

Performance Categories Key

1. **Design Concept**
2. **Materials**
3. **Sense of Place**

Category Ratings Key

0.4 = EXCELLENT
0.3 = GOOD
0.2 = SATISFACTORY
0.1 = UNSATISFACTORY
0 = NULL ASSESSMENT

Summary

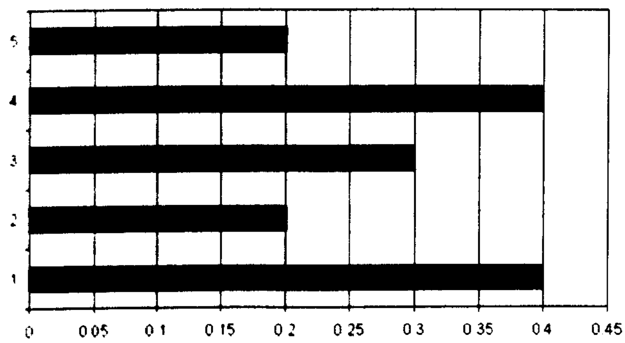
- **The architectural quality of the site gains an overall rating of 'very good' due to an innovative design concept and a sense of place. Once again, the building only achieves a 'good' rating with materials due to the local environment and suggestions in the POE of differences of opions in this regard.**

Association: Private Owner	**Project:** Zero Heating Family Home
Method of Procurement: Traditional: Design Team	HAG Level (£): None
Number of Units 1	
Form of Assessment: Standard (Benchmark)	**Development Stage:** Post-Completion Review
Assessor: Jonathan R Scott	**Date:** 20/05/2000

Housing Quality Assessment Program

Scottish Homes

REPORT: SECURITY CONSCIOUS DESIGN



Default Performance Rating for SECURITY CONSCIOUS DESIGN Quality Dimension =

Good

Performance Categories Key

1. **Defensible Space (1)**
2. **Defensible Space (2)**
3. **Physical Security**
4. **Lighting**

Category Ratings Key

0.4 = EXCELLENT
0.3 = GOOD
0.2 = SATISFACTORY
0.1 = UNSATISFACTORY
0 = NULL ASSESSMENT

Summary

It is important to note that the 'zero-heat' home has adequate security but this, since it was a one-off development, had no critical need for excessive sercurity design. In addition this is an area of low risk.

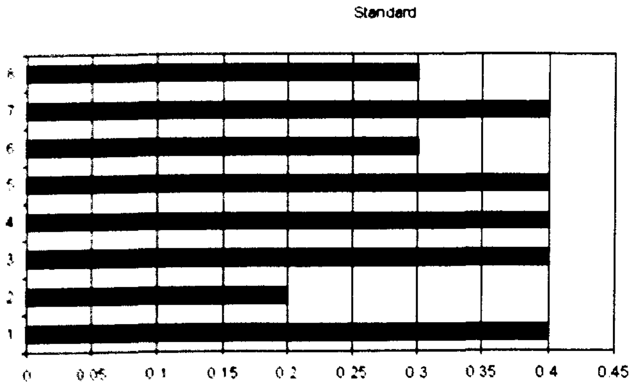
The design did poorly with defensible space due mainly to the landscape and location of the site, with poor visibility and many hiding places. However, the site provides most of the needs for the average family, including off-street parking and secure locks, etc.

Association:	Project:
Private Owner	Zero Heating Family Home
Method of Procurement:	HAG Level (£):
Traditional: Design Team	None
Number of Units	
1	
Form of Assessment:	Development Stage:
Standard (Benchmark)	Post-Completion Review
Assessor:	Date:
Jonathan R Scott	20/05/2000

Housing Quality Assessment Program

Scottish Homes

REPORT: SUSTAINABILITY



Default Performance Rating for SUSTAINABILITY Quality Dimension =

Very Good

Performance Categories Key

1. Project Delivery
2. Social Value
3. Site Development
4. Energy Strategy
5. Environmental Systems
6. Resource Conservation
7. Healthy Buildings
8. Maintenance and Adaptability

Category Ratings Key

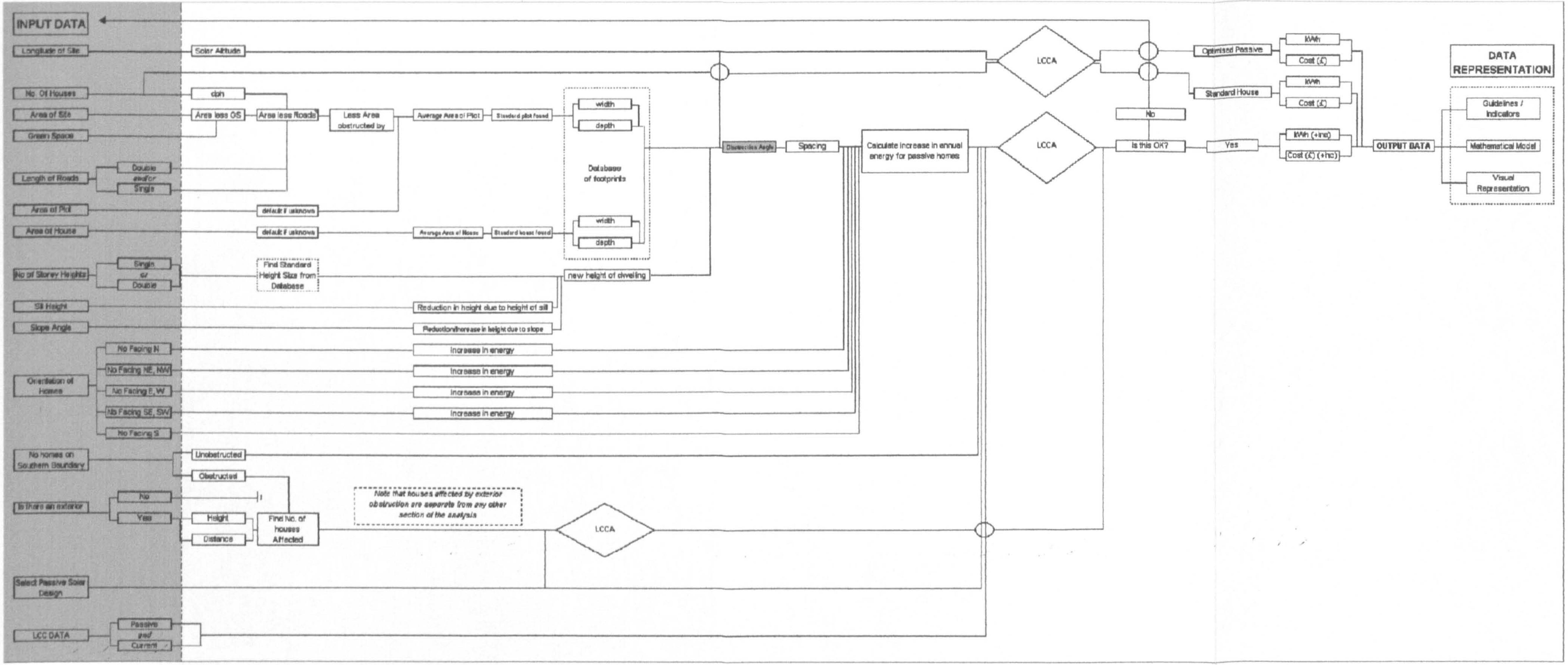
0.4 = EXCELLENT
0.3 = GOOD
0.2 = SATISFACTORY
0.1 = UNSATISFACTORY
0 = NULL ASSESSMENT

Summary

The 'zero-heat' home had innovative and clear objectives in regard to sustainable design concepts, and the overall rating of 'very good' reflects this.

Due to the limited community transport and the private road access to the site the 'social value' aspect of the design is only 'satisfactory'. However, four of the other categories rate 'excellent' in their application in this building for the reason stated above.

Association: Private Owner	Project: Zero Heating Family Home
Method of Procurement: Traditional: Design Team	HAG Level (£): None
Number of Units: 1	
Form of Assessment: Standard (Benchmark)	Development Stage: Post-Completion Review
Assessor: Jonathan R Scott	Date: 20/05/2000



INPUT DATA
Longitude of Site
Solar Altitude
No. Of Houses
dph
Area of Site
Area less GS
Area less Roads
Less Area obstructed by
Average Area of Plot
Standard plot found
Green Space
Length of Roads
Double
and/or
Single
Area of Plot
default if unknown
Area of House
default if unknown
Average Area of House
Standard house found
width
depth
Database of footprints
width
depth
No of Storey Heights
Single
or
Double
Find Standard Height Size from Database
new height of dwelling
Sill Height
Reduction in height due to height of sill
Slope Angle
Reduction/Increase in height due to slope
Orientation of Homes
No Facing N
Increase in energy
No Facing NE, NW
Increase in energy
No Facing E, W
Increase in energy
No Facing SE, SW
Increase in energy
No Facing S
No homes on Southern Boundary
Unobstructed
Obstructed
Is there an exterior
No
Yes
Height
Distance
Find No. of houses Affected
Note that houses affected by exterior obstruction are separate from any other section of the analysis
LCCA
Select Passive Solar Design
LCC DATA
Passive
and
Current
Obstruction Angle
Spacing
Calculate increase in annual energy for passive homes
LCCA
LCCA
No
Is this OK?
Yes
Optimised Passive
kWh
Cost (£)
Standard House
kWh
Cost (£)
kWh (+inc)
Cost (£) (+inc)
OUTPUT DATA
DATA REPRESENTATION
Guidelines / Indicators
Mathematical Model
Visual Representation

APPENDIX D
PAPER FROM CONFERENCE

OPTIMISING THE RELATIONSHIP BETWEEN PASSIVE SOLAR DESIGN OF NEW HOUSING AND THE ECONOMICS OF CONSTRUCTION AND LAND VALUE

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ABSTRACT: In recent years the focus of mass housing developments built by speculative developers in the UK has broadly been on maximizing density whilst retaining a predominantly detached housing form. This economically led strategy, aimed at maximizing return on investment, can conflict with the aim of radically reducing environmental impacts. A variety of products have been developed, which enable design professionals to model and assess the environmental performance (especially in energy use terms) of individual buildings. There are, however, currently no tools for modeling the environmental performance of the whole developments, based on variables such as site layout, density, orientation and topography. Using passive solar design as an exemplar of the wider field of sustainable development offers the opportunity to improve the environmental, spatial and aesthetic performance of speculative developments. This paper describes the development of a tool for planners of housing developments to optimise the passive solar characteristics of a development through an environmental site assessment.

Key words: Housing and Planning; Sustainability; Passive Solar Design

1. INTRODUCTION

This research has investigated the use of passive solar design, as an exemplar of environmental design, for whole developments, as a means to overcoming the resistance to adopting sustainable housing practices. With the emphasis in current housing construction on density rather than environmental objectives, and a lack of expertise in planning, designing and building environmentally sensitive projects, there is a need for a method, which ascertains the sustainability of a site. With this in mind, the aim of this research was to produce a framework for an environmental site assessment tool for the optimisation of passive solar detached housing layouts in a development during the planning process. This product will be useful to planners in ascertaining the potential of a site, and providing detailed recommendations for a site. It is further argued that a system, which can ascertain the potential of a site at an early stage of the design, can aid in the acceleration of the planning process. The framework produced for the research has demonstrated the potential for such a system, which requires further work to develop it for practical application.

2. BACKGROUND TO RESEARCH

2.1 Introducing the need for long-term housing goals

The construction industry has a history of achieving short-term goals, without reaching sustainable, long-term objectives for housing. Many inner city residential areas, in particular, are obsolete little over fifty years after they have been built, for a variety of reasons such as poor planning, changing demographics, lifestyle and societal change and loss of amenities. The Urban Task Force has been created to find 'radical solutions' to solving this problem (ODPM, 1998), and environmental, ecological, or green design, as it has variously been called, is a means, if used appropriately, of helping to achieve sustainable, long-term housing goals. Sustainable design covers many complex criteria, which this research has not dealt with, but the research does cover aspects of economic value and environment central to a more sustainable design.

Recently there has been an increased awareness of issues affecting the environment. The Rio Summit's aim for reducing emissions, the Kyoto protocol directly affecting subsequent governmental commitments; and the recognition of global warming and climate change have all contributed to awareness of sustainability issues. Issues affecting the environment have resulted in a drive not only to produce ever more radical, energy efficient buildings, but has expanded to incorporate a whole series of other aspects on the environmental agenda in a quest for what has come to be known as *'sustainability'*, a complex topic which influences all aspects of development (Jackson, 2003; Edwards & Pawley, 2000).

Cutting edge projects have encouraged, at a somewhat sedate pace, improvements in building standards demanded by legislation culminating recently in improved thermal efficiency of building envelopes in spring 2001 (2002 in Scotland) primarily aimed at reducing CO_2 emissions. Attempts have been made to create homes, which demand much less energy than their 'standard' contemporaries, or make use of renewable energy sources. Borer & Harris (1998); Kachadorian (1997); Yannas (1994, [2]); offer examples. Many of these radical homes can be characterised as showcase developments, which employ all manner of state-of-the-art techniques, as well as sound, basic passive solar principles, to produce often expensive, prestige homes designed to demonstrate what is possible. The theory is generally that a trickle-down effect will ensure that the benefits ultimately reach a mass housing market.

There is a growing belief, encouraged by government, that long-term goals should not be forgotten in favour of short-term monetary objectives. Initial cost will always be important and many of the showcase projects have a short-term flaw in that it has generally been understood by the wider construction industry that there must be a monetary penalty when demonstration developments are transferred, in a somewhat diluted form, into the more affordable mass market.

This research suggests that the **whole design approach needs re-orientating** so that long term environmental policy goals related to climate change, for example, can be achieved. The research aimed to establish that long-term housing objectives can be achieved through environmental design with significant emission reduction and cost benefits. It used passive solar as an exemplar to develop a framework for a tool for **environmental site assessment.**

2.2 Passive solar design as an exemplar for sustainable design

Passive solar design, a broad term for designing buildings which are orientated towards the equator to benefit from solar heat gains (at high latitudes), requiring to face approximately south in the northern hemisphere, is a holistic design method for reducing the need for non-renewable fuel (Kachadorian, 1997; Balcomb, 1992). In this case orientation simply means the direction the solar collector faces in plan and its vertical tilt to the solar angle (Borer & Harris, 1998; Littlefair, 1991). In the northern hemisphere, the greatest quantity of solar energy is received on a South face, assuming it is not shaded by some obstruction, with roof glazing collecting more solar radiation compared to a greater area of vertical glazing. Figure 1 details the key considerations involved when adopting a passive solar design.

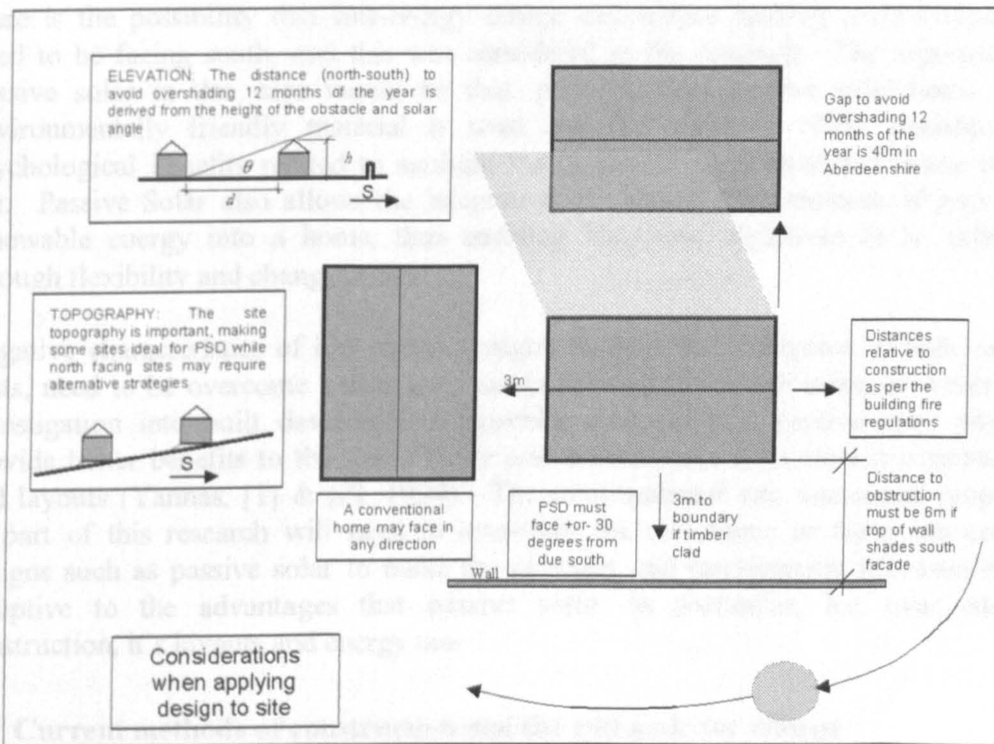

Fig. 1. Passive Solar Design Constraints

Ensuring that the orientation of glazing faces due south is not critical as solar gains from windows facing 25 degrees off due south are only slightly lower than the maximum solar gain possible (Borer & Harris, 1998; BRECSU, 1997; BRECSU, 1995; Yannas, 1994; Littlefair, 1991). The further north the building, the closer to due south the preferred orientation, however, and the consequences of overshadowing become pronounced. This has a consequence with the building form and location of a development, in addition to orientation. In real terms an ideal site, which complements a passive solar design is not likely to occur. In addition, it is unlikely that a solar heated home will make the heating system redundant, although it will reduce the energy dependency from non-renewable sources while promoting more reliance on renewable energies (DTI, 2000; EC, 2000; DTI, 1999).

Beyond the issue of solar gain, passive solar design encompasses concepts such as thermal mass, air-tightness, super-insulation, green building construction, waste reduction, renewable material, fuel and embodied energy, with few other design approaches making full use of all these features. Where *all* these strategies are used the greatest savings in terms of heating and emissions are possible and an appropriately designed passive solar home can reduce heating costs by up to 70% (Deveci, 2000) and reduce emissions by similar proportions, thus benefiting both occupier and environment.

There are some grey areas in the definition of what constitutes passive solar design. For example, whilst insulation undeniably forms part of solar design strategies, can a building, which is simply very highly insulated, be described as a passive solar design?

With the advent of inexpensive insulation, better window and structural technology, there is the possibility that low-energy design can reduce heating costs *without* the need to be facing south, and this was considered in the research. The argument for passive solar in this case would be that, perhaps, in a passive solar home more environmentally friendly material is used and that daylight offers aesthetic and psychological benefits related to sunlight that a simple super-insulated house would not. Passive Solar also allows the integration of 'active' solar methods of providing renewable energy into a home, thus enabling long-term objectives to be achieved through flexibility and change of use.

Negative characteristics of low-energy designs, such as the perception of high capital costs, need to be overcome before they can be applied to mass housing, however, but investigation into built developments provides evidence that passive solar projects provide better benefits to the home buyer and environment than current construction and layouts (Yannas, [1] & [2], 1994). The environmental site assessment proposed as part of this research will need to overcome the reluctance in using low-energy designs such as passive solar to make the planning and development processes more receptive to the advantages that passive solar, in particular, has over current construction, it's layouts and energy use.

2.3 Current methods of construction and the rationale for change

Primarily due to the high cost of building land, current methods of residential development focus on grouping homes with minimised foot-prints - detached or semi-detached dwellings which minimise road frontage while maximising density - within predetermined site boundaries. It may be surmised that the reasons for current methods of development are not only derived from business market demands, but also compounded by government calling for higher housing densities, such as through the Urban Task Force (DETR, 1996). As a result, land values increase still further and building density becomes critical for developers. Whilst on the face of it a high development density for detached homes can be seen as a basic requirement for 'sustainable' developments (in that less green-field land is built upon) such a narrow definition of sustainable development ignores aspects of the building performance. In particular the energy performance; of the building as a system (DETR, 2000); the site as a whole; and, the consequent reduction of pollutants. It should be noted that without an environmental strategy, a site with higher density would simply mean more pollution, in a smaller space.

The tensions between current mainstream building practice and sustainable development are both complex and far reaching (Edwards & Pawley, 2000). Many see sustainable development as an idealistic moral high ground, rather than a serious mainstream option (Edwards & Pawley, 2000; Serchuk, 2000). For the Government to overcome this, the publication, "*Building a Better Quality of Life*" (2000) aimed to stimulate sustainable development and details the aspects that the Government associates with sustainable development. This by no means overcomes the problems associated with the practical application of environmental developments, but is a sign of increasing awareness and a step forward.

Previous studies by the DETR and the DTI (BRESCU, 1997 and 1995) indicate that there is some reluctance to adopt passive solar design principles fully, for a number of reasons. In particular, constructors/developers currently build dense, narrow-fronted and detached or semi-detached housing primarily to suit market demand, with dwellings traditionally facing each other across a distribution road. With passive solar design, the orientation requires to be to the south, (though there is some degree of flexibility), with implications for the streetscape.
The fact that current housing development patterns can provide more homes on most sites compared to a more sustainable, passive solar development is a major factor against any form of alternative housing layout. As a result of this problem, sustainable developments may be less profitable because they have a lower density (the primary reasons for high densities are land value and government housing targets (DETR, 2000; Edwards, 2000; DETR, 1996)).

Bordass (2000) highlights that one reason why environmental design is not accepted in common building practice is because it is seen as, 'special'. The connotations of a building, or development, being 'special', whatever that may be, results in poor economic value in terms of re-sale value – categorised as a high risk if you need to sell a home.

This research proposes that using a **balanced passive solar design**, within a **sustainable development**, will enable current aesthetic and spatial approaches to housing to take on an enhanced level of environmental acceptability.

The authors suggest that the resolution of the tension between current methods of housing construction and environmental methods, such as passive solar design, lie in the combination of the following;

1. Addressing issues of long-term land value through planning;
2. Improved government driven incentives for passive solar dwellings which take account of the density imperative; and
3. Improved information on the benefit to the purchaser of passive solar homes and the reduction of CO_2 emissions.

2.4 Restrictions at the planning stage

The planning stage is the ideal time to adopt passive solar principles, but there is some key obstacles described by Yannas ([1], 1994) namely; the lack of design information; credibility and applicability; marketability; lack of incentive; costs; and design quality. Local planning officials have little enforceable influence if they want to encourage environmental issues, such as type of insulation or renewable fuel, since they have no way of enforcing the principles of environmental design at such a specific level.

In addition, planning officials have to deal with a number of pressures, of which environmental concerns may be low on the priority list. Aspects of environmental design are often vague during the planning stage, leading to a flaw in the decision making process if professionals are not properly trained in environmental architecture. Bordass (2000) states that it is often difficult for environmental 'green' professionals to differentiate between an environmentally friendly dwelling and one, which claims to be. If environmental design professionals find it difficult, how can planning officers be expected to differentiate, without proper training, or an appropriate site assessment tool?

Across the construction industry housing developers plan, design and build on very similar principles, which restricts innovation in housing making alternative principles, such as environmental design, difficult to adopt (Blackler, 2002). Issues such as sustainability, green design and brown-field sites can be, as Cullingworth and Nadin (2002) describe, 'extraneous' - meaning they have additional cost risk to the homebuyer. On the other hand these concerns are central to the objectives of the planning office and government (Cullingworth & Nadin, 2002). In short, the principal housing form of densely packed, detached homes built to minimum building regulation standard is the result of economic imperatives coupled to risk aversion.

Housing developers remain the driving force behind early planning decisions, however - decisions such as basic layout, quality, strategy, process, management, and, importantly density. Their main aim, as discussed, is economically driven, while ensuring it meets the stipulations of local planning authorities. Environmental professionals, and even designers, may not be involved at this stage, yet this is where the key decisions influencing passive solar are made - leading in some cases to increases in capital cost and the loss of the potential to save heating costs and emissions if added later in the design process.

Currently, the only place where a change can be made to the developer's planning methods is at the planning consent stage; however the adoption of environmental designs at this stage still relies on government incentives. For an environmental design to be adopted, one incentive that a housing developer may find attractive would be a rapid planning consent. It is hoped that the tool developed will speed up the planning consent for the housing developer, if adopted during the planning stage.

3. METHODOLOGY FOR THE DEVELOPMENT OF THE ENVIRONMENTAL SITE ASSESSMENT

The development of the environmental site assessment tool in the research has included four key activities as follows:

- preliminary site investigations
- developing housing databases
- financial considerations
- data representation

3.2 Preliminary site investigations

The main aim of the research was to create a product termed the 'environmental site assessment tool', for use during the planning of housing developments. Very little definitive information on a site, its buildings, their aesthetic design and their specification will be known at this stage. Therefore, a tool, which assesses a site's potential, needs to work from limited criteria such as simple shapes and building footprints. This research was also aware from an early stage that the potential users would be unable to differentiate between what is, and what is not, an environmental design.

The preliminary research began by analysing variables such as height, footprint, area, topography and density of a sample of local housing sites in Aberdeenshire, chosen from the Aberdeenshire Local Plan. In order to optimise passive solar in the north-east of Scotland, over-shadowing distances needed to be calculated to allow for full year access to the sun, meaning that passive solar site densities are limited according to height of dwellings and solar angle. Comparison between existing and proposed sites against an optimised passive solar alternative was undertaken to analyse if significant differences in densities occur.

3.2 Developing housing databases

The required data for the environmental site assessment is readily available from most environmental sources, and involves mathematically determining distances and angles to establish, for example, the accurate over-shadowing distance. Research into passive solar design in the 1970's and 80's established much of the parameters surrounding passive solar and this tool has brought together the existing knowledge on the topic. The tool also aims to ensure that this information is brought together in a user-friendly manner for those not familiar with the principles of passive solar design.

The tools main output, it was determined at an early stage, is to compare passive solar alternatives against a standard home – termed the base home. In order to establish design of the base home, a database of the current typologies of the main housing developers in the Northeast was established. This allowed the creation of an average home for the Northeast of Scotland (the base home). As a comparative alternative an optimised passive solar home was derived by investigation of solar case studies at similar latitudes to Britain, as well as a case study situated in Aberdeen.

By using energy calculating software a range of passive solar homes, on a m^2 basis, were derived to form an environmental housing database. The database has been integrated into the environmental site assessment so that costs and emissions can be obtained from this passive solar database, without any prior knowledge of how these buildings operate. These buildings can be selected from the database using simple specifications. A similar methodology was used by Turrent (1981) to establish the effects of a range of benefits accrued by using passive solar, and this research uses a similar system, brought up to date to include recent building regulation changes, to establish the same benefits. Figure 2 illustrates a simplified version of the database relationships in the environmental site assessment.

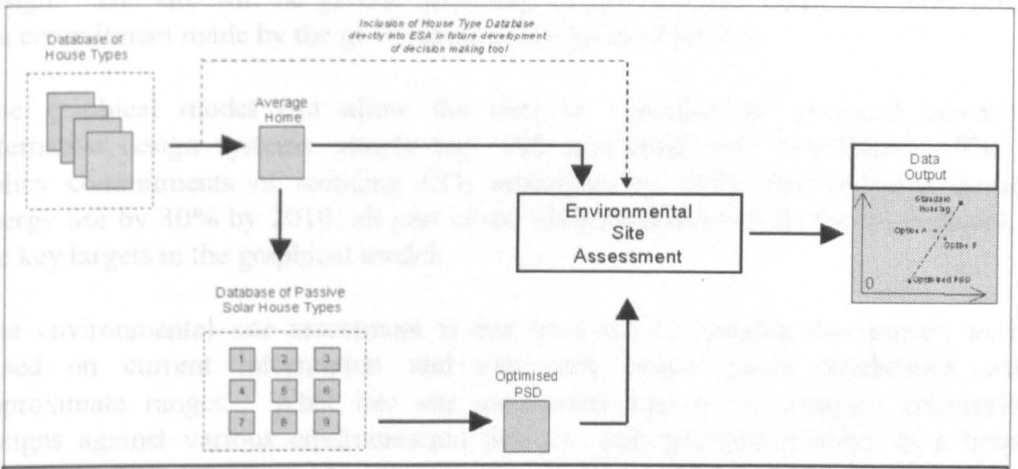

Fig. 2. Environmental Site Assessment

In addition to the databases created for standard and passive housing types, databases have been embedded into the assessment procedure so as to select appropriate housing types. These databases are needed to determine elements of simplified housing types, such as storey height and house footprint, in order to establish key passive solar trade-offs between current methods of construction and passive solar.

The environmental site assessment was created using information garnered primarily from BRE sources, and calculates the effect density and site topography has upon a passive solar design. The tool can determine the effect changing the density has upon a passive solar development, and adjusts the costs and emissions accordingly. The aim is to establish the effect of the trade-off that is required for a passive solar development, in comparison to current methods of development, in order to fulfil a sites density target.

3.3 Financial considerations

The key output from this analysis is the determination of the costs involved. The main costs are the energy costs, and these are arrived at with the use of energy calculating software. The software used to calculate costs can be inaccurate in comparison with historical data from existing buildings, but as a comparative analysis between standard and passive homes it provides decision making statistics.

The costs in the analysis are not only based on the energy elements of each home, but also on the whole life cycle costs. The assessment procedure includes an exemplar life cycle costing element to the analysis. At this stage the life cycle cost component of the tool is restricted. Future evolutions of this assessment procedure will see a more integrated role using whole life costs in determining the monetary costs and benefits of various options.

3.4 Data representation

The outcome of the product is a graphical model (of emissions against whole life costs), which has been developed to rate a project. The output is scaled between the conventional alternative (the base home in this case) and the optimised passive solar design. The site will be graded according to government objectives, most notably the commitment made by the government to the Kyoto Protocol.

The graphical model can allow the user to visualise the potential benefits of alternative design systems, simply and with maximum user friendliness. The key policy commitments of reducing CO_2 emissions by 20%, and reducing domestic energy use by 30% by 2010, all part of the obligation to meet the Kyoto Protocol, are the key targets in the graphical model.

The environmental site assessment is not intended to 'predict the future', as it is based on current information and can only make future predictions within approximate ranges. What this site assessment can do is compare conventional designs against various environmental designs, and give the planner of a housing development feedback regarding the potential of any given site.

The model is in the preliminary stages of testing, before undergoing more rigorous testing amongst housing planners who have some expertise of environmental design. The testing is aimed at establishing the usability of the tool, its potential and the need for further refinements and amendments.

4. CONCLUSIONS

Passive solar homes are built to benefit from a free source of energy, and some experience with passive solar design suggests that this can be achieved without significant capital cost increases (Deveci, 2000). The passive solar home, therefore, provides an ideal model for environmental designs and can significantly reduce heating costs and emission. Passive solar homes provide an ideal foundation for a more sustainable environment. In northern climates, however, passive solar densities are restricted by low solar angle in winter. This has been confirmed by investigations of sites in the Northeast of Scotland. The environmental site assessment offers a tool to overcome these problems and to determine the potential savings a passive solar site has over current methods of construction.

The preliminary research discovered that in the north-east of Scotland, because of the low solar angle in winter, an optimised passive solar development, appropriately spaced for all year solar access, had low densities (an average of just under 25 dwellings per hectare on the sites analysed). This highlighted a significant problem as the average dwelling per hectare for the north east of Scotland using current construction techniques was between 35-45dph, some as high as 60dph. There was a significant discrepancy between the two, highlighting the need for a tool to establish what this means in terms of cost and emissions.

The main product of the research has been a tool producing an environmental site assessment, which can determine the potential of a site in a comparative analysis between current methods of development and an optimised passive solar development. At this stage the tool is a prototype and aims to showcase the possibility of what can be achieved and overcome the complex issues which result in the lack of use of environmental, sustainable design. Piloting of the product has highlighted problem areas, which are the subject of current research, but has also highlighted the usefulness of and need for such a product.

The environmental site assessment needs further testing amongst planners and housing developers. The output of a graphical model of emissions against whole life cost will be developed further, and the addition of a more numerical output is to be explored. The indication at this stage is that the research will produce a useful tool for determining the potential of any given site given basic site parameters.

The environmental site assessment has been pilot tested to ascertain if it 'works' but the tool also needs to be tested to ascertain what **value** such a tool, if implemented, has to the planners of housing projects. This part of the research is yet to be completed, but through feedback from planning professionals, the following items can be determined.

- **usability and potential**, of the software tool and whether the tool would be utilised in a similar manner to the SAP rating, or Target U-value method
- **output requirements**, the type of expression of the results from the tool may need to be refined through exploration of numerical models, graphical representations, guidelines, or a combination of these expressions;
- **essential amendments**, any further developments/areas where the tool could be used/developed.

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APPENDIX E

DATABASE OF HOUSE TYPES ON SITES IN THE NE OF SCOTLAND (ABERDEENSHIRE)

Introducing the Database on Standard Homes being built in the North East of Scotland.

There are two parts to the database in this Appendix. The first part deals with the statistical accounts of the various house types. The second deals with the room layouts and their locations within a building. The two parts of this database are 'hyperlinked', which is a function within the database tool 'excel'. This allows the two separate parts of the database to be linked at a click of the button. In addition to this 'soft copy' database, a 'hard copy' database of each house was gained to provide further information if required.

The first database.

The following is a description of each column in the database;

No.: This is the specific reference number for each of the homes used, in most cases, to 'hyperlink' to the second part of the database.

House Name and House Builder: Is the house name given by the housing developer. The neighbouring column is the housing builder /developer.

V: Many of the homes have variations, this is not uncommon, but housing developers do not usually change the home significantly from the original premise. However, in some cases the changes are significant. These buildings are given an asterisk. This signifies that this home is one option but there is another home along the same lines that has either another storey, more glazing or some significant construction that equates to a different type of building.

House Type: In short hand form the house type is noted. The key to this is as follows;

FS – Semi-detached (two-storey)
FD – Detached (two storey)
B – Bungalow (one-storey, detached or semi-detached)
FT – Terraced Home (Two-storey)
R – Detached home with habitable roofspace

FA: Floor Area (m^2) inclusive of walls.

Main, Side A, Side B, Back: Area of glazing on each elevation of the building (m^2). The titles of the elevation are more fully explained within the body of the research. However, generally the main elevation is the elevation with the main access to the street, Side A is on the right of the main elevation and so on.

Total: Total Glazing (m^2)

Main%, A%, B%, Back%: Percentage of glazing on each façade of the total glazing.

Glass/FA: Glass to Floor area ratio. The total glazed area divided by the floor area.

The Second Database

The second database is simply number counting. The left column lists all the different rooms available for the typical home, under these room titles a descriptive is given. The descriptive is a named 'cell' of a home (cells are laid out in a grid pattern). For each time a room is located within a cell a mark is given. These marks are coded within this database and most commonly relate to the 'No' column in the first database (but not exclusively so).

No.	House Name	House Builder	V	House Type	FA	Main	Side A	Side B	Back	Total	Main%	A%	B%	Back%	Glass/ FA
1	01 Brechin	Bett Homes		FS	70.8	4.32	0.00	0.60	6.96	11.88	36.36%	0.00%	5.05%	58.59%	16.78%
2	02 Bollin	Bett Homes		FT	94.6	5.28	0.00	0.00	7.00	12.28	43.00%	0.00%	0.00%	57.00%	12.98%
3	03 Crawford	Bett Homes		FS	72.5	5.52	0.00	0.32	6.96	12.8	43.13%	0.00%	2.50%	54.38%	17.66%
4	04 Hartford	Bett Homes		FS	113.4	5.40	0.00	1.32	6.12	12.84	42.06%	0.00%	10.28%	47.66%	11.32%
5	05 Kilbride	Bett Homes		FS	63.5	4.76	0.00	0.80	7.12	12.68	37.54%	0.00%	6.31%	56.15%	19.97%
6	06 Whitley	Bett Homes		FS	77.5	5.76	0.00	0.00	7.32	13.08	44.04%	0.00%	0.00%	55.96%	16.88%
7	07 Aire	Bett Homes		FD	82.6	7.20	0.00	0.00	6.96	14.16	50.85%	0.00%	0.00%	49.15%	17.14%
8	08 Appin	Bett Homes		FD	84.9	5.76	0.00	0.00	8.28	14.04	41.03%	0.00%	0.00%	58.97%	16.54%
9	09 Edzell	Bett Homes		FD	97.7	7.92	3.52	2.88	5.76	20.08	39.44%	17.53%	14.34%	28.69%	20.55%
10	10 Falkland	Bett Homes		FD	98.9	5.76	0.00	0.00	12.16	17.92	32.14%	0.00%	0.00%	67.86%	18.12%
11	11 Forres	Bett Homes		FD	80.6	5.52	1.12	0.00	9.08	15.72	35.11%	7.12%	0.00%	57.76%	19.50%
12	12 Kintyre	Bett Homes		B	94.7	5.04	0.72	1.44	5.76	12.96	38.89%	5.56%	11.11%	44.44%	13.69%
13	13 Lauder	Bett Homes		FD	90.2	6.48	0.48	0.00	9.28	16.24	39.90%	2.96%	0.00%	57.14%	18.00%
14	14 Seaton	Bett Homes		FD	85.4	4.74	5.18	2.88	7.84	20.64	22.97%	25.10%	13.95%	37.98%	24.17%
15	15 Alford	Bett Homes		FD	106.6	9.00	0.72	2.16	9.76	21.64	41.59%	3.33%	9.98%	45.10%	20.30%
16	16 Alnwick	Bett Homes		FD	138.5	14.08	0.48	0.00	13.56	28.12	50.07%	1.71%	0.00%	48.22%	20.30%
17	17 Ardbeg	Bett Homes		FD	111.8	6.48	0.96	1.68	12.76	21.88	29.62%	4.39%	7.68%	58.32%	19.57%
18	18 Blairmore	Bett Homes		FD	98.8	4.60	0.00	0.00	13.28	17.88	25.73%	0.00%	0.00%	74.27%	18.10%
19	19 Cramond	Bett Homes		FD	86.8	7.20	0.72	0.72	9.80	18.44	39.05%	3.90%	3.90%	53.15%	21.24%
20	20 Cullen	Bett Homes		FD	94.9	6.16	0.72	0.72	10.24	17.84	34.53%	4.04%	4.04%	57.40%	18.80%
21	21 Kelso	Bett Homes		FD	112.6	10.28	0.00	0.00	12.36	22.64	45.41%	0.00%	0.00%	54.59%	20.11%
22	22 Melrose	Bett Homes		R	132.3	8.96	0.72	0.00	8.52	18.2	49.23%	3.96%	0.00%	46.81%	13.76%
23	23 Thurso	Bett Homes		FD	116.0	10.08	0.00	0.00	10.72	20.8	48.46%	0.00%	0.00%	51.54%	17.94%
24	24 Tweed	Bett Homes		FD	115.0	11.04	0.00	0.00	11.56	22.6	48.85%	0.00%	0.00%	51.15%	19.66%
25	25 Conway	Bett Homes		FD	132.5	11.92	0.00	2.16	9.28	23.36	51.03%	0.00%	9.25%	39.73%	17.64%

26	26 Dalkieth	Bett Homes	FD	146.1	14.12	0.00	0.00	14.24	28.36	49.79%	0.00%	0.00%	50.21%	19.41%
27	27 Dunkeld	Bett Homes	FD	164.9	15.44	0.00	0.72	15.84	32	48.25%	0.00%	2.25%	49.50%	19.41%
28	28 Firth	Bett Homes	FD	147.0	8.48	0.72	3.12	16.32	28.64	29.61%	2.51%	10.89%	56.98%	19.49%
29	29 Nairn	Bett Homes	FD	126.9	5.20	0.72	1.92	12.84	20.68	25.15%	3.48%	9.28%	62.09%	16.30%
30	30 Newburgh	Bett Homes	FD	120.9	6.36	0.72	0.72	13.96	21.76	29.23%	3.31%	3.31%	64.15%	18.00%
31	31 Perth II	Bett Homes	FD	136.9	13.04	1.68	0.00	14.68	29.4	44.35%	5.71%	0.00%	49.93%	21.48%
32	32 Strathmore	Bett Homes	R	125.6	9.04	0.00	0.72	12.16	21.92	41.24%	0.00%	3.28%	55.47%	17.46%
33	33 Glamis	Bett Homes	FD	168.6	13.50	2.70	0.00	13.26	29.46	45.82%	9.16%	0.00%	45.01%	17.48%
34	34 Braemar	Bett Homes	FD	190.1	12.64	0.72	2.40	22.00	37.76	33.47%	1.91%	6.36%	58.26%	19.87%
35	35 Scott	Cala Homes	FD	845.0	9.80	5.40	5.92	17.92	39.04	25.10%	13.83%	15.16%	45.90%	4.62%
36	36 Deploe	Cala Homes	FD	823.0	14.36	1.68	0.84	23.46	40.34	35.60%	4.16%	2.08%	58.16%	4.90%
37	37 Naismith	Cala Homes	FD	735.0	18.72	1.68	1.56	18.28	40.24	46.52%	4.17%	3.88%	45.43%	5.47%
38	38 Fraser	Cala Homes	FD	544.0	6.32	4.48	14.08	6.88	31.76	19.90%	14.11%	44.33%	21.66%	5.84%
39	39 Dewar	Cala Homes	B	764.0	6.08	5.52	4.32	19.12	35.04	17.35%	15.75%	12.33%	54.57%	4.59%
40	40 Maxwell	Cala Homes	FD	657.0	10.60	2.52	0.72	16.08	29.92	35.43%	8.42%	2.41%	53.74%	4.55%
41	41 Lorimer	Cala Homes	FD	651.0	9.94	4.96	2.88	16.12	33.9	29.32%	14.63%	8.50%	47.55%	5.21%
42	42 Cullen	Cala Homes	FD	530.0	14.48	4.48	0.00	13.72	32.68	44.31%	13.71%	0.00%	41.98%	6.17%
43	43 Baillie	Cala Homes	FD	385.0	7.84	0.64	0.00	7.28	15.76	49.75%	4.06%	0.00%	46.19%	4.09%
44	44 Caddell	Cala Homes	FD	472.0	10.92	0.00	0.00	12.48	23.4	46.67%	0.00%	0.00%	53.33%	4.96%
45	45 Buchanan	Cala Homes	FD	428.0	7.44	3.00	0.00	16.56	27	27.56%	11.11%	0.00%	61.33%	6.31%
46	46 Brodie	Cala Homes	FD	374.0	6.48	0.96	2.88	10.68	21	30.86%	4.57%	13.71%	50.86%	5.61%
47	47 Drummond	Cala Homes	FD	477.0	12.52	0.00	0.96	12.52	26	48.15%	0.00%	3.69%	48.15%	5.45%
48	48 Moidart	Cala Homes	FD	551.0	9.76	0.00	10.20	5.40	25.36	38.49%	0.00%	40.22%	21.29%	4.60%
49	49 Ballantyne	Cala Homes	FD	377.0	9.92	1.92	1.92	15.00	28.76	34.49%	6.68%	6.68%	52.16%	7.63%
50	50 Bruce	Cala Homes	FD	403.0	8.96	0.00	0.00	7.66	16.62	53.91%	0.00%	0.00%	46.09%	4.12%
51	51 Kennaway	Cala Homes	FD	588.0	14.68	0.00	0.00	12.00	26.68	55.02%	0.00%	0.00%	44.98%	4.54%
52	52 Eardley	Cala Homes	FD	594.0	12.12	1.68	2.76	9.96	26.52	45.70%	6.33%	10.41%	37.56%	4.46%
53	53 Guthrie	Cala Homes	FD	576.0	8.08	1.12	11.00	9.08	29.28	27.60%	3.83%	37.57%	31.01%	5.08%

54	54 Mylne	Cala Homes	FD	717.0	12.40	0.72	1.68	14.96	29.76	41.67%	2.42%	5.65%	50.27%	4.15%
55	55 Carlyle	Cala Homes	FD	447.0	7.92	0.84	0.84	14.92	24.52	32.30%	3.43%	3.43%	60.85%	5.49%
56	56 Forres	Cala Homes	FD	555.0	10.80	0.72	9.80	8.64	29.96	36.05%	2.40%	32.71%	28.84%	5.40%
57	57 Carolina	Cala Homes	B	502.0	13.60	3.24	0.00	9.28	26.12	52.07%	12.40%	0.00%	35.53%	5.20%
58	58 Colorado	Cala Homes	B	568.0	7.28	1.44	5.04	8.52	22.28	32.68%	6.46%	22.62%	38.24%	3.92%
59	59 Farnham	Cala Homes	FD	521.0	6.16	3.64	3.12	8.12	21.04	29.28%	17.30%	14.83%	38.59%	4.04%
60	60 Horseley	Cala Homes	FD	543.0	10.08	4.20	8.84	9.52	32.64	30.88%	12.87%	27.08%	29.17%	6.01%
61	61 Suilven	Cala Homes	FD	529.0	5.44	3.08	2.04	14.56	25.12	21.66%	12.26%	8.12%	57.96%	4.75%
62	62 Cockburn	Cala Homes	FD	462.0	9.32	3.60	1.68	11.08	25.68	36.29%	14.02%	6.54%	43.15%	5.56%
63	63 Melville	Cala Homes	FD	691.0	12.52	1.68	3.36	13.80	31.36	39.92%	5.36%	10.71%	44.01%	4.54%
64	64 Suilven2	Cala Homes	FD	552.0	7.28	2.24	3.80	14.28	27.6	26.38%	8.12%	13.77%	51.74%	5.00%
65	65 Aytoun	Cala Homes	R	363.0	8.88	6.68	0.84	4.56	20.96	42.37%	31.87%	4.01%	21.76%	5.77%
66	66 Pageant	Wimpey Homes	FD	135.0	11.76	0.84	0.84	18.48	31.92	36.84%	2.63%	2.63%	57.89%	23.64%
67	67 Mardi Gras	Wimpey Homes	FD	133.7	10.40	0.84	0.00	13.96	25.2	41.27%	3.33%	0.00%	55.40%	18.85%
68	68 Carnival	Wimpey Homes	FD	99.5	9.68	0.00	0.72	10.64	21.04	46.01%	0.00%	3.42%	50.57%	21.15%
69	69 Accors	Wimpey Homes	FD	106.1	10.00	0.00	2.52	11.12	23.64	42.30%	0.00%	10.66%	47.04%	22.29%
70	70 Jubilee	Wimpey Homes	FD	148.1	9.00	1.44	0.00	13.12	23.56	38.20%	6.11%	0.00%	55.69%	15.90%
71	71 Braemar	McLean Homes	FD	102.0	7.00	0.84	0.00	11.88	19.72	35.50%	4.26%	0.00%	60.24%	19.34%
72	72 Nevis	McLean Homes	FD	115.0	8.40	3.12	0.72	11.60	23.84	35.23%	13.09%	3.02%	48.66%	20.73%
73	73 Culzean	McLean Homes	FD	120.9	8.12	0.72	0.72	13.60	23.16	35.06%	3.11%	3.11%	58.72%	19.15%
74	74 Holyrood	McLean Homes	FD	104.2	11.04	0.00	1.28	10.92	23.24	47.50%	0.00%	5.51%	46.99%	22.30%
75	75 Maxima	Wimpey Homes	FT	59.4	4.08	0.00	0.84	6.24	11.16	36.56%	0.00%	7.53%	55.91%	18.79%
76	76 Practica	Wimpey Homes	FT	66.2	7.12	0.00	0.84	7.96	15.92	44.72%	0.00%	5.28%	50.00%	24.03%
77	77 Ultima	Wimpey Homes	FT	76.9	7.28	0.84	0.00	6.84	14.96	48.66%	5.61%	0.00%	45.72%	19.46%
78	78 Alpha	Wimpey Homes	FT	76.9	7.28	0.00	0.84	6.84	14.96	48.66%	0.00%	5.61%	45.72%	19.46%
79	79 Carnegie	Wimpey Homes	FS	79.6	7.28	0.00	1.40	6.84	15.52	46.91%	0.00%	9.02%	44.07%	19.50%
80	80 Baird	Wimpey Homes	FS	85.0	7.28	1.44	0.96	6.72	16.4	44.39%	8.78%	5.85%	40.98%	19.29%
81	81 Fleming	Wimpey Homes	FS	67.9	5.88	0.00	0.00	7.12	13	45.23%	0.00%	0.00%	54.77%	19.15%

82	82 Strathspey	McLean Homes	FD	151.9	7.64	5.32	2.52	11.32	26.8	28.51%	19.85%	9.40%	42.24%	17.64%
83	83 Buchan	Wimpey Homes	FD	90.0	6.32	0.72	0.72	8.40	16.16	39.11%	4.46%	4.46%	51.98%	17.96%
84	84 Bruce	Wimpey Homes	FS	70.0	5.60	0.72	0.72	6.72	13.76	40.70%	5.23%	5.23%	48.84%	19.66%
85	85 Scott	Wimpey Homes	FD	80.0	5.56	0.72	0.72	8.04	15.04	36.97%	4.79%	4.79%	53.46%	18.80%
86	86 Gala	Wimpey Homes	FD	105.6	12.40	0.00	3.08	12.60	28.08	44.16%	0.00%	10.97%	44.87%	26.60%
87	87 Sienna	Wimpey Homes	FD	83.1	8.58	0.00	0.00	8.48	17.06	50.29%	0.00%	0.00%	49.71%	20.53%
88	88 Prima	Wimpey Homes	FT	77.8	6.32	0.00	0.72	7.44	14.48	43.65%	0.00%	4.97%	51.38%	18.61%
89	89 Sancta	Wimpey Homes	FD	85.3	7.44	0.00	0.00	6.56	14	53.14%	0.00%	0.00%	46.86%	16.42%
90	90 Tableau	Wimpey Homes	FD	117.9	10.20	0.00	0.00	14.12	24.32	41.94%	0.00%	0.00%	58.06%	20.64%
91	91 Rio	Wimpey Homes	FD	85.9	5.60	0.72	0.00	10.44	16.76	33.41%	4.30%	0.00%	62.29%	19.51%
92	92 Lara	Wimpey Homes	FT	55.2	4.32	0.00	0.00	6.72	11.04	39.13%	0.00%	0.00%	60.87%	20.00%
93	93 Anthem	Wimpey Homes	FD	129.7	13.02	0.00	0.72	14.00	27.74	46.94%	0.00%	2.60%	50.47%	21.39%
94	94 Laurel	Wimpey Homes	FD	109.5	10.40	0.72	0.00	11.76	22.88	45.45%	3.15%	0.00%	51.40%	20.90%
95	95 Beta	Wimpey Homes	FS	64.5	4.52	0.00	0.00	6.48	11	41.09%	0.00%	0.00%	58.91%	17.06%
96	96 Crail	McLean Homes	FD	90.0	5.04	2.40	0.00	9.20	16.64	30.29%	14.42%	0.00%	55.29%	18.49%
97	97 Gullane	McLean Homes	FD	115.0	10.16	0.72	0.00	10.96	21.84	46.52%	3.30%	0.00%	50.18%	18.99%
98	98 Ravelston	McLean Homes	FD	120.0	10.60	0.72	0.00	14.96	26.28	40.33%	2.74%	0.00%	56.93%	21.90%
99	99 Leven	McLean Homes	FD	120.0	10.00	0.00	0.72	13.88	24.6	40.65%	0.00%	2.93%	56.42%	20.50%
100	A1 Earn	McLean Homes	FD	115.0	8.92	0.72	2.28	9.96	21.88	40.77%	3.29%	10.42%	45.52%	19.03%
101	A2 Belcaskie	Stewart Milne	FS	75.0	5.40	0.00	0.72	6.68	12.8	42.19%	0.00%	5.63%	52.19%	17.07%
102	A3 Doune	Stewart Milne	FS	78.3	6.28	0.00	1.32	7.24	14.84	42.32%	0.00%	8.89%	48.79%	18.95%
103	A4 Airth	Stewart Milne	FS	84.0	5.68	0.60	1.44	9.64	17.36	32.72%	3.46%	8.29%	55.53%	20.67%
104	A5 Kilbryde	Stewart Milne	FD	93.6	6.08	0.60	0.00	7.04	13.72	44.31%	4.37%	0.00%	51.31%	14.65%
105	A6 Chestnut	Stewart Milne	B	105.2	7.62	4.48	1.20	3.48	16.78	45.41%	26.70%	7.15%	20.74%	15.96%
106	A7 Alder	Stewart Milne	R	148.7	11.54	0.00	0.00	8.96	20.5	56.29%	0.00%	0.00%	43.71%	13.79%
107	A8 Willow	Stewart Milne	B	79.5	7.62	0.00	0.60	3.36	11.58	65.80%	0.00%	5.18%	29.02%	14.57%
108	A9 Aspen	Stewart Milne	B	96.5	7.52	1.68	0.66	5.68	15.54	48.39%	10.81%	4.25%	36.55%	16.11%
109	A0 Lime	Stewart Milne	B	103.0	9.30	0.00	0.60	8.36	18.26	50.93%	0.00%	3.29%	45.78%	17.74%

110	B1 Holly	Stewart Milne		B	84.2	9.30	0.00	0.00	5.64	14.94	62.25%	0.00%	0.00%	37.75%	17.74%
111	B2 Ash	Stewart Milne		FD	189.0	9.06	2.16	1.20	13.32	25.74	35.20%	8.39%	4.66%	51.75%	13.62%
112	B3 Oak	Stewart Milne		FD	170.5	10.98	0.00	1.20	9.36	21.54	50.97%	0.00%	5.57%	43.45%	12.63%
113	B4 Hawthorn	Stewart Milne		FD	176.2	16.42	3.12	0.00	11.60	31.14	52.73%	10.02%	0.00%	37.25%	17.67%
114	B5 Laurel	Stewart Milne		FD	176.5	15.48	0.60	9.84	11.96	37.88	40.87%	1.58%	25.98%	31.57%	21.46%
115	B6 Birch	Stewart Milne		R	229.9	12.44	4.56	3.00	5.88	25.88	48.07%	17.62%	11.59%	22.72%	11.26%
116	B7 Cypress	Stewart Milne		R	190.5	14.58	0.00	0.00	12.32	26.9	54.20%	0.00%	0.00%	45.80%	14.12%
117	B8 Hazel	Stewart Milne		B	180.0	9.88	5.24	1.20	12.36	28.68	34.45%	18.27%	4.18%	43.10%	15.93%
118	B9 Sycamore	Stewart Milne		B	166.0	11.44	4.08	3.06	11.28	29.86	38.31%	13.66%	10.25%	37.78%	17.99%
119	B0 Beech	Stewart Milne		B	141.2	10.08	3.52	0.66	10.16	24.42	41.28%	14.41%	2.70%	41.61%	17.30%
120	C1 Maple	Stewart Milne		B	112.3	8.18	3.52	0.00	10.32	22.02	37.15%	15.99%	0.00%	46.87%	19.60%
121	C2 Walnut	Stewart Milne		R	138.4	13.68	0.00	0.72	12.60	27	50.67%	0.00%	2.67%	46.67%	19.51%
122	C3 Mulberry	Stewart Milne		B	68.6	5.34	0.00	0.72	3.36	9.42	56.69%	0.00%	7.64%	35.67%	13.72%
123	C4 Larch	Stewart Milne		R	138.8	10.82	0.00	0.00	9.80	20.62	52.47%	0.00%	0.00%	47.53%	14.85%
124	C5 Poplar	Stewart Milne		R	123.8	10.10	0.00	1.32	7.12	18.54	54.48%	0.00%	7.12%	38.40%	14.97%
125	C6 Cedar	Stewart Milne		B	203.4	8.88	5.28	5.28	19.20	38.64	22.98%	13.66%	13.66%	49.69%	19.00%
126	C7 House One	Robertson Homes	*	B	69.1	3.60	0.00	0.00	3.80	7.4	48.65%	0.00%	0.00%	51.35%	10.71%
127	C8 House Two	Robertson Homes	*	B	79.6	6.32	0.00	0.60	3.60	10.52	60.08%	0.00%	5.70%	34.22%	13.22%
128	C9 House Three	Robertson Homes	*	R	159.5	6.96	3.20	1.20	7.84	19.2	36.25%	16.67%	6.25%	40.83%	12.03%
129	C0 House Four	Robertson Homes	*	B	98.7	0.80	5.52	7.24	2.40	15.96	5.01%	34.59%	45.36%	15.04%	16.18%
130	D1 House Five	Robertson Homes	*	B	100.1	7.00	3.08	0.00	4.48	14.56	48.08%	21.15%	0.00%	30.77%	14.55%
131	D2 House Six	Robertson Homes	*	R	184.8	13.68	0.60	0.60	7.16	22.04	62.07%	2.72%	2.72%	32.49%	11.93%
132	D3 House Seven	Robertson Homes	*	R	189.6	9.20	5.08	3.08	5.56	22.92	40.14%	22.16%	13.44%	24.26%	12.09%
133	D4 House Eight	Robertson Homes	*	B	118.1	8.16	0.00	1.68	5.28	15.12	53.97%	0.00%	11.11%	34.92%	12.80%
134	D5 House Nine	Robertson Homes	*	B	146.7	6.44	3.60	3.96	5.08	19.08	33.75%	18.87%	20.75%	26.62%	13.01%
135	D6 House 11	Robertson	*	B	180.5	13.44	3.40	2.16	11.08	30.08	44.68%	11.30%	7.18%	36.84%	16.66%

		Homes													
136	D7 House 13	Robertson Homes	*	R	109.8	8.20	0.72	0.72	3.68	13.32	61.56%	5.41%	5.41%	27.63%	12.13%
137	D8 House 14	Robertson Homes	*	R	149.3	10.72	0.00	0.00	8.80	19.52	54.92%	0.00%	0.00%	45.08%	13.08%
138	D9 House 15	Robertson Homes	*	R	133.7	8.80	0.00	0.60	7.20	16.6	53.01%	0.00%	3.61%	43.37%	12.41%
139	D0 House 16	Robertson Homes	*	R	162.6	11.20	0.00	0.00	8.56	19.76	56.68%	0.00%	0.00%	43.32%	12.15%
140	E1 House 17	Robertson Homes	*	R	168.0	10.16	2.80	1.00	7.32	21.28	47.74%	13.16%	4.70%	34.40%	12.67%
141	E2 House 18	Robertson Homes	*	R	178.5	11.96	0.00	0.00	9.76	21.72	55.06%	0.00%	0.00%	44.94%	12.17%
142	E3 House 19	Robertson Homes	*	R	169.5	11.28	10.32	2.20	2.80	26.6	42.41%	38.80%	8.27%	10.53%	15.70%
143	E4 House 20	Robertson Homes	*	R	195.1	11.80	4.96	0.00	8.80	25.56	46.17%	19.41%	0.00%	34.43%	13.10%
144	E5 House 21	Robertson Homes	*	R	164.1	9.84	1.20	4.08	12.20	27.32	36.02%	4.39%	14.93%	44.66%	16.64%
145	E6 House 22	Robertson Homes	*	R	205.9	13.68	4.40	3.52	7.66	29.26	46.75%	15.04%	12.03%	26.18%	14.21%
146	E7 House 23	Robertson Homes	*	R	158.9	7.68	3.80	0.72	7.20	19.4	39.59%	19.59%	3.71%	37.11%	12.21%
147	E8 House 24	Robertson Homes	*	FD	181.2	16.40	0.84	6.04	15.36	38.64	42.44%	2.17%	15.63%	39.75%	21.33%
148	E9 House 25	Robertson Homes	*	FD	169.6	10.82	1.44	2.16	13.16	27.58	39.23%	5.22%	7.83%	47.72%	16.27%
149	E0 House 26	Robertson Homes	*	FD	195.2	12.40	1.44	3.48	11.96	29.28	42.35%	4.92%	11.89%	40.85%	15.00%
150	F1 Broughton	Robertson Homes		FD	135.0	9.40	0.96	0.00	12.76	23.12	40.66%	4.15%	0.00%	55.19%	17.13%
151	F2 Kilkerran	Robertson Homes		B	130.0	5.36	3.96	1.20	9.60	20.12	26.64%	19.68%	5.96%	47.71%	15.48%
152	F3 Kindrugan	Robertson Homes		FD	230.0	15.24	0.00	2.04	11.64	28.92	52.70%	0.00%	7.05%	40.25%	12.57%
153	F4 Kinneil	Robertson Homes		FD	185.0	11.16	0.48	0.00	11.04	22.68	49.21%	2.12%	0.00%	48.68%	12.26%
154	F5 Manderston	Robertson Homes		R	230.0	14.36	1.60	0.60	8.28	24.84	57.81%	6.44%	2.42%	33.33%	10.80%
155	F6 Tarquair	Robertson Homes		B	135.0	3.60	4.68	4.80	14.40	27.48	13.10%	17.03%	17.47%	52.40%	20.36%
156	F7 Albion	Robertson Homes		FS	62.8	5.08	0.00	0.00	5.88	10.96	46.35%	0.00%	0.00%	53.65%	17.47%

157	F8 Armida	Robertson Homes	FD	135.0	10.56	1.20	1.20	9.36	22.32	47.31%	5.38%	5.38%	41.94%	16.53%
158	F9 Avalon	Robertson Homes	FD	130.0	8.64	0.00	0.60	10.56	19.8	43.64%	0.00%	3.03%	53.33%	15.23%
159	F0 Bayard	Robertson Homes	FS	80.0	5.72	0.00	0.60	6.32	12.64	45.25%	0.00%	4.75%	50.00%	15.80%
160	G1 Cressida	Robertson Homes	FD	160.0	11.76	0.60	0.00	9.40	21.76	54.04%	2.76%	0.00%	43.20%	13.60%
161	G2 Graces	Robertson Homes	B	75.0	5.28	0.00	0.60	2.88	8.76	60.27%	0.00%	6.85%	32.88%	11.68%
162	G3 Merlin	Robertson Homes	FD	120.0	7.32	0.00	0.00	10.96	18.28	40.04%	0.00%	0.00%	59.96%	15.23%
163	G4 Oberon	Robertson Homes	FS	125.0	5.68	0.00	0.00	7.28	12.96	43.83%	0.00%	0.00%	56.17%	10.37%
164	G5 Orion	Robertson Homes	FD	115.0	5.76	0.80	0.80	8.84	16.2	35.56%	4.94%	4.94%	54.57%	14.09%
165	G6 Rowland	Robertson Homes	FD	120.0	5.56	0.00	0.00	9.36	14.92	37.27%	0.00%	0.00%	62.73%	12.43%
166	G7 Wayland	Robertson Homes	FD	140.0	4.48	0.48	0.40	9.96	15.32	29.24%	3.13%	2.61%	65.01%	10.94%
167	G8 Westerton	Robertson Homes	B	100.0	6.00	0.00	1.00	4.08	11.08	54.15%	0.00%	9.03%	36.82%	11.08%
168	G9 Brodie	Robertson Homes	B	85.0	3.60	0.00	0.60	4.32	8.52	42.25%	0.00%	7.04%	50.70%	10.02%
169	G0 Drummuir	Robertson Homes	R	110.0	6.48	0.60	0.00	4.32	11.4	56.84%	5.26%	0.00%	37.89%	10.36%
170	H1 Aberlour	Robertson Homes	FS	65.0	3.92	0.00	0.60	3.36	7.88	49.75%	0.00%	7.61%	42.64%	12.12%
171	H2 Pitreavie	Robertson Homes	B	85.0	3.68	1.68	1.36	3.44	10.16	36.22%	16.54%	13.39%	33.86%	11.95%
172	H3 Dunure	Robertson Homes	FD	126.0	6.70	0.60	0.00	9.24	16.54	40.51%	3.63%	0.00%	55.86%	13.13%
173	H4 Finavon	Robertson Homes	FD	190.0	11.80	0.00	1.40	11.00	24.2	48.76%	0.00%	5.79%	45.45%	12.74%
174	H5 Kilochan	Robertson Homes	FS	125.0	6.68	0.00	0.00	9.00	15.68	42.60%	0.00%	0.00%	57.40%	12.54%
175	H6 Kilavock	Robertson Homes	FD	145.0	6.20	2.04	1.08	9.56	18.88	32.84%	10.81%	5.72%	50.64%	13.02%
176	H7 Belgrave	Scotia Homes	FD	152.0	8.96	5.12	2.16	11.16	27.4	32.70%	18.69%	7.88%	40.73%	18.03%
177	H8 Gladstone	Scotia Homes	FD	182.0	7.92	0.00	1.44	13.12	22.48	35.23%	0.00%	6.41%	58.36%	12.35%
178	H9 Blenheim	Scotia Homes	FD	217.0	7.92	0.96	3.44	13.12	25.44	31.13%	3.77%	13.52%	51.57%	11.72%
179	H0 Atholl	Scotia Homes	FD	138.0	9.36	0.72	0.00	9.96	20.04	46.71%	3.59%	0.00%	49.70%	14.52%

180	I1 Ballogie	Scotia Homes	FD	113.0	7.52	0.72	0.72	8.12	17.08	44.03%	4.22%	4.22%	47.54%	15.12%
181	I2 Dalhousie	Scotia Homes	B	99.0	6.40	1.68	0.00	6.20	14.28	44.82%	11.76%	0.00%	43.42%	14.42%
182	I3 Dalwhinnie	Scotia Homes	FD	143.0	10.80	0.72	0.72	9.96	22.2	48.65%	3.24%	3.24%	44.86%	15.52%
183	I4 Glenlivet	Scotia Homes	FD	112.0	8.64	0.00	0.00	8.80	17.44	49.54%	0.00%	0.00%	50.46%	15.57%
184	I5 Hoptoun	Scotia Homes	FD	87.0	7.04	0.60	0.00	7.60	15.24	46.19%	3.94%	0.00%	49.87%	17.52%
185	I6 Invercauld	Scotia Homes	B	105.0	6.64	4.52	0.00	6.96	18.12	36.64%	24.94%	0.00%	38.41%	17.26%
186	I7 Kincardine	Scotia Homes	FD	104.0	6.98	0.00	0.00	10.04	17.02	41.01%	0.00%	0.00%	58.99%	16.37%
187	I8 Lochmore	Scotia Homes	FD	126.0	8.42	0.96	0.96	10.00	20.34	41.40%	4.72%	4.72%	49.16%	16.14%
188	I9 Strathallan	Scotia Homes	R	112.0	6.98	0.00	1.12	6.88	14.98	46.60%	0.00%	7.48%	45.93%	13.38%
189	I0 Brodie	Scotia Homes	B	91.0	8.02	0.72	0.00	8.52	17.26	46.47%	4.17%	0.00%	49.36%	18.97%
190	J1 Cluny	Scotia Homes	FD	143.0	8.98	0.72	0.72	10.84	21.26	42.24%	3.39%	3.39%	50.99%	14.87%
191	J2 Earlston	Scotia Homes	R	140.0	10.58	0.00	0.00	10.68	21.26	49.76%	0.00%	0.00%	50.24%	15.19%
192	J3 Huntly	Scotia Homes	FD	178.0	21.78	0.00	1.44	13.04	36.26	60.07%	0.00%	3.97%	35.96%	20.37%
193	J4 Kenmure	Scotia Homes	FD	145.0	8.66	0.72	0.72	15.16	25.26	34.28%	2.85%	2.85%	60.02%	17.42%
194	J5 Lanrick	Scotia Homes	B	101.0	7.04	0.00	1.44	7.32	15.8	44.56%	0.00%	9.11%	46.33%	15.64%
195	J6 Lismore	Scotia Homes	FD	178.0	10.70	1.44	0.00	22.20	34.34	31.16%	4.19%	0.00%	64.65%	19.29%
196	J7 Menzies	Scotia Homes	B	77.0	7.70	0.00	0.00	4.32	12.02	64.06%	0.00%	0.00%	35.94%	15.61%
197	J8 Stuart	Scotia Homes	R	109.0	8.42	0.00	0.00	8.20	16.62	50.66%	0.00%	0.00%	49.34%	15.25%
198	J9 Baillie	Scotia Homes	FD	140.0	11.30	0.72	0.00	10.48	22.5	50.22%	3.20%	0.00%	46.58%	16.07%
199	J0 Carnegie	Scotia Homes	B	133.0	10.10	1.68	0.96	9.28	22.02	45.87%	7.63%	4.36%	42.14%	16.56%
200	K1 Gairloch	Scotia Homes	B	91.0	6.74	0.72	0.00	8.08	15.54	43.37%	4.63%	0.00%	51.99%	17.08%
201	K2 Kinnaird	Scotia Homes	B	76.0	6.74	0.00	0.00	4.56	11.3	59.65%	0.00%	0.00%	40.35%	14.87%
202	K3 Kinnell	Scotia Homes	R	122.0	8.66	1.68	0.00	8.80	19.14	45.25%	8.78%	0.00%	45.98%	15.69%
203	K4 Laudale	Scotia Homes	FD	193.0	11.14	0.72	0.72	12.36	24.94	44.67%	2.89%	2.89%	49.56%	12.92%
204									0	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!

Key

FS	Semi-detached two-storey
FD	Detached two-storey
B	Bungalow (detached or semi-)
FT	Terraced home (one/two-storey)
R	Detached home with Habitable Roof

LOCATION OF ROOMS IN A DETACHED HOME

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50
Door
Main Elevation Left	62	a1
Main Elevation	7	8	9	10	11	13	14	15	16	17	18	19	20	21	23	24	25	26	27	29	30	31	33	35	36	37	40	41	42	43	44	45	46	47	49	50	51	53	54	55	59	60	61	63	64	66	67	68	69	70
	71	72	73	74	82	83	85	86	87	89	90	91	93	94	96	97	98	99	a5	b2	b3	b4	b5	e8	e9	e0	f3	f4	f8	f9	g1	g3	g5	g6	g7	h3	h4	h6	h7	h8	h9	h0	i1	i3	i4	i5	i7	j1	j3	j4
	j6	j9	k4
Main Elevation Right	52	f1	i8
Side A	38
Side B
Back Elevation	48	56
Other (specify)	28	34
	28/34 - Side A but from porch
Living Room location
Main elevation left	17	25	33	37	38	45	46	51	52	63	67	93	b4	b5	e8	e9	f4	h6	h7	h0	i3	i4	i5	i7	i8	j1	j3	j6	j9	k4
Main Elevation	17	39	56	62	a1	e0
Main Elevation right	8	9	10	11	13	15	19	20	21	23	24	26	28	31	34	40	42	43	48	54	55	56	59	62	66	68	69	70	73	74	82	83	85	86	87	89	90	94	97	99	a1	a5	b2	b3	e0	f3	g1	g3	g5	g6
	h3	h4	i1
Side A Top	9	14	16	26	27	28	30	34	35	36	50	66	87	b2	b3	f1	f8	g7
Side A Mid	9	13	14	15	16	19	20	21	23	24	26	27	28	30	31	34	35	36	40	42	43	47	48	54	55	56	59	62	66	68	69	70	73	74	82	83	85	86	87	89	90	94	97	99	a1	a5	b2	b3	e0	f3
	f8	g6	h3	h4	i1
Side A Bottom	8	9	10	11	13	15	19	20	21	23	24	26	28	31	34	38	40	42	43	48	54	55	58	59	62	66	68	69	70	73	74	82	83	85	86	87	89	90	94	97	99	a1	a5	b2	b3	e0	f3	g1	g3	g5
	g6	h3	h4	i1
Side B Top	18	29	33	41	44	45	46	49	51	53	61	64	71	72	91	96	98	e8	e9	f9	h8	h9	i3	j4	j6	k4
Side B Mid	29	33	37	41	45	46	49	51	52	61	63	64	67	93	b4	b5	e8	e9	f4	h0	i3	i4	i5	i8	j1	j3	j4	j6	j9	k4
Side B Bottom	17	25	33	37	38	45	46	51	52	63	67	93	b4	b5	e8	e9	f4	h6	h7	h0	i3	i4	i5	i7	i8	j1	j3	j6	j9	k4
Back Elevation left	7	18	29	33	41	44	45	46	49	51	53	61	64	71	72	91	96	98	e8	e9	f9	h8	h9	i3	j4	j6	k4
Back Elevation	7	18	44	50	60	71	72	91	96	98	f9	g7	h7	h9
Back Elevation right	7	9	14	16	26	27	28	30	34	35	36	47	50	66	87	b2	b3	f1	f8	g7
Interior
None
Kitchen location
Main elevation left	50	96
Main Elevation
Main Elevation right	7	g7
Side A Top	29	41	44	46	51	60	64	71	72	89	91	98	b5	e9	f9	g1	h8	h9	i3	i5	j1	j4
Side A Mid	18	33	44	45	61	64	71	k4
Side A Bottom	7	61	g7
Side B Top	8	9	10	11	13	14	15	16	19	20	21	23	24	26	27	30	36	38	40	42	47	48	52	55	56	66	70	73	74	82	83	85	87	90	94	97	99	a1	b2	b3	e0	f8	g3	g6
Side B Mid	28	34	35	50
Side B Bottom	50	96
Back Elevation left	8	9	10	11	13	14	15	16	19	20	21	23	24	26	27	30	36	38	40	42	47	48	52	55	56	66	70	73	74	82	83	85	87	90	94	97	99	a1	b2	b3	e0	f8	g3	g6
Back Elevation	17	25	27	31	37	38	43	49	53	54	59	62	63	67	68	69	74	82	85	86	93	a5	b3	b4	b5	e8	f1	f3	f4	g5	g6	h3	h4	h6	h7	h0	i1	i3	i4	i7	i8	j1	j3	j4	j6	j9
Back Elevation right	29	41	44	46	51	60	64	71	72	89	91	98	b5	e9	f9	g1	h8	h9	i3	i5	j1	j4
Interior
None
Dining location
Main elevation left	9	14	26	41	47	49	56	87	f1	f3	h8	h9	j4
Main Elevation	52	53	62	64	f1
Main Elevation right	16	18	25	27	29	30	36	44	51	71	72	91	98	e8	f8	f9	j3	j6
Side A Top	8	10	11	13	15	19	20	21	23	24	31	40	42	43	48	54	55	59	68	69	70	73	74	82	83	85	86	90	94	96	97	99	a1	a5	b3	e8	e0	g3	g5	g6	h3	h4	i1
Side A Mid	7	e8	j3
Side A Bottom	16	18	25	27	29	30	36	44	51	53	71	72	91	98	e8	f8	f9	j3	j6
Side B Top	17	37	50	60	63	67	89	93	b4	f4	g1	g7	h6	h7	h0	i3	i4	i5	i7	i8	j1	j9
Side B Mid	14	38	56	b5
Side B Bottom	9	14	26	41	47	49	56	87	f1	f3	h8	h9	j4
Back Elevation left	17	37	50	60	63	67	89	93	b4	f4	g1	g7	h6	h7	h0	i3	i4	i5	i7	i8	j1	j9
Back Elevation	28	33	34	35	45	46	61	66	b2	e9	g1	k4
Back Elevation right	8	10	11	13	15	19	20	21	23	24	31	40	42	43	48	54	55	59	68	69	70	73	74	82	83	85	86	90	94	96	97	99	a1	a5	b3	e8	e0	g3	g5	g6	h3	h4	i1
Interior
None
Utility location
Main elevation left	16	30
Main Elevation
Main Elevation right	33	45	46	61	64
Side A Top	17	37	38	49	52	53	56	63	67	93	b4	f4	h6	h7	h0	i4	i8	j3	j9	k4
Side A Mid	29	41	50	51	60	e9	f9	g1	h8	h9	i3	j1	j4	j6
Side A Bottom	33	45	46	61	64
Side B Top	25	31	43	54	62	68	69	86	a5	b5	f1	f3	g5	h3	h4	i1
Side B Mid	10	11	19	20	21	26	27	36	40	42	44	47	55	59	66	70	82	90	b2	b3	e0	f1	g3	g6	h3
Side B Bottom	16	28	30	34	35
Back Elevation left	25	31	43	54	62	68	69	86	a5	b5	f1	f3	g5	h3	h4	i1
Back Elevation	48	e8	f8
Back Elevation right	17	37	38	49	52	53	56	63	67	93	b4	f4	h6	h7	h0	i4	i8	j3	j9	k4
Interior
None	7	8	9	13	14	15	18	23	24	71	72	73	74	83	85	87	89	91	94	96	97	98	99	a1	g7	i5	i7
Family/Study location
Main elevation left	48	54	60	66	82	b3	h4
Main Elevation	50	b2	e8
Main Elevation right	63	b4	e9	f4	i3	j1	j4	j9
Side A Top	18	25	33	45	61	62	f3	j6
Side A Mid	61	b5	h9
Side A Bottom	63	b4	e9	f4	i3	j1	j4	j9
Side B Top	28	34	35	59
Side B Mid
Side B Bottom	48	54	60	66	82	b3	h4
Back Elevation left	28	34	35	59
Back Elevation	14	15	19	20	21	23	24	26	29	30	31	36	37	40	41	42	44	46	47	51	52	53	55	64	67	70	90	93	97	99	e0	j3	k4
Back Elevation right	18	25	33	45	61	62	f3	j6
Interior
None	7	8	9	10	11	13	16	17	38	43	49	56	68	69	71	72	73	74	83	85	86	87	89	91	94	96	98	a1	a5	f1	f8	f9	g1	g3	g5	g6	g7	h3	h6	h7	h8	h0	i1	i4	i5	i7	i8
Toilet location
Main elevation left	7	44	83	85	89	h3	i1
Main Elevation	9	13	14	16	18	23	24	26	27	28	31	33	34	35	36	37	40	43	45	46	49	54	61	63	66	67	70	87	90	91	e9	g1	j3	j6	j9	k4
Main Elevation right	38	50	93	b5	h6	i5
Side A Top	i7
Side A Mid	41	52	72	b3	b4	f1	f4	h7	i4	i8
Side A Bottom	50	93	b5	h6	i5
Side B Top
Side B Mid	15	17	25	42	47	53	60	62	68	69	82	86	99	a1	a5	f3	h4	h8	h9
Side B Bottom	7	44	83	85	89	h3	i1
Back Elevation left
Back Elevation	48	55	599	94
Back Elevation right	58	i7
Interior	10	11	17	19	20	21	29	30	51	64	71	73	74	96	97	98	b2	e8	e0	f8	f9	g3	g5	g6	g7	h0	i3	j1	j4
None	8
Garage (attached to which elevation)
Main Elevation	28	29	30	31	34	35	40	45	46	48	55	56	59	61	67	68	69	70	82	b2	e9	e0	g1
Side A	17	37	38	47	49	50	52	53	60	93	96	b3	f3	f4	h6	h7	h8	h9	h0	i4	i5	i7	i8	j9
Side B	7	8	10	11	13	15	18	19	20	21	23	24	31	43	44	62	71	72	73	74	86	89	90	91	94	97	98	99	a5	f1	f8	f9	g3	g5	g6	g7	h3	i1
Back Elevation
None	9	14	16	25	26	27	33	36	41	42	51	54	63	64	66	83	85	87	a1	b4	b5	e8	h4	i3	j1	j3	j4	j6	k4
Stairs location
Main elevation left	29	91
Main Elevation	28	30	41	46	49	71	93	94	b4	e9
Main Elevation right	14	f1
Side A Top
Side A Mid	38	47	50	72	96	b3	b5	i5	j9
Side A Bottom	14	f1
Side B Top
Side B Mid	7	15	17	83	85	89	a1	g5	g7	h3	h6	i1
Side B Bottom	29
Back Elevation left
Back Elevation	9	16	37	44	87
Back Elevation right
Interior	8	10	11	13	18	19	20	21	23	24	25	26	27	31	33	34	35	36	40	42	43	45	48	51	52	53	54	55	56	59	60	61	62	63	64	66	67	68	69	70	73	74	82	86	90	97	98	99	a5	b2
	e8	e0	f3	f4	f8	f9	g1	g3	g6	h4	h7	h8	h9	h0	i3	i4	i7	i8	j1	j3	j4	j6	k4
None
Bedroom 1 location
Main elevation left	61
Main Elevation
Main Elevation right	47	60
Side A Top
Side A Mid
Side A Bottom	47	60
Side B Top
Side B Mid
Side B Bottom	61
Back Elevation left
Back Elevation
Back Elevation right
Interior
None	7	8	9	10	11	13	14	15	16	17	18	19	20	21	23	24	25	26	27	28	29	30	31	33	34	35	36	37	38	40	41	42	43	44	45	46	48	499	50	51	52	53	54	55	56	59	62	63	64	66
	67	68	69	70	71	72	73	74	82	83	85	86	87	89	90	91	93	94	96	97	98	99	a1	a5	b2	b3	b4	b5	e8	e9	e0	f1	f4	f8	f9	g1	g3	g5	g6	g7	h3	h4	h6	h7	h8	h9	h0	i1	i3	i4
	i5	i7	i8	j1	j3	j4	j6	j9	k4

LOCATION OF ROOMS IN A BUNGALOW

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40
Door																																								
Main Elevation Left																																								
Main Elevation	12	39	57	58	a6	a8	a0	b1	b8	c1	c3	c6	c7	c8	c0	d1	d5	d6	f2	f6	g9	i2	i6	i0	j5	j7	j0	k1	k2											
Main Elevation Right																																								
Side A	g2																																							
Side B	g8	h2																																						
Other (specify)	a9	b9	b0	d4																																				
	A9&b9 - Side B angle off porch																																							
Living Room location																																								
Main elevation left	12	d4	d5	i6	i0	j5	k1																																	
Main Elevation	122	g2	g8	h2																																				
Main Elevation right	57	a6	a8	a9	a0	b1	b8	b9	b0	c1	c3	c7	c8	d1	d6	f6	g2	g8	g9	h2	i2	j7	j0	k2																
Side A Top	39	f6																																						
Side A Mid	39	a8	a0	b1	c3	c7	c8	f6	g8	j0	k2																													
Side A Bottom	57	a6	a8	a9	a0	b1	b8	b9	b0	c1	c3	c7	c8	d1	d6	f6	g2	g8	g9	h2	i2	j7	j0	k2																
Side B Top	c6	c0	f2																																					
Side B Mid	c0	i0	k1																																					
Side B Bottom	12	d4	d5	i6	i0	j5	k1																																	
Back Elevation left	c6	c0	f2																																					
Back Elevation	58	f2																																						
Back Elevation right	39	f6																																						
Interior																																								
None																																								
Kitchen location																																								
Main elevation left	c6	g2																																						
Main Elevation	c0																																							
Main Elevation right																																								
Side A Top	a8	a9	c3	c7	c8	d1	d5	f2	g9	h2																														
Side A Mid	39	a6	d6	i2																																				
Side A Bottom																																								
Side B Top	12	g9	i0	j7	k1	k2																																		
Side B Mid	58	i6	j5																																					
Side B Bottom	c6	g2																																						
Back Elevation left	12	c8	g9	i0	j7	k1	k2																																	
Back Elevation	a0	b1	b8	b9	b0	c1	d4	f6	j0																															
Back Elevation right	57	a8	a9	c3	c7	d1	d5	f2	g8	h2																														
Interior																																								
None																																								
Dining location																																								
Main elevation left	c0																																							
Main Elevation	58	d5	f6																																					
Main Elevation right	39																																							
Side A Top	a0	b1	c7	j0																																				
Side A Mid	57	a6	a9	b8	b9	b0	c1	d1	g8	h2																														
Side A Bottom	39																																							
Side B Top																																								
Side B Mid	12	d4																																						
Side B Bottom	c0																																							
Back Elevation left																																								
Back Elevation	a8	c6	d6	f2	f6	i2	i6	i0	j5	k1																														
Back Elevation right	a0	b1	c7	j0																																				
Interior																																								
None	c3	c8	g2	g9	j7	k2																																		
Utility location																																								
Main elevation left																																								
Main Elevation	c0																																							
Main Elevation right	39	d5																																						
Side A Top	57	a6	b9	b0	c1	d6	i2																																	
Side A Mid	f2																																							
Side A Bottom	39	d5																																						
Side B Top	58	d4	i6	j5																																				
Side B Mid	c6	f6																																						
Side B Bottom																																								
Back Elevation left	58	d4	i6	j5																																				
Back Elevation	a0	b8	j0																																					
Back Elevation right	57	a6	b9	b0	c1	d6	i2																																	
Interior																																								
None	12	a6	a9	b1	c3	c7	c8	d1	g2	g8	g9	h2	i0	j7	k1	k2																								
Family/Study location																																								
Main elevation left	58																																							
Main Elevation																																								
Main Elevation right																																								
Side A Top	b8																																							
Side A Mid																																								
Side A Bottom																																								
Side B Top																																								
Side B Mid																																								
Side B Bottom	58																																							
Back Elevation left																																								
Back Elevation	39	57	b0	c1	c8	d5	f6																																	
Back Elevation right	b8																																							
Interior																																								
None	12	a6	a8	a9	a0	b1	b9	c3	c7	c8	c0	d1	d4	d6	f2	g2	g8	g9	h2	i2	i6	i0	j5	j7	j0	k1	k2													
Toilet location																																								
Main elevation left																																								
Main Elevation	39	c6																																						
Main Elevation right																																								
Side A Top																																								
Side A Mid																																								
Side A Bottom																																								
Side B Top																																								
Side B Mid	d4																																							
Side B Bottom																																								
Back Elevation left																																								
Back Elevation	d6																																							
Back Elevation right																																								
Interior	b8	d5																																						
None	22	57	58	a6	a8	a9	a0	b1	b9	b0	c1	c3	c7	c8	c0	d1	f2	f6	g2	g8	g9	h2	i2	i6	i0	j5	j7	j0	k1	k22										
Bathroom location																																								
Main elevation left																																								
Main Elevation	39	57	c6	d6	f6																																			
Main Elevation right																																								
Side A Top																																								
Side A Mid	58	i6																																						
Side A Bottom																																								
Side B Top																																								
Side B Mid	39	a6	a8	b8	c3	c8	d5	f2	g2	g8	g9	j7	k2																											
Side B Bottom																																								
Back Elevation left																																								
Back Elevation	a9	a0	b1	b9	b0	c1	c7	c0	d1	d4	h2	i2	j5	j0																										
Back Elevation right																																								
Interior	i0	k1																																						
None																																								
Garage																																								
Main Elevation	39	f6																																						
Side A	12	d5	f2	i2	j0																																			
Side B	c6	i6	i0	j5	j7	k1	k2																																	
Back Elevation																																								
None	57	58	a6	a8	a9	a0	b1	b8	b9	b0	c1	c3	c7	c8	c0	d1	d4	d5	d6	g2	g8	g9	h2																	
Bedroom 1 location																																								
Main elevation left	39	57	a6	a8	a0	b9	b0	c7	c8	d1	f2	g8	h2	j7	k2																									
Main Elevation																																								
Main Elevation right	58	i6																																						
Side A Top	12	c6	c0	d4	g2	g9	i0	j5	k1																															
Side A Mid																																								
Side A Bottom	58	i6																																						
Side B Top	a9	b1	b8	c1	c3	d5	d6	f6	i2	j0																														
Side B Mid	57	j0																																						
Side B Bottom	39	57	a6	a8	a0	b9	b0	c7	c8	d1	f2	g8	h2	j7	k2																									
Back Elevation left	a8	b1	b8	c1	c3	d5	d6	f6	i2	j0																														
Back Elevation																																								
Back Elevation right	12	c6	c0	d4	g2	g9	i0	j5	k1																															
Interior																																								
None																																								
Bedroom 2 location																																								
Main elevation left	a9	b1	b8	c1	c3	f6	g9	i2	j0																															
Main Elevation																																								
Main Elevation right	c0	d4	f2	i0	j5	k1																																		
Side A Top	58	c6	i6	j7	k2																																			
Side A Mid																																								
Side A Bottom	c0	d4	f2	i0	j5	k1																																		
Side B Top	39	a6	a8	a0	b9	b0	c7	d1	g2	g8																														
Side B Mid	a9	d6	h2																																					
Side B Bottom	a9	b1	b8	c1	c3	f6	g9	i2	j0																															
Back Elevation left	39	a6	a8	a0	b9	b0	c7	d1	g2	g8																														
Back Elevation	12	57	c8	d5																																				
Back Elevation right	58	c6	i6	j7	k2																																			
Interior																																								
None																																								
Bedroom 3 location																																								
Main elevation left	d6																																							
Main Elevation	12	a9	a0	b1	b9	c1	d4	f6	i2	j5	j0																													
Main Elevation right																																								
Side A Top																																								
Side A Mid	c6																																							
Side A Bottom																																								
Side B Top	57	h2																																						
Side B Mid																																								
Side B Bottom	d6																																							
Back Elevation left	57	h2																																						
Back Elevation	39	58	a6	b8	b0	c8	c0	d1	d5	g8	g9	i6	i0	j7	k1	k2																								
Back Elevation right																																								
Interior																																								
None	a8	c3	c7	f2	g2																																			
Bedroom 4 location																																								
Main elevation left																																								
Main Elevation	58	b8	b0	d6	j0																																			
Main Elevation right	c6																																							
Side A Top																																								
Side A Mid																																								
Side A Bottom	c6																																							
Side B Top																																								
Side B Mid	d6																																							
Side B Bottom																																								
Back Elevation left																																								
Back Elevation	39	57	b9																																					
Back Elevation right																																								
Interior																																								
None	12	a6	a8	a9	a0	b1	c1	c3	c7	c8	c0	d1	d4	f2	f6	g2	g8	g9	h2	i2	i6	i0	j5	j7	k1	k2														
Bedroom 5 location																																								
Main elevation left																																								
Main Elevation																																								
Main Elevation right																																								
Side A Top																																								
Side A Mid																																								
Side A Bottom																																								
Side B Top																																								
Side B Mid	39																																							
Side B Bottom																																								
Back Elevation left																																								
Back Elevation																																								
Back Elevation right																																								
Interior																																								
None	12	57	58	a6	a8	a9	a0	b1	b8	b9	b0	c1	c3	c6	c7	c8	c0	d1	d4	d5	d6	f2	f6	g2	g8	g9	h2	i2	i6	i0	j5	j7	j0	k1	k2					

LOCATION OF ROOMS IN A ROOF-SPACE HOME

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
Door																									
Main Elevation Left	a7	b7	d0	e4	f5																				
Main Elevation	22	32	65	c4	c5	d2	d3	d7	d8	d9	e1	e2	e3	e5	e7	i9	j2	j8	k3						
Main Elevation Right																									
Side A																									
Side B	g0																								
Other (specify)	b6	c9	e6																						
Living Room location																									
Main elevation left	b6	d8	e2	e5	e6	e7	g0	j2	j8																
Main Elevation	g0																								
Main Elevation right	22	32	65	a7	b7	c4	c5	c9	d2	d3	d7	d9	d0	e1	e3	e4	f5	i9	k3						
Side A Top	65																								
Side A Mid	22	32	65	a7	b7	c4	c5	d2	d7	d9	d0	e3	e4	f5	i9										
Side A Bottom	22	32	65	a7	b7	c4	c5	c9	d2	d3	d7	d9	d0	e1	e3	e4	f5	i9	k3						
Side B Top																									
Side B Mid	b6	d8	e2	e6	e7	j2	j8																		
Side B Bottom	b6	d8	e2	e5	e6	e7	g0	j2	j8																
Back Elevation left																									
Back Elevation																									
Back Elevation right	65																								
Interior																									
None																									
Kitchen location																									
Main elevation left																									
Main Elevation																									
Main Elevation right																									
Side A Top	d8	e3	e7	g0	k3																				
Side A Mid	b6	c9	e6																						
Side A Bottom																									
Side B Top	22	65	d7	e1																					
Side B Mid																									
Side B Bottom																									
Back Elevation left	22	65	a7	d7	e1																				
Back Elevation	32	b7	c4	c5	d2	d3	d9	d0	e1	e2	e4	e5	f5	i9	j2	j8									
Back Elevation right	d8	e3	e7	g0	k3																				
Interior																									
None																									
Dining location																									
Main elevation left	65																								
Main Elevation	d0																								
Main Elevation right	g0																								
Side A Top	22	32	a7	b7	c4	c5	d7	d9	e1	f5	i9														
Side A Mid	d3	e3	e4																						
Side A Bottom	g0																								
Side B Top	b6	d8	e2	e6	e7	j2	j8																		
Side B Mid	e5																								
Side B Bottom	65																								
Back Elevation left	b6	d8	e2	e6	e7	j2	j8																		
Back Elevation	c9	d2	k3																						
Back Elevation right	22	32	a7	b7	c4	c5	d7	d9	e1	f5	i9														
Interior																									
None																									
Utility location																									
Main elevation left																									
Main Elevation																									
Main Elevation right																									
Side A Top	b6	c9	d2	d3	e5	e6	j2	j8																	
Side A Mid	d8	k3																							
Side A Bottom																									
Side B Top	32	a7	b7	c4	c5	d9	d0	e4	f5	i9															
Side B Mid	65	e1																							
Side B Bottom																									
Back Elevation left	32	a7	b7	c4	c5	d9	d0	e4	f5	i9															
Back Elevation	e2	e3	e7																						
Back Elevation right	b6	c9	d2	d3	e5	e6	j2	j8																	
Interior																									
None	22	d7	g0																						
Family/Study location																									
Main elevation left	c5	d7																							
Main Elevation	a7	b7	d2	d3	f5																				
Main Elevation right	b6	e2	e6	e7	j2																				
Side A Top	d0	e4																							
Side A Mid	b6	e2	e3	e7																					
Side A Bottom	b6	e2	e6	e7	j2																				
Side B Top	e5	g0																							
Side B Mid																									
Side B Bottom	c5	d7																							
Back Elevation left	e5	g0																							
Back Elevation	d8																								
Back Elevation right	d0	e4																							
Interior																									
None	32	22	65	c4	c9	d9	e1	i9	j8	k3															
Toilet location																									
Main elevation left	i9																								
Main Elevation	32	65																							
Main Elevation right																									
Side A Top																									
Side A Mid	e5	g0																							
Side A Bottom																									
Side B Top	k3																								
Side B Mid	22	a7	b7	c5	d0	e1	e4																		
Side B Bottom	i9																								
Back Elevation left	k3																								
Back Elevation	b6	c9	d2	d3	d7	e3	e6	e7																	
Back Elevation right																									
Interior	c4	d8	d9	e2	f5	j2	j8																		
None																									
Garage																									
Main Elevation																									
Side A	e5	j8	k3																						
Side B	22	32	65	a7	b7	c4	d9	d0	e3	e4	i9														
Back Elevation	b6	e6																							
None	c5	c9	d2	d3	d7	d8	e1	e2	e7	g0	j2														
Stairs location																									
Main elevation left																									
Main Elevation	d2	e2	e7	f5																					
Main Elevation right																									
Side A Top																									
Side A Mid	22																								
Side A Bottom																									
Side B Top																									
Side B Mid	c5	g0	i9																						
Side B Bottom																									
Back Elevation left																									
Back Elevation	65	b7																							
Back Elevation right																									
Interior	32	a7	b6	c4	c9	d3	d7	d8	d9	d0	e1	e3	e4	e5	e6	j2	j8	k3							
None																									
Bedroom location																									
Main elevation left	22	d2	e1	e3	k3																				
Main Elevation	e4																								
Main Elevation right	e5																								
Side A Top																									
Side A Mid																									
Side A Bottom	e5																								
Side B Top	c9	d3																							
Side B Mid																									
Side B Bottom	22	d2	e1	e3	k3																				
Back Elevation left	c9	d3																							
Back Elevation																									
Back Elevation right																									
Interior																									
None	32	65	a7	b6	b7	c4	c5	d7	d8	d9	d0	e2	e6	e7	f5	g0	i9	j2	j8						
Bedroom location																									
Main elevation left	c9	d3																							
Main Elevation																									
Main Elevation right																									
Side A Top																									
Side A Mid																									
Side A Bottom																									
Side B Top	d2																								
Side B Mid																									
Side B Bottom	c9	d3																							
Back Elevation left	d2																								
Back Elevation																									
Back Elevation right																									
Interior																									
None	22	e3	e4	e5	k3																				

LOCATION OF ROOMS IN A SEMI-DETACHED HOME

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Door																		
Main Elevation Left	6	a2	f0															
Main Elevation	79	80	84	95	a3	a4	f7	g4	h5									
Main Elevation Right	1	3	5															
Side A	4																	
Side B	h1																	
Other (specify)	81																	
	81 - Side on into Porch																	
Living Room location																		
Main elevation left	1	3	4	5	h5													
Main Elevation	4	a2	h1															
Main Elevation right	4	6	79	80	81	84	95	a2	a3	a4	f7	f0	g4	h1				
Side A Top																		
Side A Mid	79	80	81	84	95	a2	a3	a4	f7	f0								
Side A Bottom	4	6	79	80	81	84	95	a2	a3	a4	f7	f0	g4	1h				
Side B Top																		
Side B Mid	h5																	
Side B Bottom	1	3	4	5	h5													
Back Elevation left																		
Back Elevation																		
Back Elevation right																		
Interior																		
None																		
Kitchen location																		
Main elevation left																		
Main Elevation																		
Main Elevation right																		
Side A Top	5	79	81	84	95	f7	f0											
Side A Mid																		
Side A Bottom																		
Side B Top	1	3	4	6	80	a2	a3	a4	h1									
Side B Mid																		
Side B Bottom																		
Back Elevation left	1	3	4	6	80	a2	a3	a4	h1									
Back Elevation	g4	h5																
Back Elevation right	5	79	81	84	95	f7	f0											
Interior																		
None																		
Dining location																		
Main elevation left																		
Main Elevation																		
Main Elevation right																		
Side A Top	1	3	4	6	80	a2	a3	a4										
Side A Mid																		
Side A Bottom																		
Side B Top	5	79	81	84	95	f7	f0	g4	h5									
Side B Mid																		
Side B Bottom																		
Back Elevation left	5	79	81	84	95	f7	f0	g4	h5									
Back Elevation																		
Back Elevation right	1	3	4	6	80	a2	a3	a4										
Interior																		
None	h1																	
Utility location																		
Main elevation left																		
Main Elevation																		
Main Elevation right																		
Side A Top	h5																	
Side A Mid	g4																	
Side A Bottom																		
Side B Top																		
Side B Mid																		
Side B Bottom																		
Back Elevation left																		
Back Elevation																		
Back Elevation right	h5																	
Interior																		
None	1	3	4	5	6	79	80	81	84	95	a2	a3	a4	f7	f0	h1		
Family/Study location																		
Main elevation left																		
Main Elevation																		
Main Elevation right																		
Side A Top																		
Side A Mid																		
Side A Bottom																		
Side B Top																		
Side B Mid																		
Side B Bottom																		
Back Elevation left																		
Back Elevation																		
Back Elevation right																		
Interior																		
None	1	3	4	5	6	79	80	81	84	95	a2	a3	a4	f7	f0	g4	h1	h5
Toilet location																		
Main elevation left	79	80	81	84	95	a3	f7											
Main Elevation	1	3	5	6	f0	h5												
Main Elevation right																		
Side A Top	g4																	
Side A Mid	4	h1																
Side A Bottom	h5																	
Side B Top																		
Side B Mid	a2	a4																
Side B Bottom	79	80	81	84	95	a3	f7											
Back Elevation left																		
Back Elevation																		
Back Elevation right	g4																	
Interior																		
None																		
Garage																		
Main Elevation																		
Side A	h5																	
Side B	a4	g4																
Back Elevation																		
None	1	3	4	5	6	79	80	81	84	95	a2	a3	f7	f0	h1			
Stairs location																		
Main elevation left																		
Main Elevation																		
Main Elevation right																		
Side A Top																		
Side A Mid	1	3	5	h5														
Side A Bottom																		
Side B Top																		
Side B Mid	4	6	79	80	81	84	95	a2	a3	a4	f7	g4						
Side B Bottom																		
Back Elevation left																		
Back Elevation																		
Back Elevation right																		
Interior																		
None	h1																	
Bedroom location																		
Main elevation left																		
Main Elevation																		
Main Elevation right	h1																	
Side A Top	h1																	
Side A Mid																		
Side A Bottom																		
Side B Top																		
Side B Mid																		
Side B Bottom																		
Back Elevation left																		
Back Elevation																		
Back Elevation right																		
Interior																		
None	1	3	4	5	6	79	80	81	84	95	a2	a3	a4	f7	g4	h5		

LOCATION OF ROOMS IN A TERRACED HOME

	1	2	3	4	5	6	7	8	9	10
Door										
Main Elevation Left	2	75	76	78	92					
Main Elevation	88									
Main Elevation Right	77									
Side A										
Side B										
Other (specify)										
Living Room location										
Main elevation left	77									
Main Elevation	75	76	77	92						
Main Elevation right	75	76	78	88	92					
Side A Top										
Side A Mid	75	76	78	88	92					
Side A Bottom	75	76	78	88	92					
Side B Top										
Side B Mid	77									
Side B Bottom	77									
Back Elevation left	2									
Back Elevation	2									
Back Elevation right	2									
Interior										
None										
Kitchen location										
Main elevation left	77									
Main Elevation										
Main Elevation right	2									
Side A Top	75	76	78	88	92					
Side A Mid										
Side A Bottom	2									
Side B Top	77									
Side B Mid										
Side B Bottom										
Back Elevation left										
Back Elevation	75									
Back Elevation right	75	76	78	88	92					
Interior										
None										
Dining location										
Main elevation left										
Main Elevation										
Main Elevation right										
Side A Top	77									
Side A Mid	2									
Side A Bottom										
Side B Top	75	76	78	88	92					
Side B Mid										
Side B Bottom										
Back Elevation left	75	76	78	88	92					
Back Elevation										
Back Elevation right	77									
Interior										
None										
Utility location										
Main elevation left										
Main Elevation										
Main Elevation right										
Side A Top										
Side A Mid										
Side A Bottom										
Side B Top										
Side B Mid										
Side B Bottom										
Back Elevation left										
Back Elevation										
Back Elevation right										
Interior										
None	2	75	76	77	78	88	92			
Family Study location										
Main elevation left										
Main Elevation										
Main Elevation right										
Side A Top										
Side A Mid										
Side A Bottom										
Side B Top										
Side B Mid										
Side B Bottom										
Back Elevation left										
Back Elevation										
Back Elevation right										
Interior										
None	2	75	76	77	78	88	92			
Toilet location										
Main elevation left	2	88								
Main Elevation	77	78								
Main Elevation right										
Side A Top										
Side A Mid										
Side A Bottom										
Side B Top										
Side B Mid	75	76	92							
Side B Bottom	88									
Back Elevation left										
Back Elevation										
Back Elevation right										
Interior										
None										
Garage										
Main Elevation										
Side A										
Side B										
Back Elevation										
None	2	75	76	77	78	88	92			
Stairs location										
Main elevation left										
Main Elevation										
Main Elevation right										
Side A Top										
Side A Mid	77									
Side A Bottom										
Side B Top										
Side B Mid	2	75	76	78	88	92				
Side B Bottom										
Back Elevation left										
Back Elevation										
Back Elevation right										
Interior										
None										