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Passive solar space heating in housing with particular reference to the Scottish climate.

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PASSIVE SOLAR SPACE HEATING IN HOUSING WITH PARTICULAR REFERENCE TO THE SCOTTISH CLIMATE

by

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ABSTRACT

COLIN PORTEOUS

PASSIVE SOLAR SPACE HEATING IN HOUSING WITH PARTICULAR REFERENCE TO THE SCOTTISH CLIMATE

The objective of this work was to examine the technical and economic scope for partial passive solar space heating of housing in Scotland.

Initially an appraisal of current need and policy within an historical framework, established that trends towards low-rise, medium density housing with reduced maintenance costs and condensation risk, provide a favourable scenario for passive solar collection.

Climatic analysis has verified quantities of solar irradiation, particularly on vertical surfaces, over a range of Scottish locations. For example, readings for key orientations/slope, taken during 1983 at the Scott Sutherland School of Architecture, indicated close correlation to predicted values using simple sunshine data-based calculation procedures. Solar irradiation values have been cross-related to other relevant climatic features, and a representative hourly Scottish climate year had been compiled for use with a dynamic thermal simulation programme. It was also established that within the U.K. context, Scottish sites are generally in a favourable position for solar utilisation, since heat demand increases with latitude faster than the solar supply decreases.

Known passive solar techniques were thereafter reviewed with the emphasis on establishing thermal design constraints, where the spring to autumn solar heating contribution is seasonally out of phase with an intermittently operated traditional winter heating system. This led to the design of four representative housing models incorporating direct, indirect and isolated passive solar gain features. Included was a local authority project for 22 single person flats, currently under construction in Stornoway, 58° 15'N. Comparative energy simulation analysis has given encouraging results. For example a typical solar flat is predicted to use 36% less electricity for heating than the equivalent non-solar flat.

The conclusion of this work is that passive solar gains and insulative savings are economically compatible thermal strategies for Scottish housing; fuel reductions and/or increased comfort being realised with simultaneous qualitative enhancement of natural sunlight.

NOMENCLATURE

Section 1		unit
f1	frontage width	m
d1	depth of house at ground level	m
d2	depth of house at roof level	m
dx	difference between north faces of d1 & d2	m
h1	height from eaves to ground	m
h2	height from eaves to ridge	m.
h3	height from eaves to ground of adjacent terrace	m
w	wall thickness	m
a_n	net floor area of house within external walls	m^2
z	number of storeys	-
x	plot depth, including share of access roads	m
^{o}R	ridge shading angle to base of adjacent terrace	degrees
^{o}P	roof pitch	degrees
^{o}S	slope of ground between parallel terraces	degrees
Dn	net density of housing development	houses/ha
Dc	'characteristic' density of housing plots	houses/ha
t	proportion total site area devoted to house plots or ratio Dn:Dc	-
y	permitted radiation loss on a surface	%

Section 2		unit
Ho	solar irradiation on a horizontal plane in the absence of any atmosphere	MJ/m^2 or KWh/m^2
H	global solar irradiation on a horizontal plane	MJ/m^2 or KWh/m^2
Hd	diffuse solar irradiation on a horizontal plane	MJ/m^2 or KWh/m^2
HG	global solar irradiation on vertical and inclined planes	MJ/m^2 or kWh/m^2
HGVS	global solar irradiation on a south facing vertical plane	MJ/m^2 or KWh/m^2
HGLS	global solar irradiation on a south facing latitude angle plane	MJ/m^2 or KWh/m^2
HGVE	global solar irradiation on an east facing vertical plane	MJ/m^2 or KWh/m^2
HGVW	global solar irradiation on a west facing vertical plane	MJ/m^2 or KWh/m^2
HGVN	global solar irradiation on a north facing vertical plane	MJ/m^2 or KWh/m^2
Note:	unless otherwise stated in text, above symbols denote monthly mean daily values	
n	monthly mean daily duration of bright sunshine	hours
No	monthly mean of possible daily duration of bright sunshine	hours
R	monthly mean solar geometry factor for surface of given latitude, slope and azimuth	-
r	ground reflection co-efficient (taken as 0.2 unless otherwise stated)	-
s	angle of inclination of surface	degrees
a & b	climatically determined constants used in regression equation (i): $H/Ho = a + (b \times n/No)$	-
c & d	climatically determined constants used in equation (ii): $Hd/H = c + (d \times H/Ho)$	-

Section 3

		unit
t_o	outside air temperature	^oC
ti	inside air temperature	^oC
Δt	temperature differential	K
D	density	kg/m^3
V	volume	m^3
m	mass (=D X V)	kg
$Q/m\Delta t$	specific heat J/kgK÷3600 =	Wh/kgK
$Q/\Delta t$	thermal capacity (m x $Q/m\Delta t$÷1000)	kWh/K
U sp	specific heat loss	W/K
U a	heat loss per unit area	W/m^2K
U vol	volumetric heat loss	W/m^3K
Qg	gross space heating energy load (including casual and solar load surplus to ti requirements)	kWh or MJ
Qs	casual/solar load surplus to ti requirements	kWh or MJ
Q	net space heating energy load (building fabric/conductance losses) (Qg-Qs)	kWh or MJ
Qg.cas	gross casual load (from people, lighting and appliances)	kWh or MJ
Qs.cas	surplus casual load	kWh or MJ
Qcas	useful casual load (Qg.cas - Qs.cas)	kWh or MJ
Qg.sol	gross solar load	kWh or MJ
Qs.sol	surplus solar load	kWh or MJ
Qsol	useful solar load (Qg.sol - Qs.sol)	kWh or MJ
Q htg	heating plant load (Q - Qcas - Qsol)	kWh or MJ

INTRODUCTION

A positive passive solar design approach to meet a significant proportion of the energy requirements of a dwelling has only recently begun to be analysed systematically for sites in northern Europe. While there are low winter irradiation levels, with a high diffuse proportion, in the U.K. 50-60^{o}N latitude range, there is also a relatively long heating season. The heat demand, generated by air temperature, wind and relative humidity also increases significantly with latitude. Scottish locations can therefore be in a more favourable position with respect to passive solar utilisation for space heating, than typical English locations much further to the south. However, since the late 1970's, although some attention has been given to opportunities within the U.K. medium density mass housing market, there are still very few completed projects, and none in Scotland. One reason for this lack of impetus is assumed to be the lack of sufficient data for building designers to predict the delicate balance between performance and cost.

The problem with compiling a useful information library in the field of passive solar design, as with all scientific research, lies with identifying the limits of the relevant variables in the system to be analysed. One set of variables which dictate the potential for collecting solar irradiation stems from planning policy. These are primarily concerned with the geometric characteristics of housing layout - for example, height, spacing and frontage width. Then there are a further set of building design variables still within the architects control - for example, proportions of glazing, of various orientations and tilt, to heated volume and thermal storage capacity; the thermal resistance provided by the composite constructional elements; and the thermal response of interior spaces to heat input, associated with the location of resistance, or insulation, in relation to high or low thermal capacity room linings.

Another series of variables critical to analysis is the annual, seasonal, monthly, daily and hourly fluctuations of relevant climatic features. However, even Scotland's apparently unpredictable weather, with intermittent solar supply, displays uniform characteristics over a reasonable period of time. For example, measurement of radiation on a surface in a particular hour on each day of a month may typically vary 85% above or below the mean. However, the limits of both maximum and minimum values for that particular hour do not vary greatly, and the monthly mean hourly value in any year, is likely to be within ± 10% of the corresponding value over a period of several years. It has therefore been possible, to compile a representative Scottish climate file, where maximum, minimum and mean hourly, daily, monthly and annual values correspond closely with long-term measured values.

Finally, and perhaps most difficult to identify, are human occupancy variables. These may be dictated by such factors as individual physiological differences, setting comfort levels for heat and ventilation, the thermal needs of various family groupings related to occupancy profiles, and/or the economic means to purchase traditional heating energy.

Having set limits or reasonable means to all critical variables, useful comparative analysis has been possible, establishing economically feasible directions for passive solar heating design, within current statutary building standards for housing in Scotland. The project by the Western Isles Islands Council, currently under construction in Stornoway will hopefully provide an increased data-base of knowledge, and encourage other housing authorities to embark on passive solar heating systems.

SECTION 1

HOUSING STRATEGY ANALYSIS

1.1 Analysis of Scottish Housing Statistics, Characteristics and Future Strategy

1.1.1 Housing Need

(i) Number of Dwellings Related to Number of Households

Since 1952 Scotland has moved from an approximate balance between the number of households and number of dwellings, to a position of imbalance, where by 1978 there were 1.96 million houses to 1.78 million households.

However, this does not mean that the housing need is met[1]. This is due to a number of factors, such as the large number of dwellings below a tolerable standard, and the mis-match of geographical distribution of excess stock to current need, brought about by shifting patterns of industry and employment.

Rather, the emergence of a theoretical housing surplus does mean that past strategies, with emphasis simply on increasing housing stock, requires re-appraisal - for example, house-building to meet the needs of specific groups such as elderly, disabled and single persons. Most important for future housing policy will be identifying not only the changes in population, household and family trends, but also the thermal/energy related causes of physical and social deprivation within the housing context.

(ii) Trends in Household Size

The underlying trend in the Scottish housing situation throughout this century does directly reflect general improvements of living standards, resulting in an increasing number of households with correspondingly decreasing household size and increasing space per person. This trend is maintained while the population itself is generally decreasing, and in growth areas where there is still an increasing population, for example Grampian, Central and Fife regions, there is a proportionately higher rate of growth of the number of households.

In 1901 the average household size was 4.6, with 1.5 persons per room, in 1971 3.0, with 0.8 persons per room, and this is predicted to fall to 2.6 over the 20 year period to 1991[2]. Since it is estimated that a 0.1 reduction per household produces 65,000 additional households over a 10 year period[3], a 0.4 reduction over 20 years represents 260,000 households, a mean growth of 13,000 per annum. On current trends, approximately 77% of this growth will be in the public sector[2].

It is also noteworthy that currently 47% of the total public sector comprises 1-2 person households[1], and there is a rapid increase in the number of single person households, expected to reach 25% of the total by 1991[2]. Since 1-2 person households form such a large percentage of the total, this means that larger family households comprising approximately half the stock will have a mean size of approximately 3.5, considerably higher than the 2.6 predicted mean for 1991.

(iii) Summary of Predicted Demand

The predicted trend in the forseeable future in Scotland, is for 3,4 and 5 person households to comprise approximately half, and 2 and 1 person households one quarter each of the total stock. Homes should increase by 10,000 per annum in the public sector in order to fulfil the need during this decade.

1.1.2. Tenure, Age and Type

(i) Tenure

The tenure distribution in Scotland is markedly different compared with the U.K. as a whole. Public sector housing was launched in 1919 with the Housing, Town Planning etc (Scotland) Act, and since 1945 over 80% of the new housing in Scotland has been in the public sector. In 1978 a tenure breakdown of total housing stock in Scotland, compared to the U.K. as a whole, was as follows[3]:

	Public Rented	Private Rented & Others	Owner Occupied
Total Scotland	54.2%	12.7%	33.1%
Post '45 "	80.0%	3.0%	17.0%
Total U.K.	31.3%	15.9%	52.8%

(ii) Type

An appraisal of housing types shows a definite trend back from high density flats to medium density terraces[1]:

	detached	semi-d	terraced	flats
Post-War:	9%	22%	31%	38%
Inter-War:	9%	23%	9%	59%

It should be noted, however, that most inter-war flats were low to medium-rise whilst the majority of the post-war flats are high-rise. This culminated in the late 1960's and early 1970's when Scotland built proportionately more high-rise, high density public sector housing than the rest of the U.K. For example in 1966, Glasgow was noted for having built the highest flats in Europe at 25 storeys. However, realisation of the severity of social and practical problems associated with vertical isolation, has now led to a radical policy re-appraisal, tending back to a low-rise, medium density, terraced configuration[4]. Glasgow District Council, for example, has recently taken the decision to limit housing height to 3 storeys. This is significant in that political housing strategy now runs with the grain of passive solar design precepts, favouring two fundamental criteria - maximum shelter and minimum overshading.

1.1.3. Thermal and Social Factors

(i) Thermal/Social Characteristics

The thermal characteristics of much of the post-1945 Scottish housing stock are also distinctive, and linked to social factors in the following respects:

a Severe exposure to wind and rain, due to both natural climatic features and also high-rise developments, resulting in high rates of heat transfer, and hence increased condensation risk.

b Poor insulation and massive precast concrete construction, particularly of high-rise housing, resulting in slow thermal response, low surface temperatures and high incidence of condensation unless continuously heated.

c Low capital cost motivation, resulting in specification of inappropriate, slow-response heating systems, such as electric underfloor heating, with running costs outwith the financial means of a large proportion of the occupants. Long-term economic recession, with high fuel cost increases in the 1970's, has resulted in progressively more widespread social deprivation of a nature formerly associated only with Scotland's declining industrial areas. Together with a high heating demand due to climate, this has resulted in extensive use of flueless, portable gas and paraffin appliances in new as well as old housing. These provide an immediate source of convected/ radiant heat, but with a high water vapour output, exacerbating the condensation risk which is already high, due to the first two factors. A recent 'new town' survey in an all-electric scheme showed that as many as 50% of the households were using such appliances in lieu of the designed heating system[5].

d Another feature of space heating in housing occupied by low income groups, is that although a greater proportion of income is spent on fuel, it is a lower absolute expenditure than that of higher income groups, resulting in a lower quality thermal environment[6]. This leads not only to temperatures well below comfort standards, but also to spatial shrinkage - that is rooms not used during winter months in the lowest income sector.

(ii) Thermal Standards

Thermal/social characteristics, therefore, ensure that homes are unhealthy, damp and uncomfortably cold during the heating season for a large section of the population. Thermal standards are currently defined by Building Standards (Scotland) Regulations 1981 and Building Standards (Scotland) Amendment Regulations 1982 in three ways:

a Minimum areas and ceiling heights - ie minimum volumes, (Regulations Q5 and Q6).

b Provision of a heating system, (regulation Q15), and adequate ventilation, (Regulations K3-K7).

c Maximum U-values for opaque external bounding surfaces and maximum percentage glazed areas for roofs and perimeter walls, including party walls, (Regulation J3). Percentages are adjusted for double and triple glazing, and 'trade-offs' are permitted between windows and roof lights. Similar 'trade-offs' are permitted between opaque wall and roof surfaces, but none are permitted between opaque and glazed surfaces. In other words window areas cannot be increased above the stipulated percentages, by increasing the thermal resistance of the adjacent wall or roof surfaces.

It is possible for housing to comply in every respect to current regulations, but in reality to be thermally sub-standard due to factors described above. A practical improvement therefore, is that standards should be re-defined by specifying a maximum rate of heat loss per unit volume of house. This would place a limit on fuel expenditure in relation to comfort conditions, and take account of regional or local climatic variations. It would also be more in sympathy with a passive solar design approach, taking account of insolation and thermal storage capacity.

1.2. Analysis of Influence of Housing Strategy/Land Use on Passive Solar Design

1.2.1. Introducing a System

The purpose of this section is to analyse interactions between standards, constraints, built form and land use in order to define basic planning guidelines for passive solar heating design, the criterion being that amount of overshadowing which causes a certain percentage of available energy to be lost.

Section 1.1 has established the extent and categories of housing need in Scotland for the forseeable future, and qualitatively judged that aspects of official housing policy, whether derived from political, social or economic considerations, now broadly favour passive solar prerequisites. This sub-section explores limits for variables in measured geometric terms within the context of a recognisable architectural/planning model or system.

1.2.2. Defining a System

(i) A considerable amount of work in this field has been carried out by the Martin Centre of Urban and Architectural Studies at Cambridge. Notably, O'Cathain[7] has developed a simple graphical output, for a system expressing a terraced housing configuration. This enables the designer to read at a glance what combination of frontage widths, storey heights and plot depths are possible, at a given density, proportion of total site devoted to house plots, orientation and level of radiation loss.

His findings are encouraging, showing that passive solar housing is feasible at a wide range of densities, and even with 3 storey housing.

(ii) In order to set reasonable limits to the variables in the system, the following has been assumed:

(a) Frontage width, 'fl', to vary between 4-10 metres.

(b) Plot depth, 'x', to be in the range from 20-40 metres.

(c) Net densities, 'Dn', to be in the range of 30-60 houses per hectare.

(d) Proportion of total site area devoted to house plots, 't', (ie ratio of net to 'characteristic' density), to be in range 0.4 - 0.7.

(e) Height limited from single up to 3 storeys.

(f) Variation from due north/south orientation limited to 45° east or west.

(g) Permissable radiation loss limits during Nov-March 10% and 20%.

(iii) O'Cathain's model also assumes the following geometric constraints:

(a) Terraces are parallel.

(b) Terraces are symmetrically spaced around roads and rear gardens, to equalise over-shading of all south facing facades.

(c) The net floor area, 'a_n' for the 'system' house is assumed to be the housing minimum standard for a 5-person dwelling, the value varying according to the number of floors. The relationship assumes that each floor occupies the same area, ie north and south walls are coincident at each floor level, as are party walls. Therefore, frontage width, 'f1', also determines depth, 'd1', the relationship being expressed by $d1 = \frac{an/z}{f1-w} + 2w$, where z = number of storeys and w = wall thickness.

(d) Radiation losses, due to overshadowing, assume roofs are symmetrically pitched at 30^{o}, and a reference level 1.2 m above a level ground.

1.2.3. Modifying the State of the System

Following O'Cathain's work, further variables can be introduced, and the change in the state of the system measured, using the original model as a control.

(i) Variable Roof Pitch

Assuming the ridge shading angle, ^{o}R, $\leqslant$ roof pitch, ^{o}P, the relationship between the roof pitch overshading, and spacing is given by:

$$\tan {}^{o}R = \frac{h1 + h2}{x - d1/2} = \frac{h1 + (\tan {}^{o}P \times d1/2)}{x - d1/2}$$

$$\text{Therefore } x = \frac{d1/2\ (\tan {}^{o}R + \tan {}^{o}P) + h1}{\tan {}^{o}R} \qquad \text{(a)}$$

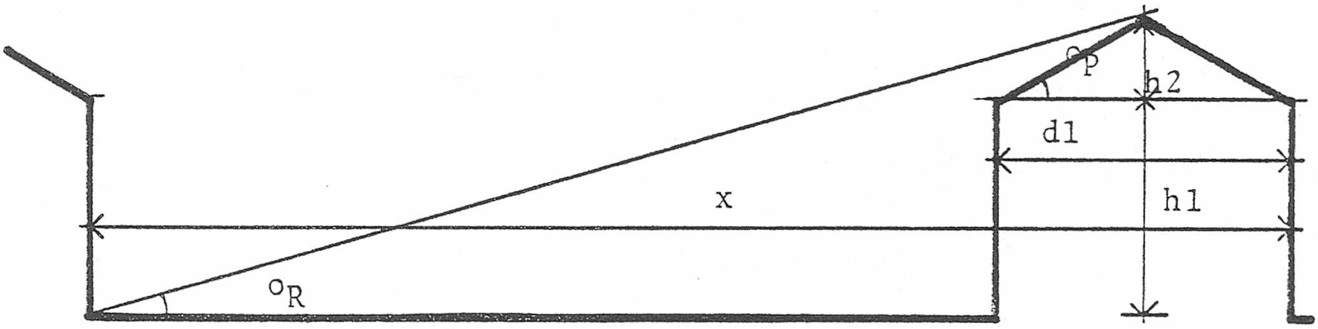


Fig 1 variable roof pitch

For example, by reference to Fig 1, if $d1 = 7.5$ m, $h1 = 5.4$ m, $^{o}P = 30^{o}$ and $^{o}R = 16^{o}$, (corresponding to mid-Nov and mid-Jan, noon solar altitude for 57^{o}N, then:

$$x = \frac{3.75\ (\tan 16 + \tan 30) + 5.4}{\tan 16} = 30 \text{ m approx.}$$

Therefore spacing between terraces = 30-7.5 = 22.5 m. This value corresponds to 10% radiation loss, assuming a medium frontage 2-storey house of 6 m. This could be achieved, for example, at a density of approximately 35 houses per hectare when t = 0.5, or 40 when t = 0.6. Reducing P to 22.5°, results in a spacing reduction of 2 m, consequently increasing density for a given t-value. If the roof pitch remained at 30° and a spacing of 20.5 m were used, then the radiation loss would be in excess of 10%.

(ii) Asymmetric Cross-section

If the first floor does not coincide with the ground floor, and the 1st floor depth is given a second value, 'd2', the north face of which is a distance, 'dx', from the north face of the ground floor, and the ridge is symmetrically located in relation to 'd2', the relationship between ridge overshadowing and spacing will be altered as follows:

$$\tan {}^{o}R = \frac{h1 + h2}{x - (d1 - (dx + d2/2))} = \frac{h1 + d2/2 \tan {}^{o}P}{x - d1 + dx + d2/2}$$

$$\text{Then } x = \frac{\tan {}^{o}R\,(d1 - dx) - d2/2\,(\tan {}^{o}R - \tan {}^{o}P) + h1}{\tan {}^{o}R} \qquad (b)$$

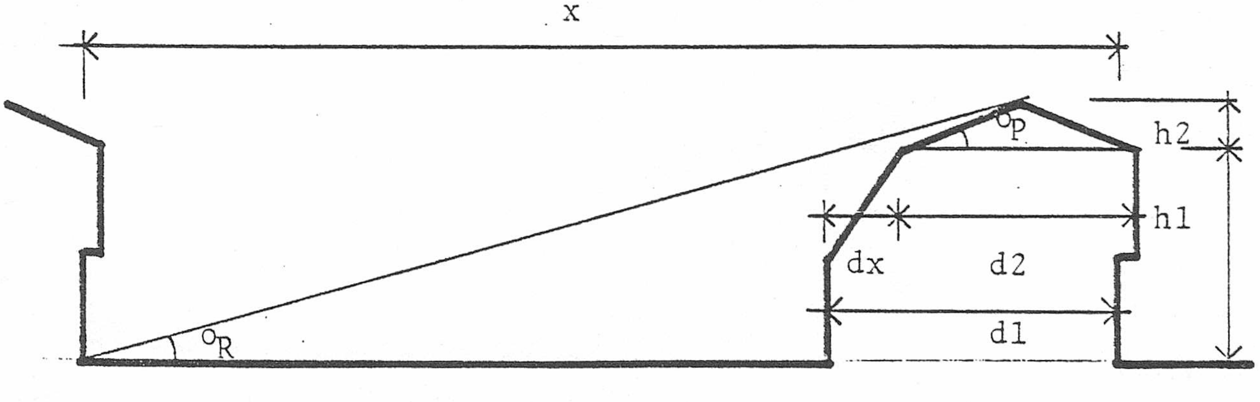


Fig 2 asymmetric cross-section

For example, by reference to Fig 2, if $^{\circ}R$ remains at 16°, $^{\circ}P$ at 22.5°, h1 at 5.4 m, d1 at 7.5 m, and d2 is 6 m and dx is 1.8 m, then:

$$x = \frac{\tan 16(7.5 - 1.8) - 3(\tan 16 - \tan 22.5) + 5.4}{\tan 16}$$

$= 25.86$ m.

Therefore spacing can be reduced to 18.36 m for 10% radiation loss. This demonstrates that blocks can be spaced 4.0 m closer than the system model, without loss of radiation, by slightly modifying the geometry of the cross-section.

(iii) <u>Variable Ground Slope</u>

Ground slope will have either a positive or negative effect on overshadowing. In either case the value of 'h1' in equations (a) and (b) will require to be substituted with a value giving the difference between eaves level in block A to ground level on block B. This is denoted 'h3', where

$h3 = h1 - \tan {^{\circ}S} \, (x - d1)$ for a positive slope.

Substituting this value in equation (a), then:

$$x = \frac{d1/2\ (\text{Tan } {^{\circ}R} + \text{Tan } {^{\circ}P}) + (h1 - \text{Tan } {^{\circ}S}\ (x - d1))}{\tan R}$$

or

$$x = \frac{d1/2\ (\text{Tan } {^{\circ}R} + \text{Tan } {^{\circ}P} + 2\ \text{Tan } {^{\circ}S}) + h1}{\tan {^{\circ}R} + \tan {^{\circ}S}} \qquad (c)$$

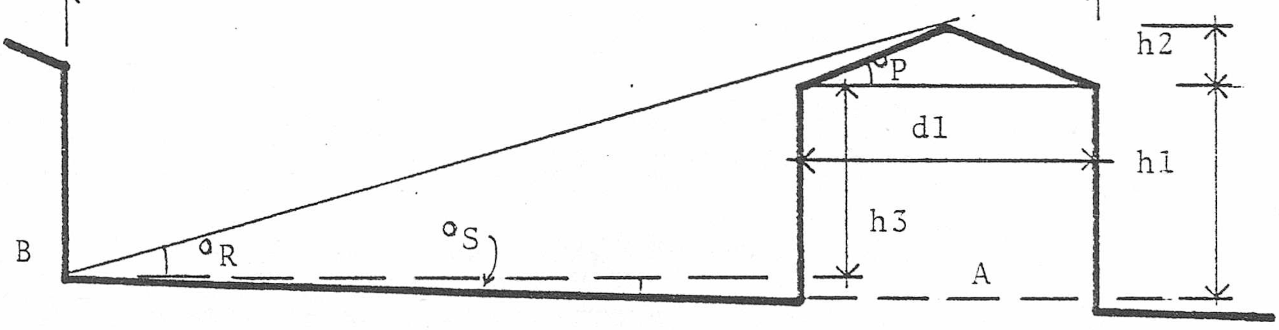


Fig 3 variable ground slope

For example, by reference to Fig 3, if $^{o}S = 2^{o}$, and ^{o}R remains at 16^{o}, ^{o}P at 22.5^{o}, d1 at 7.5 m and h1 at 5.4 m, then:

$$x = \frac{3.75\ (\tan 16 + \tan 22.5 + 2(\tan 2) + 5.4}{\tan 16 + \tan 2} = 25.77\ \mathrm{m}.$$

Therefore spacing can be reduced to 18.27 m within 10% radiation loss.

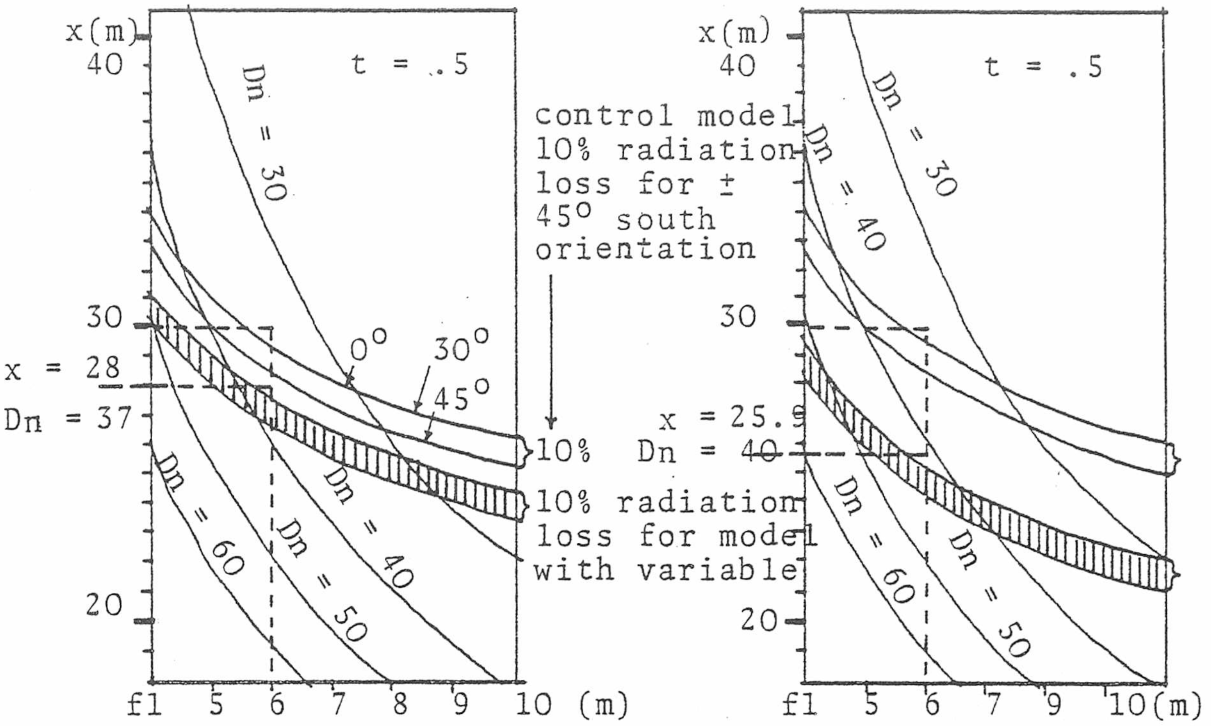
Substituting the value for h3 in lieu of h1 in equation (b),

$$x = \frac{\tan {^{o}R}(d1 - dx) - d2/2(\tan {^{o}R} - \tan {^{o}P}) + \tan {^{o}S}\ d1 + h1}{\tan {^{o}R} + \tan {^{o}S}} \qquad (d)$$

Using the values in the previous example, x = 23.87 m. Therefore spacing can be reduced to 16.37 m, within 10% radiation loss.

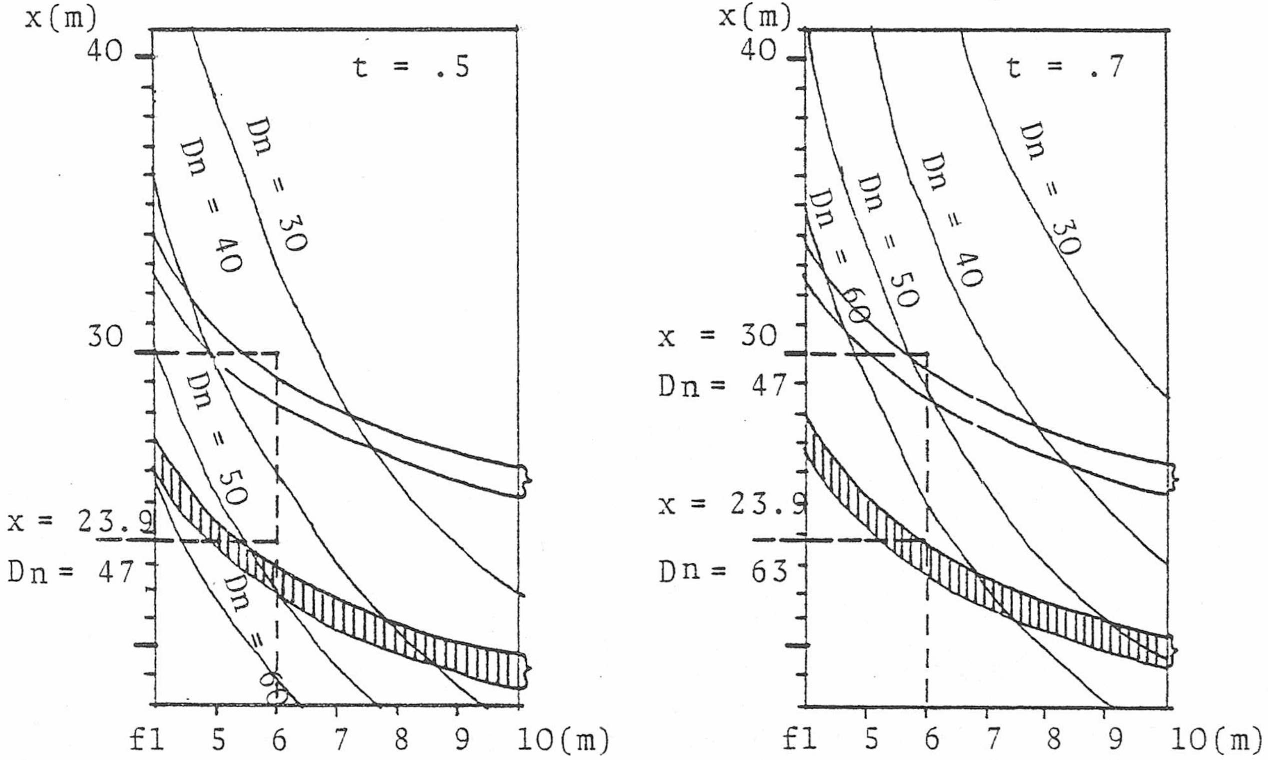
(iv) Influencing the Ratio of Net to Characteristic Density - 't'

The graphic output in Fig 4 shows clearly that the scope for passive solar design is extremely sensitive to this variable. It can also be assumed that the larger the site the greater the passive solar scope in this respect. Predominant land use additional to that for house plots and access roads is for parking and open space. If the housing configuration model is altered to include these land uses within the house plot zone, characteristic density will be much closer in value to the net density. Fig 5 shows that this could be achieved by restricting private garden space to the south side of terraces only, and by introducing open space between every second terrace corresponding to an access road/parking zone. The open space



(i) varying roof pitch $^{o}P = 22\frac{1}{2}^{o}$

(ii) asymmetric section
$dx = 1.05$ m
$^{o}P = 22\frac{1}{2}^{o}$



(iii) varying ground slope $^{o}S = 2^{o}$
$^{o}P = 22\frac{1}{2}^{o}$ $dx = 1.05$ m

(iv) varying ratio Dn:Dc
$^{o}S = 2^{o}$ $^{o}P = 22\frac{1}{2}^{o}$
$dx = 1.05$ m

Note - Control example assumes: $z = 2$, $^{o}P = 30^{o}$, $^{o}R = 16^{o}$ $fl = 6$ m, $x = 30$ m, $hl = 5.4$ m, $y < 10\%$ for $\pm\ 45^{o}S$; introduce variables keeping y, hl and fl constant.

Fig 4 geometric constraints for solar collection in a parallel terrace housing model can be modulated to give greater planning flexibility on site and to avoid the monotony of parallel terraces.

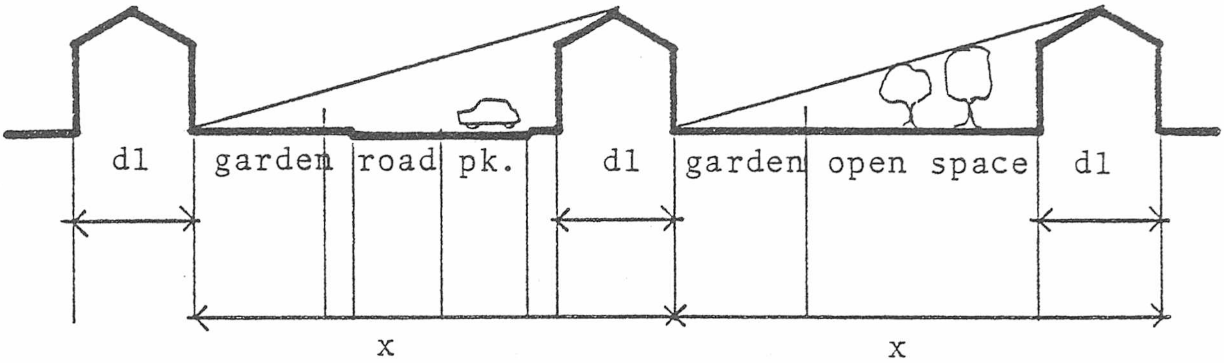


Fig 5 ratio net to characteristic density

Using this technique, the upper assumed limit of t = .7 would be quite realistic even for quite small sites. Fig 4, introducing additional geometric variations, (i) - (iii), outlined above, illustrates that radiation losses of less than 10% are compatible with 2 storey housing at relatively high densities up to 60 houses per hectare, with orientation varying from 0 - 45° from due south.

(v) Increasing Range of Orientations

The possibility for further increasing planning flexibility clearly exists if the range of orientations is increased to 90° east and west of due south. It is therefore proposed to conduct a detailed comparative analysis between a medium frontage, south-facing, 4 person house type, and a narrow frontage east/west facing, 4 person house type of identical area. This will comprise part of the third section, which includes comparative analysis of detailed aspects of 4 basic housing configurations, using the Energy Simulation Programme (ESP) developed by ABACUS at Strathclyde University[8].

The human variable factor is not relevant to the simple system used in this section, concerned only with building and site geometry, but the analysis using ESP will be a comprehensive dynamic thermal appraisal of all aspects of particular housing configurations, including orientation. Therefore, assumptions with regard to occupant heating demand and ventilation rates will have to be made. The system will then be subject to unpredictable changes of state due to the economic and social influences, described in Section 1.1. However, the main architect of ESP, Clarke[9], maintains that this is "paradoxically a justification rather than criticism of the CAD approach, since it is only when a large series of tests, under different behavioural assumptions, can be undertaken, that robust design solutions can be proposed which will accommodate the variability of human behaviour".

References - Section 1

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SECTION 2

CLIMATIC ANALYSIS

2.1 Introduction

2.2 External Temperature, Wind & Rainfall - Heat Demand & Rate of Loss

2.3 Sunshine

2.4 Solar Radiation - Prediction & Measurement

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2.9 Conclusion

2. Climatic Analysis

2.1. Introduction

The aim of this section is to validate predictions of available solar irradiation on vertical and inclined surfaces; and to correlate to other characteristics, geographically and seasonally, of the Scottish weather, which are relevant to passive solar heating design. In order to provide a comparative base to the analysis this section also attempts to ascertain how the potential solar contribution to annual heating bills in Scottish locations may compare to English locations at substantially lower latitudes. Such key meteorological characteristics, with comprehensive records available over a long period, and a wide spread of geographical locations, are air temperature, wind speed and direction, rainfall and bright sunshine.

2.2. External Temperature, Wind & Rainfall - Heat Demand & Rate of Loss

'Degree days' are the summation of the daily difference between an internal base temperature and the mean external air temperature, when below the base, over a period of time. They are usually totalled either annually or over a defined heating season and are commonly used as a measure of climatic severity in terms of heat requirement. Using a base temperature of 15.5°C, the number of degree days at any location bears a linear relationship to the amount of fuel that will be required to maintain given house temperatures. Seasonal variations over the UK can be seen in Fig 6[1]. These figures indicate for example a 20% difference between the West of Scotland

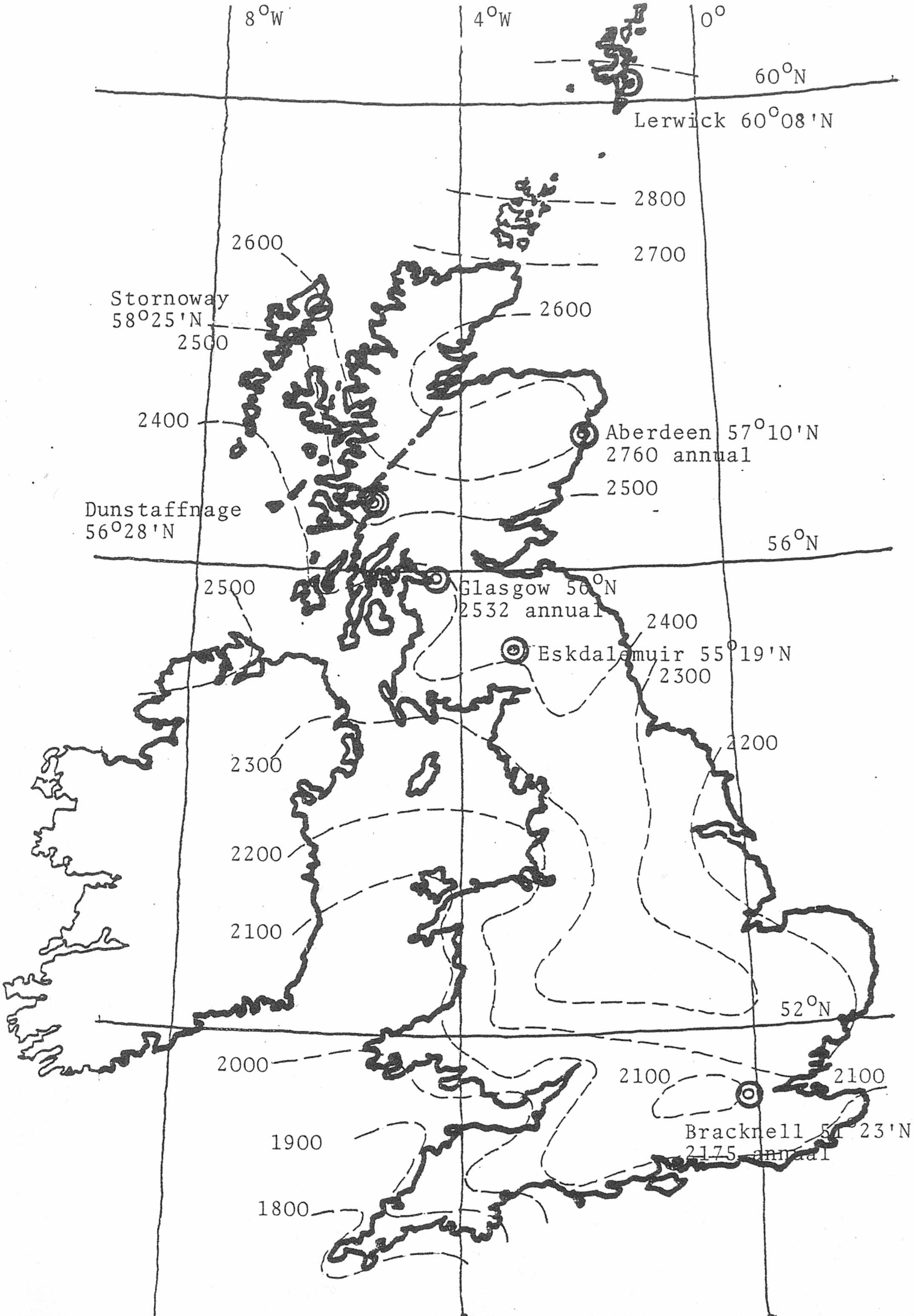


Fig 6 September to May degree days to base 15.5°C 1957-76

and the South-West of England, and even within Scotland the difference between Aberdeen and Glasgow is 10%, indicating that a house in Aberdeen would require 30% more fuel than one in Bristol over the heating season.

The crudest method of estimating degree day values is to multiply the difference between the base temperature and monthly mean temperature by the number of days in the month, and summate over the year. However, this can lead to underestimates, of up to 8% at 15°C, and a number of methods have been developed to increase accuracy by applying a factor to the mean external air temperature - notably Thom's method and Steadman's method[2]. Also, the degree days method becomes progressively more inaccurate as insulation levels improve, effectively lowering the base temperature, which is derived from desired internal temperature less mean incidental gains, divided by total building conductance. Besides increased insulation standards and the effect on casual gains, building conductance is influenced by the combined hypothermia effect of wind speeds and rainfall. According to Plant[3], wind cooling effect is approximately proportional to the square root of wind speed. For example a wind of 12 mph or 5.4 m/s, in cold air, will have a cooling effect in excess of three times greater than the loss at the same temperature in calm air. According to Markus[4], infiltration losses due to wind may account for as much as 40-50% of total heat loss. Also rain saturation of external walls has the effect of reducing thermal insulation values below theoretical U-values; particularly in the case of single-skin 'no-fines' walls, combining structure and insulation.

Lacy[5] has collated values for wind speed and rain in a 'Driving Rain Index', measured in m^2/s, with factors to take account of exposure and altitude:

$$\text{Driving Rain Index} = \frac{\text{annual rainfall in mm x av windspeed m/s}}{1000}\ m^2/s$$

Fig 7 shows the annual mean driving rain index contour map of the UK. With the exception of Wales, the Lake District and the West Country, values in England vary generally from 3 m^2/s in the London/Home Counties region to 4 or 5 m^2/s in the north and west. In Scotland, Aberdeen in the east has a value of 4 m^2/s, Glasgow in the west is 25% greater at 5 m^2/s, while values in the west of Scotland generally may be much higher, from 7-10 m^2/s in populated areas, and even 15 m^2/s in extremely exposed locations.

2.3. Sunshine

Records of annual mean daily durations of bright sunshine[6], measured in hours and illustrated in Fig 8, show an average of 3.5 for populated regions of Scotland, both west and east, increasing to 4.0 on extreme eastern coastal areas, corresponding to the value for the Home Counties of England. Averages of daily sunshine hours over a September to April heating season have also been collated, and show a similar pattern with a figure of 2.6 corresponding to the annual 3.5, and 3.0 to the annual 4.0 hours.

2.4 Solar Radiation - Prediction and Measurement

Sunshine hours do not in themselves provide a measure of solar radiation, but since the sources of

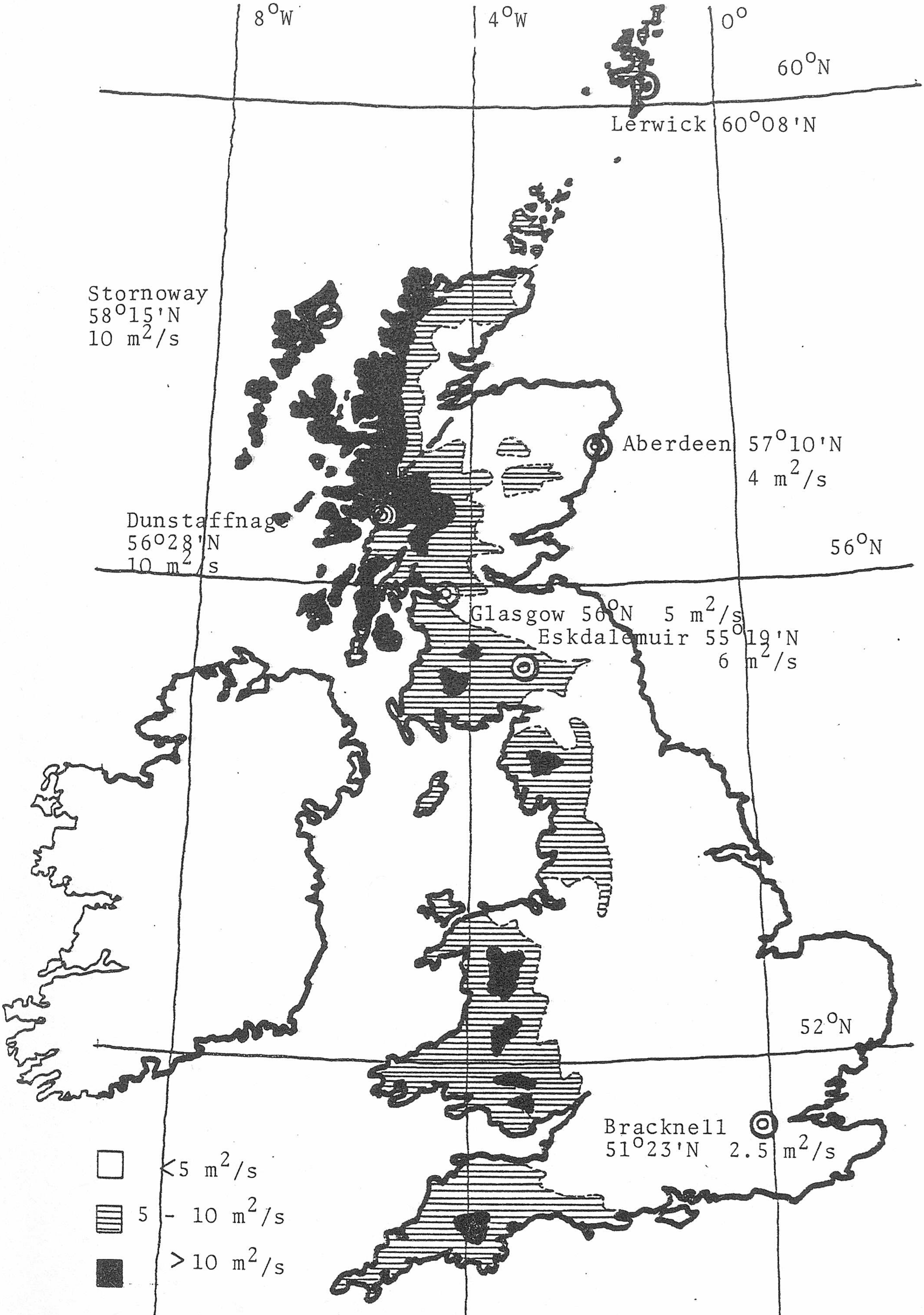


Fig 7 annual mean driving rain index m^2/s

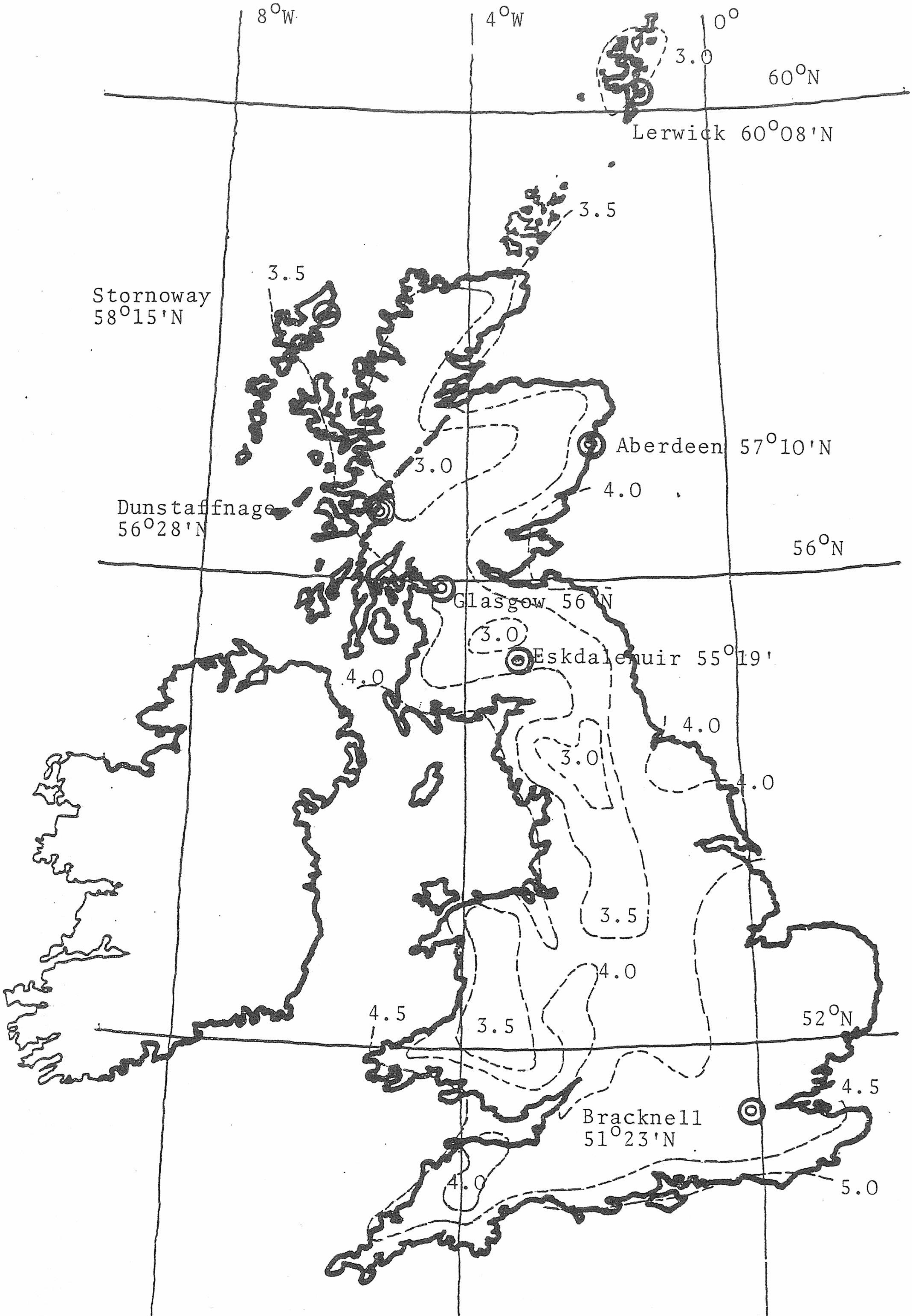


Fig 8 annual mean daily duration of bright sunshine hours measured radiation data are sparse in comparison with sunshine data, they are an important factor in the prediction of radiation values for vertical and inclined surfaces. Of the 6 stations in Scotland, taking radiation readings of any kind, only Aberdeen and Mylnefield (Dundee) are in representative populated areas, while Lerwick has recently become the second UK meteorological station to record irradiation on vertical and south facing latitude angle surfaces. Fig 9 shows a UK contour map of annual mean daily global irradiation on the horizontal[7]. Monthly mean daily solar irradiation on surfaces of varying orientation and inclination has been predicted for a representative number of Scottish locations, using simple calculation procedures to be described below. Predicted values are compared to measured data where this is available.

The global irradiation on a vertical or inclined surface is expressed as the sum of the direct, diffuse and ground reflected components. The latter is deliberately screened from predictions, as in measured values at Lerwick and Bracknell (Easthampstead), to give the same basis of comparison which is not dependent on varying ground surfaces. The fundamental problem lies in accurately separating out diffuse from global irradiation, particularly in an inherently cloudy climate such as in Scotland, and over the winter season when the diffuse element is greatest. Global irradiation on a horizontal surface can be determined in a regression equation, using two climatically determined constants, unique to a location, known values for global irradiation outside the earth's

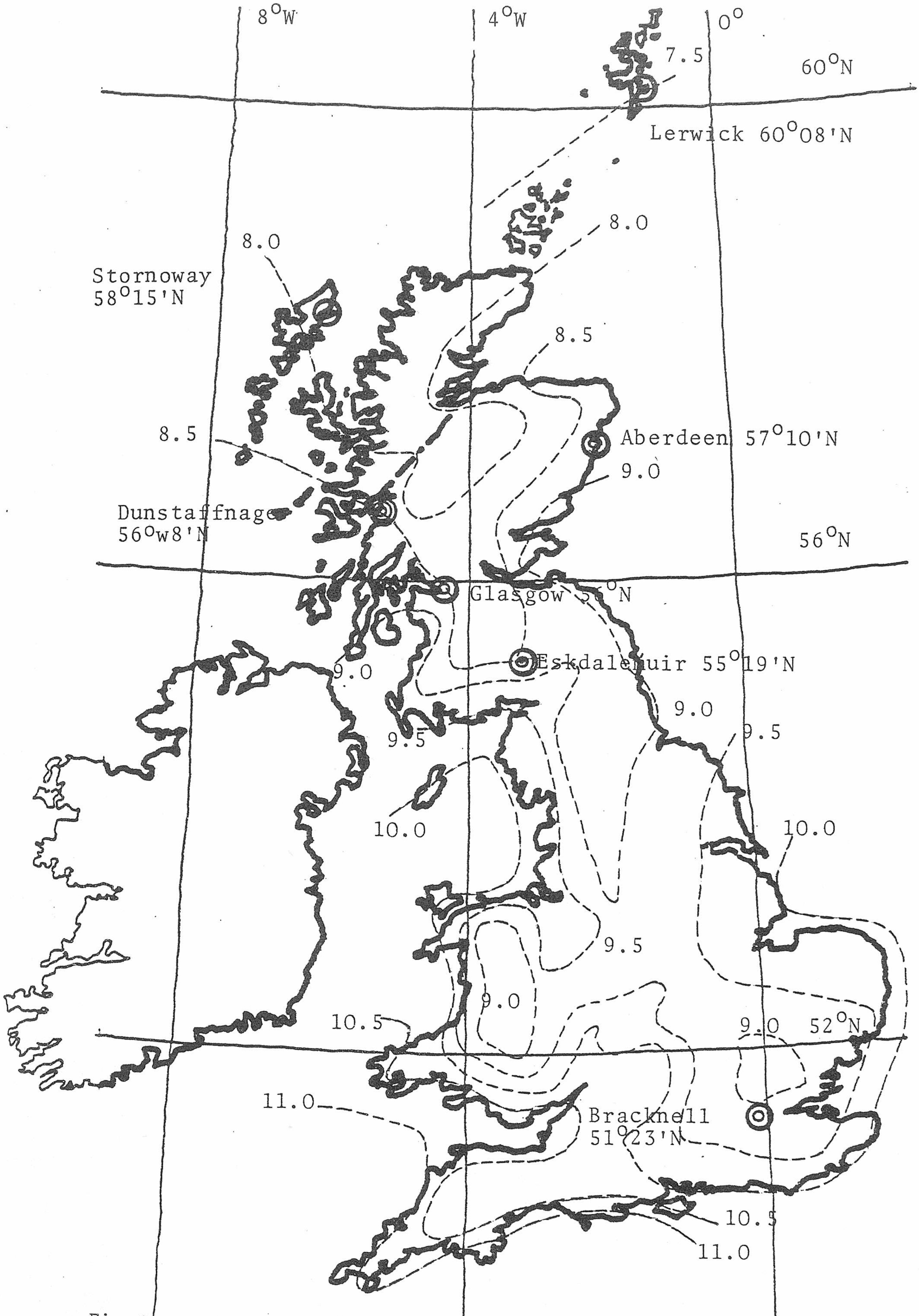


Fig 9 annual mean daily global irradiation on a horizontal surface MJ/m^2

atmosphere and records of bright sunshine hours:

(i) % possible radiation, or mean atmospheric transmission) = a + (b x % possible sunshine)

$$H/Ho = a + (b \times n/No)$$

Fig 10 clearly shows the linear relationship between percentage possible radiation and percentage possible sunshine. Diffuse irradiation on a horizontal surface can then be found, using a further regression equation with two more climatically determined constants:

(ii) proportion diffuse to global = c + (d x mean atmospheric transmission)

$$Hd/H = c + (d \times H/Ho)$$

Values for constants 'a', 'b', 'c' and 'd' in equations (i) and (ii) have been calculated for various UK locations by Page et al[8,9,10] as a result of comprehensive computer prediction programmes, correlated to available measured data from meteorological stations. Knowing the diffuse element on the horizontal, both monthly mean daily and hourly values for irradiation on vertical and inclined surfaces can be calculated using solar geometry. Markus and Morris[11] have compiled tables of 'R' values, denoting mean solar geometry factors for each month for a surface of given latitude, slope and azimuth. These have been used in the prediction validation calculations for monthly mean daily values, using the equation:

$$\text{(iii)} \quad HG = \underbrace{(H - Hd)\,R}_{\text{Direct Component}} + \underbrace{Hd/2\,(1 + \cos s)}_{\text{Diffuse Component}} + \underbrace{r.H/2\,(1 - \cos s)}_{\text{Ground Reflected Component}}$$

Using sunshine records for Lerwick, predicted values for monthly mean daily global and diffuse irradiation

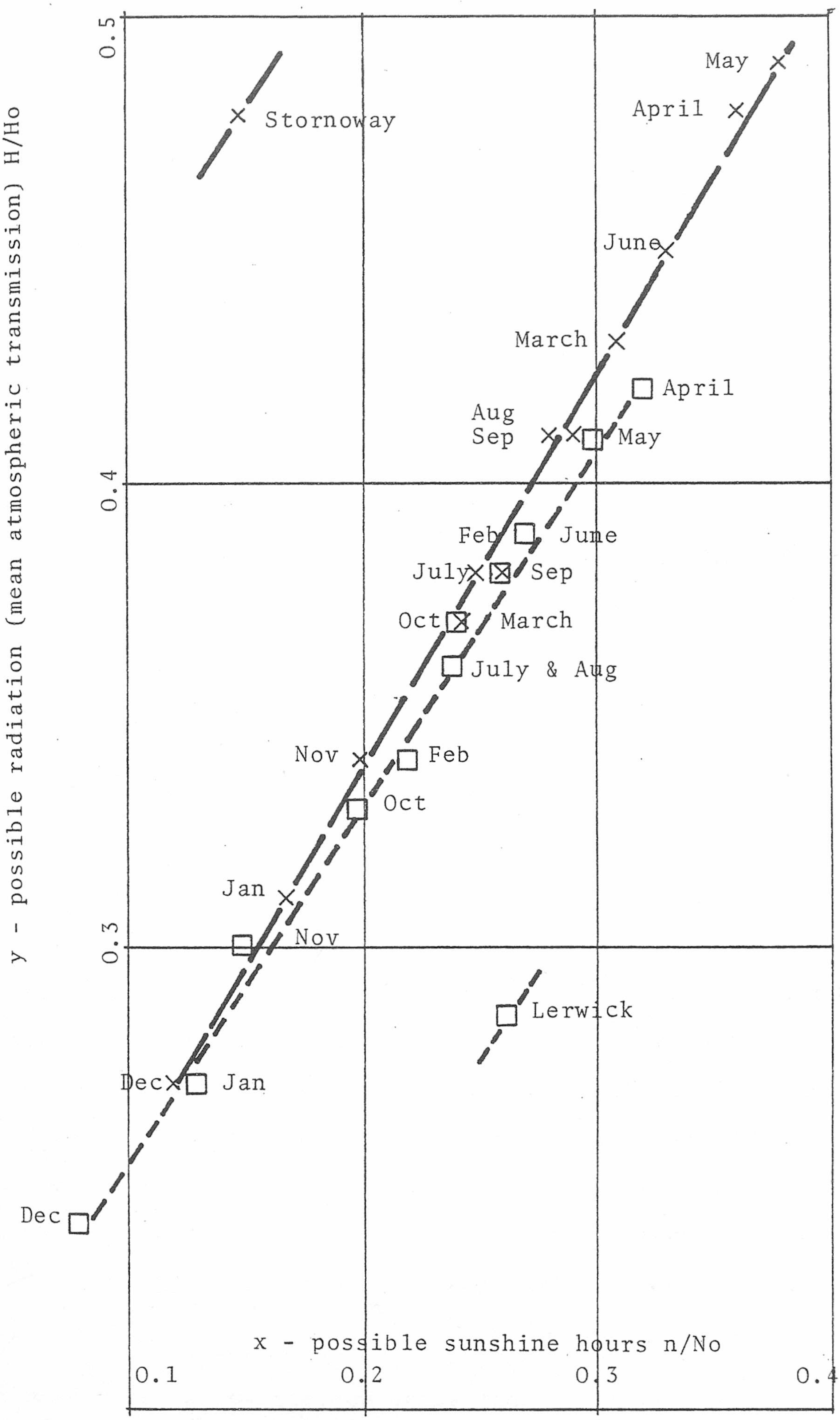


Fig 10 graph showing linear relationship between radiation and sunshine in two Scottish locations.

on a horizontal surface, and global on a south facing vertical surface, show fairly consistent correlation with 1981[12] and long-term measured values[7]. This is particularly the case for global and diffuse irradiation on the horizontal, and is shown in Table 1, Appendix 1, and graphically in Fig 11. The graph for global irradiation on a south facing vertical surface shows a slightly greater discrepancy from October to March, indicating that the error arising from the use of mean 'R' factors is predictably greater as the solar altitude decreases. However, if 'R' factors are derived from measured values for Lerwick on east, west and north vertical surfaces, as shown in Tables 2 & 3, an unacceptable margin of error in the tabulated values of Markus and Morris is found. This is shown graphically in Fig 12. Corresponding adjustments to 'R' factors, also shown in Table 3, have been made for Aberdeen in order to provide a sound basis for radiation prediction for east, west and north vertical surfaces in addition to south facing vertical and sloping surfaces. These results are shown together with measured global irradiation on a horizontal surface in Fig 13 and Table 4. Also shown on this table are equivalent values by Robertson[13] using a solar radiation prediction programme CASD. It should be noted that predicted values for diffuse irradiation in Table 4 are slightly at variance to those in Table 8. This is because alternative values for constants 'c' & 'd' have been used in the predictions.

With the exception of diffuse irradiation all predicted values are now being measured at the Scott Sutherland School of Architecture in Aberdeen. Results

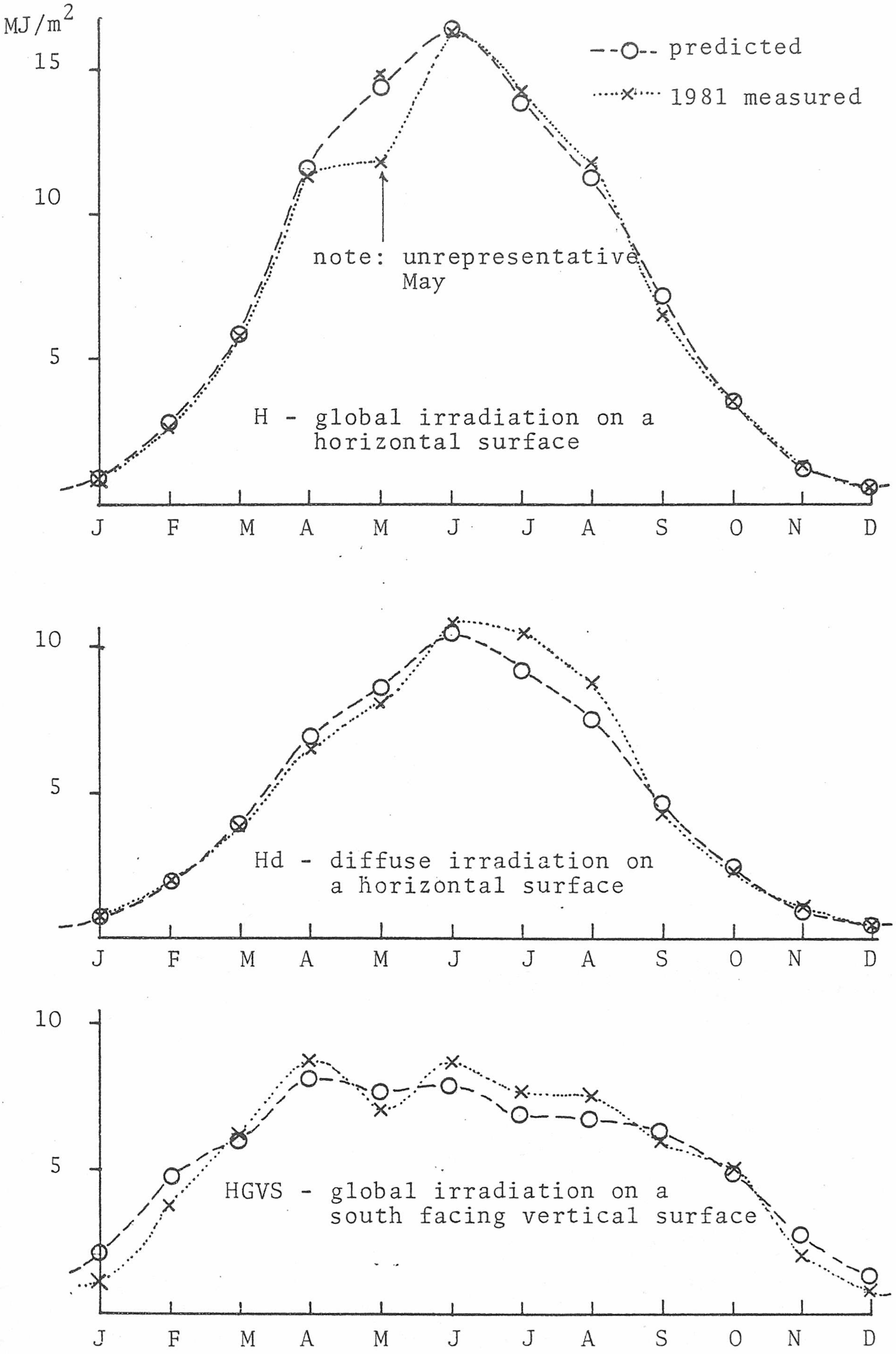


Fig 11 Lerwick 60°08'N - predicted and measured values for monthly mean daily irradiation - MJ/m^2

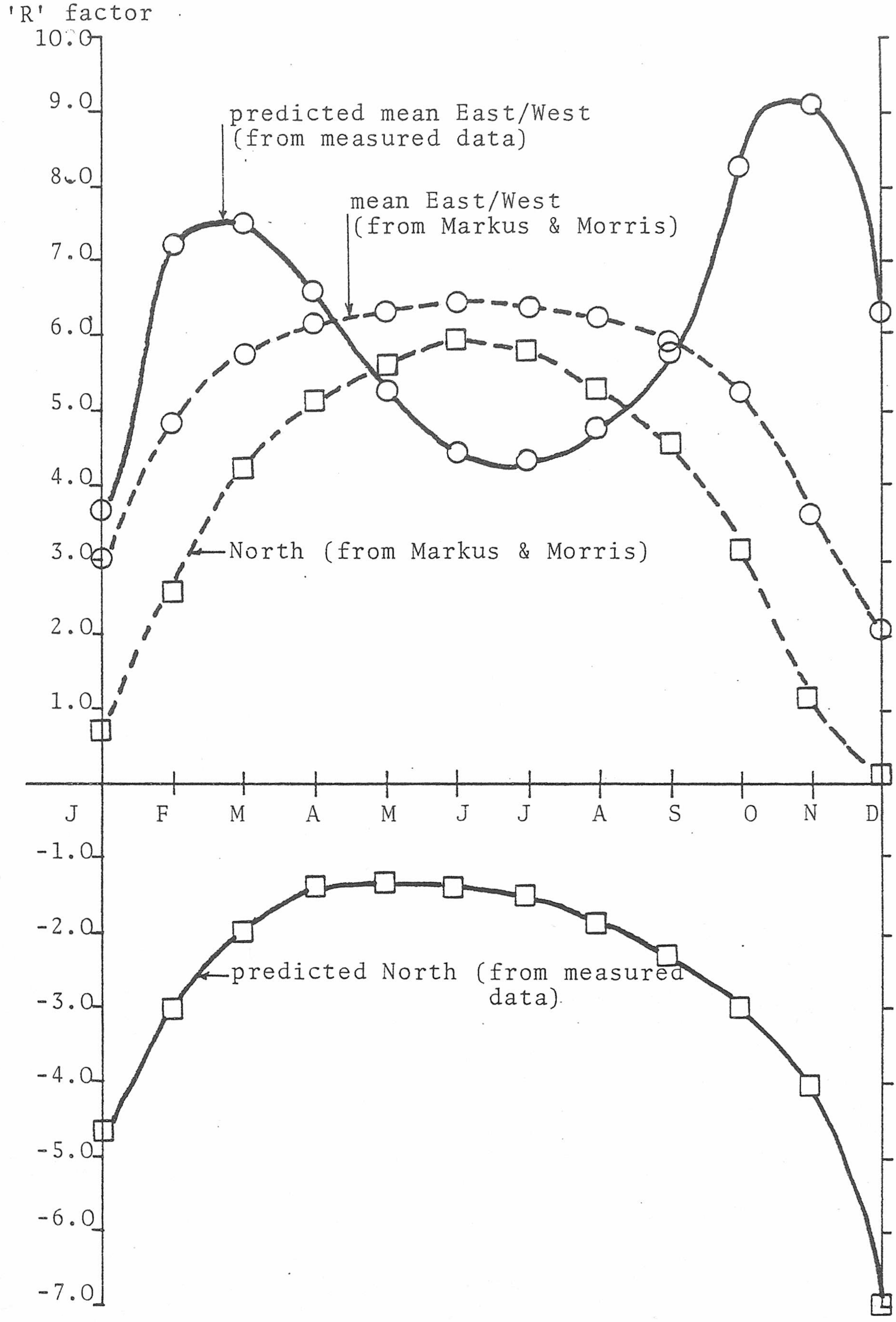


Fig 12 Lerwick - 'R' values for North, East, West and South Latitude angle surfaces

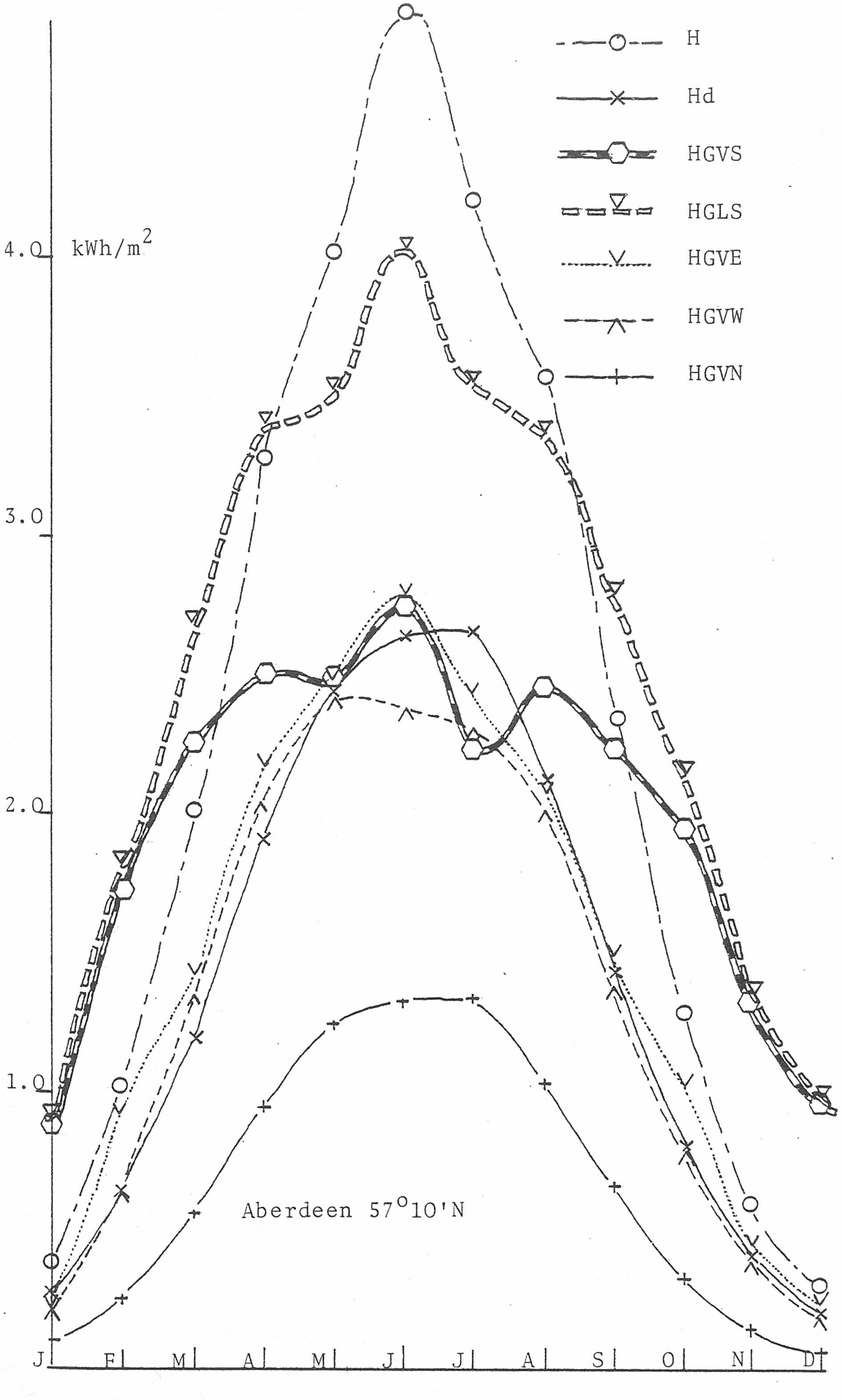


Fig 13 predicted monthly mean daily radiation values for March '83 show good correlation between monthly mean daily measured values and predicted values, particularly to the figures obtained using the 'c' and 'd' constants and 'R' factor. Daily totals are shown in Table 5, while mean hourly values for global irradiation on the horizontal, shown graphically in Fig 14, illustrate the relationship between measured values for a particular year and long term means taken from measured data at Aberdeen University[7] 1968-1975. Table 6 and Fig 15 show mean hourly values for all six surfaces, five of which bear comparison in terms of latitude differential with long term measured hourly values for Bracknell 6° to the south, (see also 2.5 below).

The exercise has confirmed the validity of simple calculation procedures based on widely available records of sunshine hours; together with Page's geographically determined constants, to isolate the diffuse component; and the Markus and Morris solar geometry 'R' factor applied to the direct component, assuming appropriate modifications for north, east and west facing vertical surfaces.

2.5. Solar Radiation - Latitude Differential

A comparison of measured values for global irradiation on the horizontal between Aberdeen 57°N and Bracknell 51°N shows considerable differentials, particularly during winter months. However, when comparing figures for a south-facing vertical surface, the latitude differential is greatly decreased. These comparisons can be seen in tabular form, Table 8, Appendix 1, and graphically, Figs 16 and 17. Over the year, the mean daily

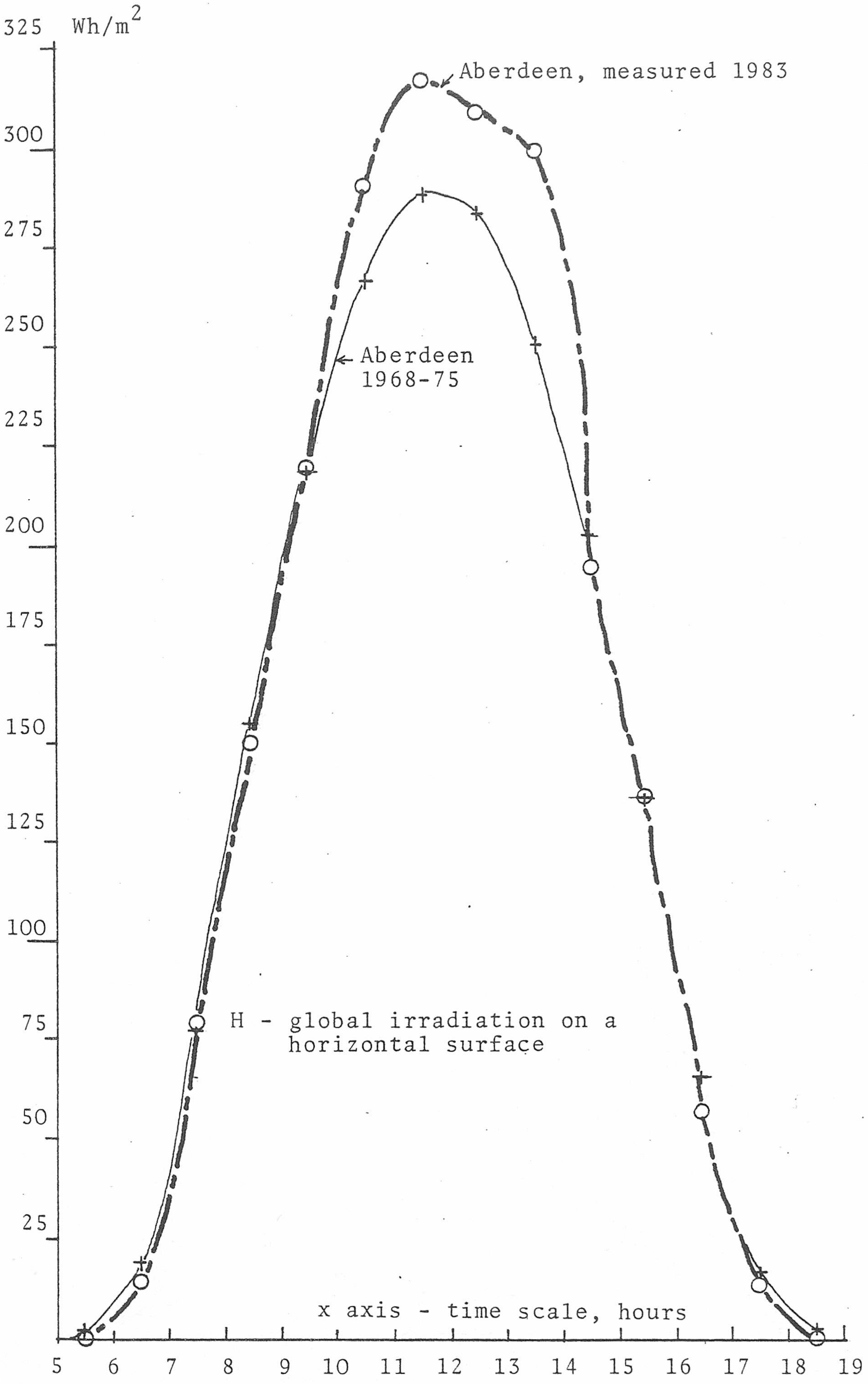


Fig 14 Aberdeen - mean hourly irradiation values for March

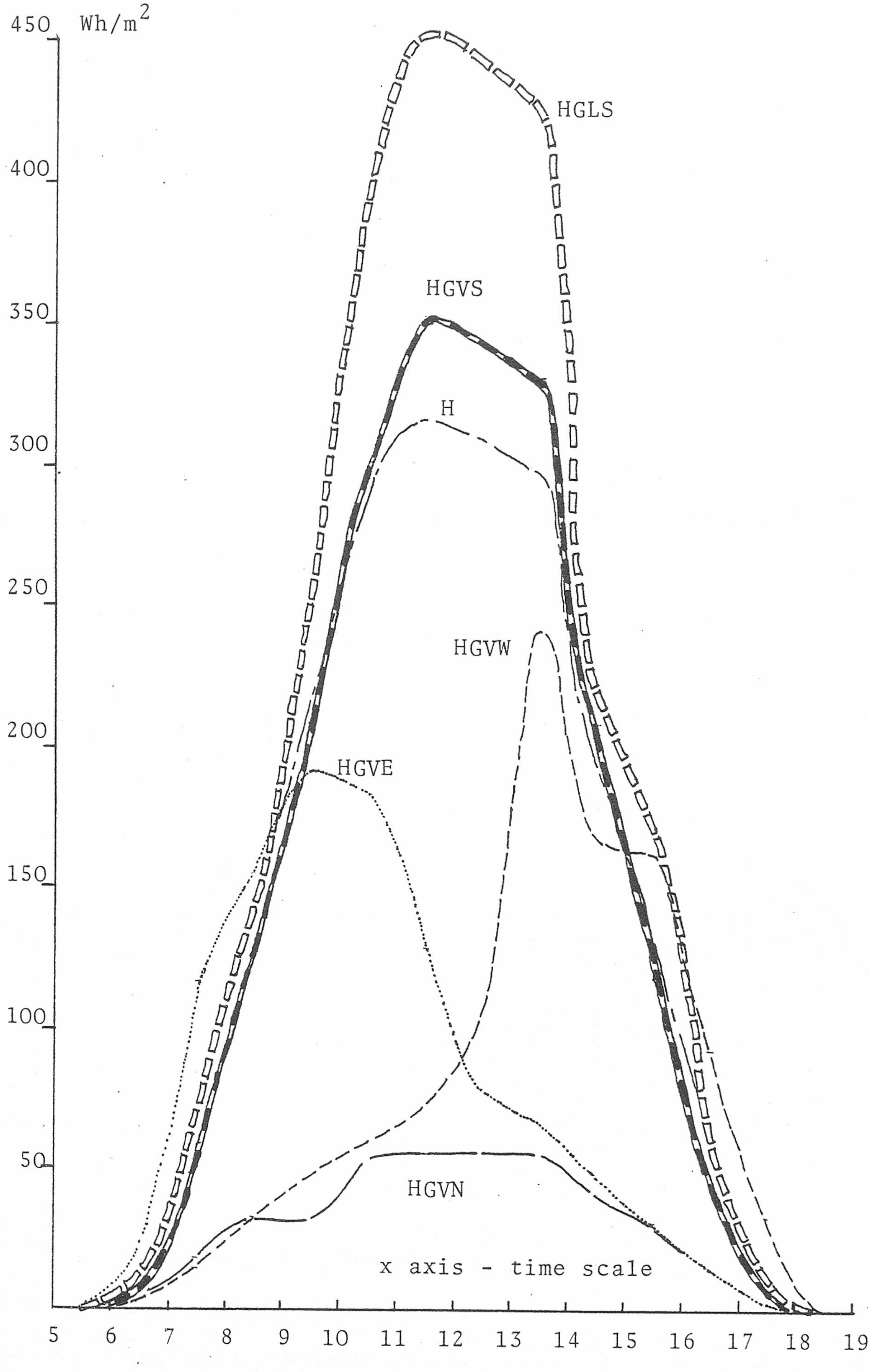
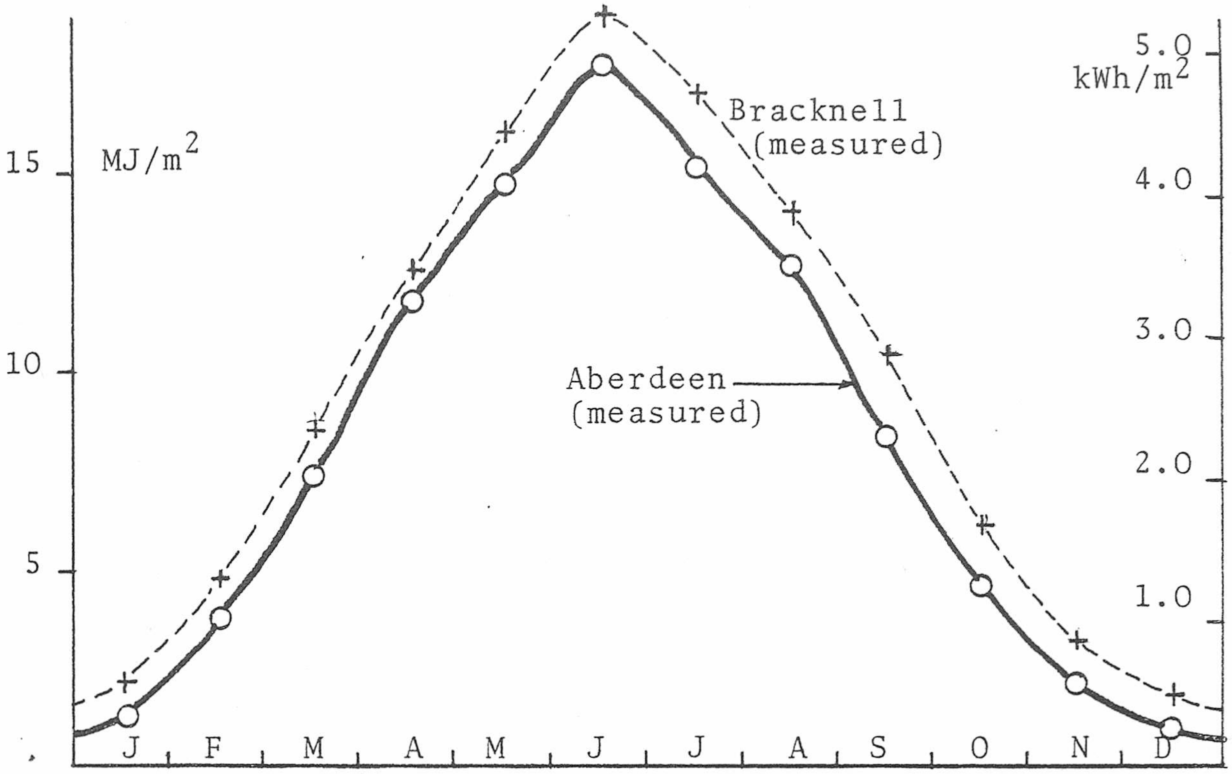
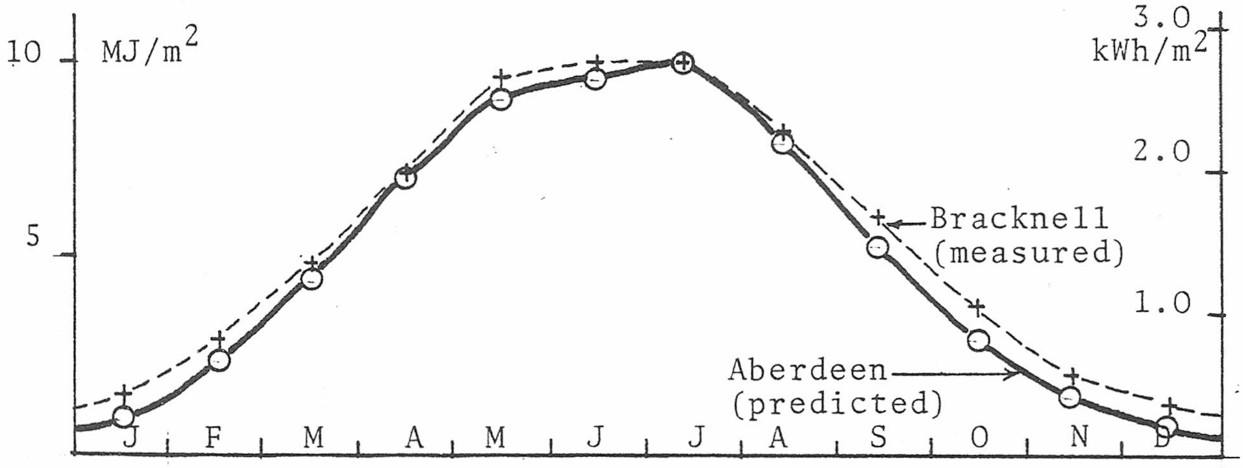


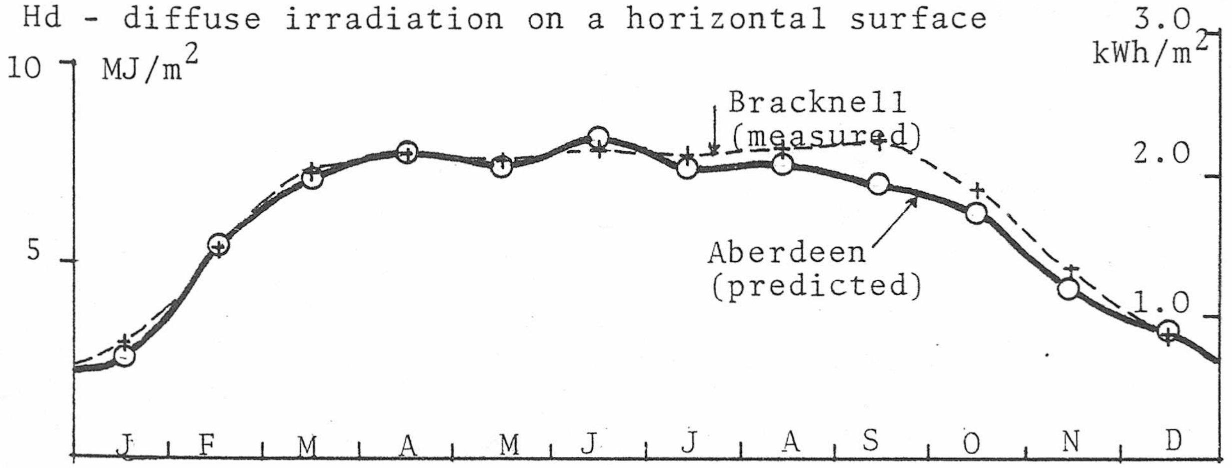
Fig 15 Aberdeen, measured mean hourly irradiation values March 1983



H - global irradiation on a horizontal surface



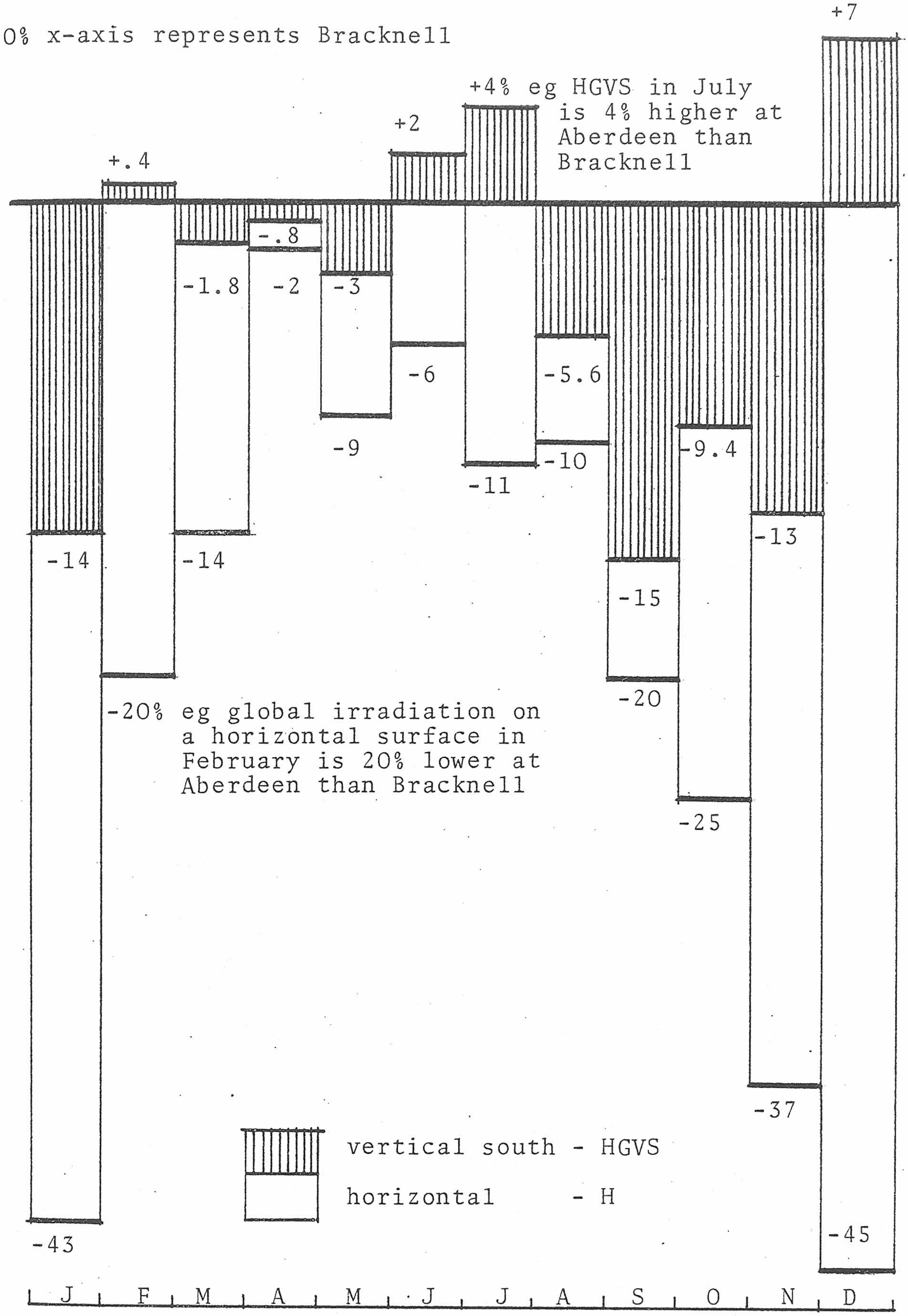
Hd - diffuse irradiation on a horizontal surface



HGVS - global irradiation on a south facing vertical surface

Fig. 16 comparison between monthly mean daily irradiation values: Aberdeen, $57^{o}10'$N and Bracknell $51^{o}23'$N

0% x-axis represents Bracknell



+4% eg HGVS in July is 4% higher at Aberdeen than Bracknell

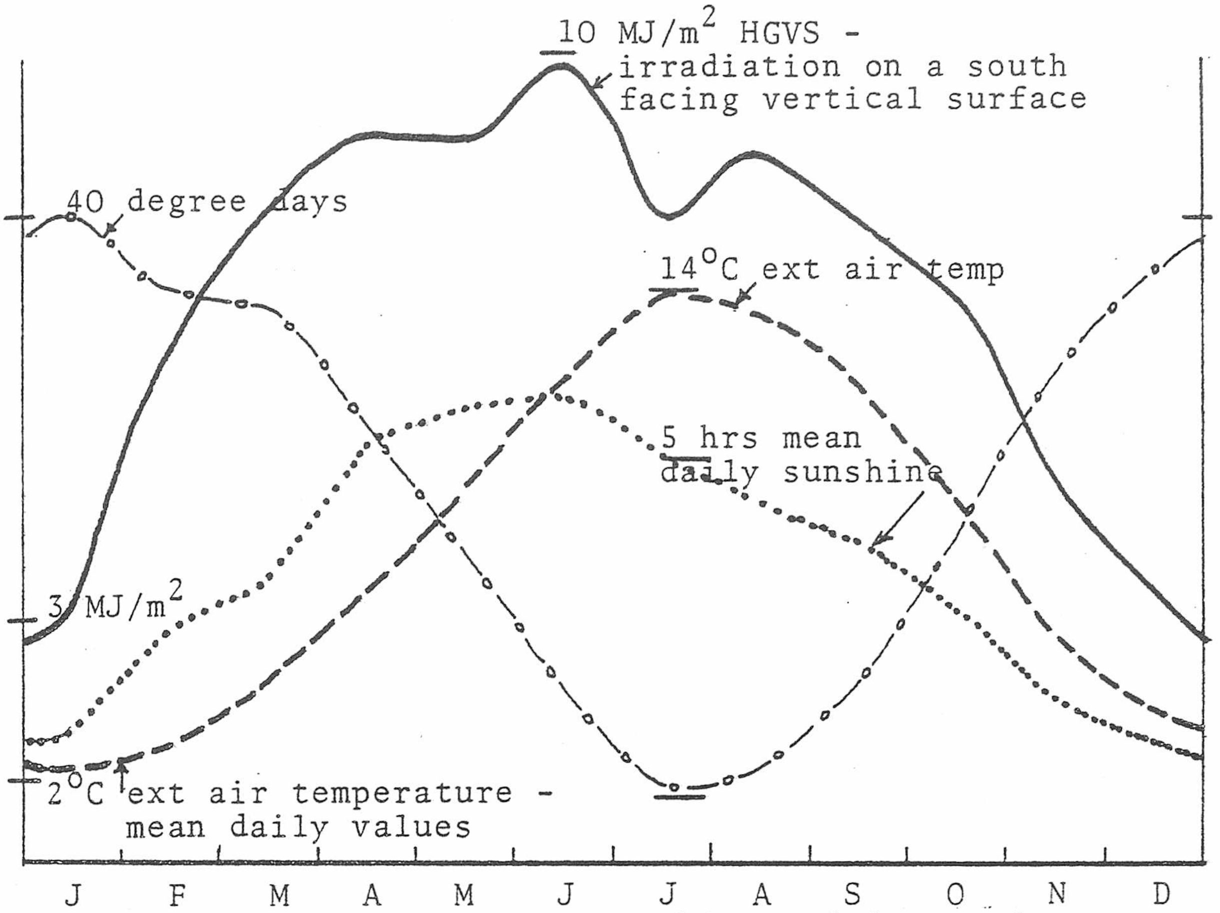
-20% eg global irradiation on a horizontal surface in February is 20% lower at Aberdeen than Bracknell

Fig 17 percentage variations of monthly mean daily irradiation on horizontal and vertical surfaces from Bracknell 51°23' to Aberdeen 57°10' total for Aberdeen is 6.13 MJ/m^2 compared to 6.44 MJ/m^2 at Bracknell, only 4.8% less. In a September to May heating season the difference is 6%, while in the spring quarter March to May there is a marginal reduction of 1%. The autumn period is less favourable in terms of solar radiation, which bears out the normal weather pattern in Scotland as a whole for this period.

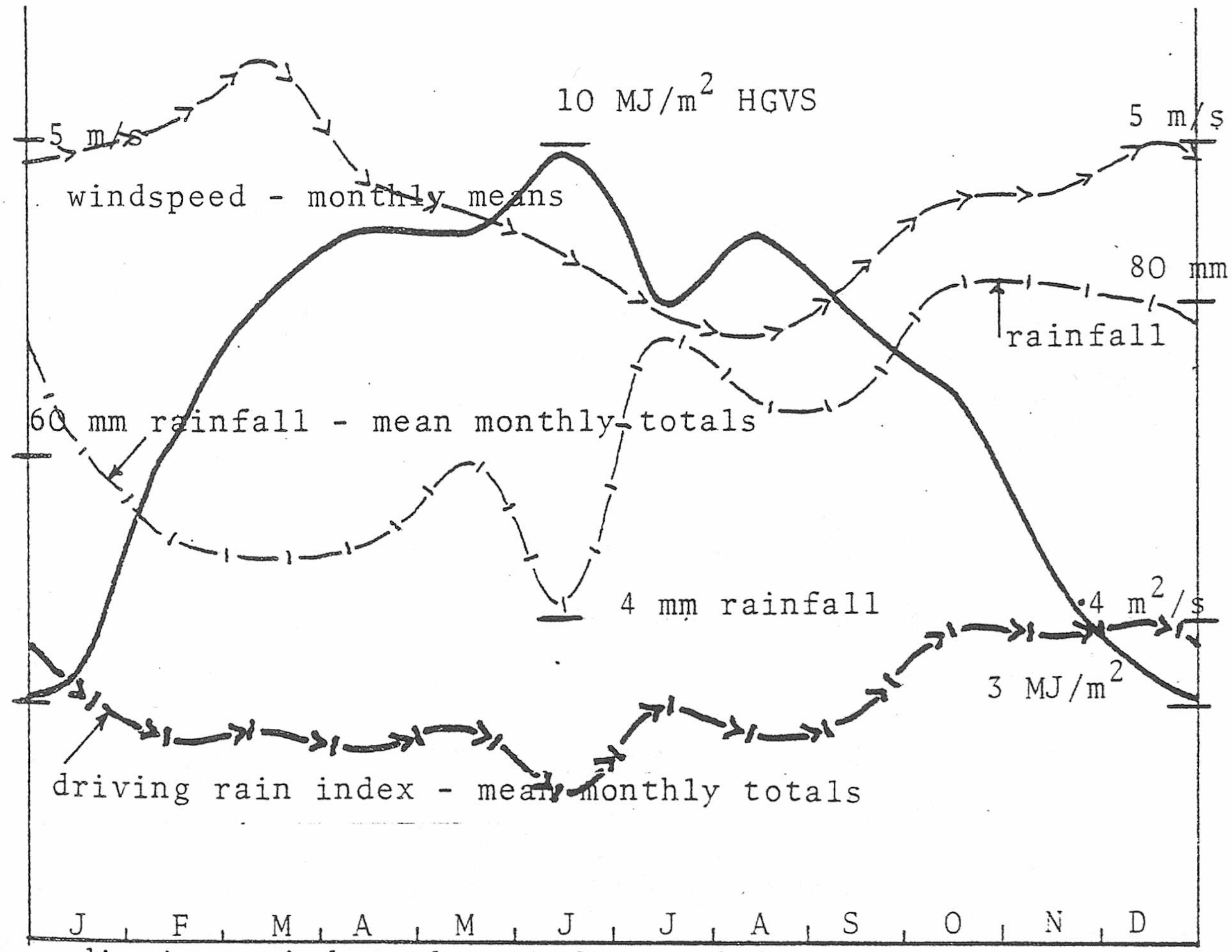
2.6 Solar Radiation Related to Temperature Windspeed, Rainfall and Sunshine

Reference to values in Table 9, Appendix 1, shown graphically in Fig 18, confirms that solar irradiation on a south facing vertical surface correlates closely to sunshine hours, with the peak occurring from April till June, but that conversely autumn air temperatures are considerably higher than corresponding months in spring. This clearly favours a relatively high solar contribution in the spring period. Monthly mean daily temperatures are given by Plant[14] over the period 1931-60 at Dyce Airport, Aberdeen, and monthly mean daily sunshine hours are given by the Meteorological Office[6] over the period 1941-70, also at Dyce.

Comparison of radiation and rain-fall, also Table 9 and Fig 18, confirms a closely opposing relationship. Rainfall peaks are coincident with radiation troughs, even in summer months when the radiation curve flattens due to increased solar altitude. There is not such a close relationship between windspeed and radiation, but the former generally follows the same curve as degree days, with highest values in spring



radiation, air temperature, sunshine and degree days



radiation, windspeed, rainfall and driving rain index

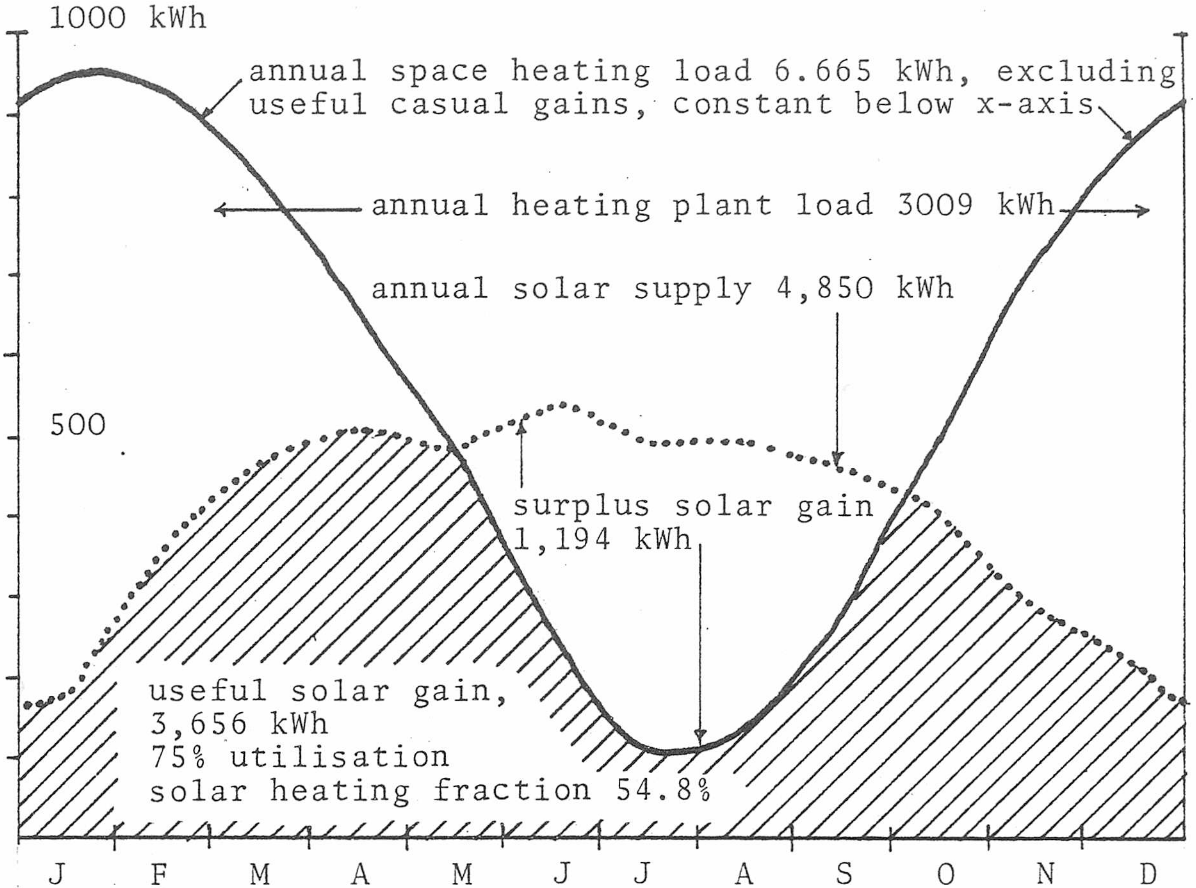
Fig 18 characteristic climatic relationships, Aberdeen rather than autumn. Since both fabric and ventilation losses will increase with windspeed, this will further favour a high solar contribution in the spring period. However, the combined cooling effect of windspeed and rainfall, expressed by the driving rain index, due to the opposition of high winds in spring and correspondingly higher rainfall in autumn, tends to produce a fairly level curve, with a mean of 0.3 m^2/s per month. This suggests that for Aberdeen at least, it would be reasonable to introduce the driving rain index as a constant monthly factor, to be taken into account when estimating the specific heat loss of a building. Monthly mean values for rainfall are given by Plant[14] over the period 1913-68 at Mannofield Reservoir, Aberdeen, and also monthly mean windspeeds, which are derived from tables of monthly percentage frequency of winds, within a range of velocities at Dyce Airport over the period 1959-68. Using these sources the summation of monthly driving rain index values for the whole year gives a figure of 3.559 m^2/s which correlated well with Lacy[5].

2.7. A Comparative Model - Heat Demand Related to Solar Supply

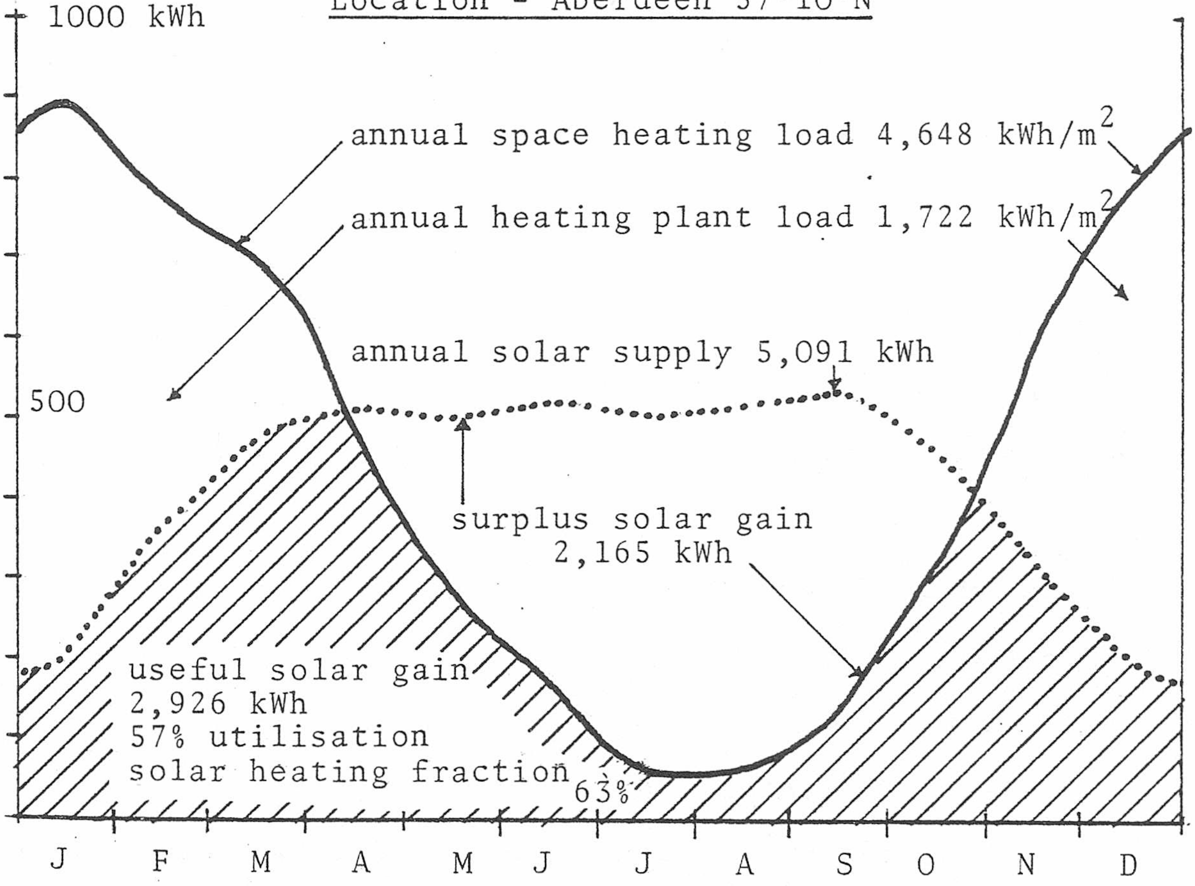
As the solar irradiation on a south facing surface in Aberdeen, at 57°N, is only marginally less than Bracknell at 51°N, and the heating demand is considerably larger, the potential exists for a greater proportion of the solar supply to become a 'useful gain'. However, this may still represent a smaller fraction of the total heating load.

MacGregor[15] has carried out a comparative study of the suitability of various locations within Europe. In his model, he assumes identical small, well insulated houses at each location, each with a specific heat loss of 100 W/K, and each with a relatively high south facing vertical collection area of 26 m^2, and an efficiency of 0.3. Using the same figures, with a base temperature of 15.5°C, to take account of internal casual gains, the annual heating load for Aberdeen is 43% more than Bracknell, significantly more than the 585 degree day differential. However, the annual solar supply at Aberdeen is less than 5% below Bracknell. This means that at Aberdeen 75% of the solar supply is 'useful', representing a solar fraction of 55% of the heating load; but at Bracknell, while only 57% of the supply is useful, this still represents a greater solar fraction of 63%. These results can be seen in Table 10, Appendix 1 and graphically in Fig 19.

The other point to note from the graphs illustrating this model is that although the solar supply is greater than the demand from May to September in Aberdeen and April to October in Bracknell, there is still a small space heating energy demand during these summer months, so that there could be said to be a 12 month heating season. If a factor is added to the specific heat loss of the Aberdeen case, to take account of the 33% greater driving rain index, there would be a corresponding increase in the heat demand, so that the quantity of solar supply used usefully will increase, particularly in the summer period. Using a lower base



Location - Aberdeen 57°10'N



Location - Bracknell 51°23'N

Fig 19 comparative study of solar utilisation related to heat demand: small house model in 2 UK locations temperature to allow for higher insulation levels (see 2.2 above) would have the opposite effect, reducing the annual heat load; but this would be equally applicable to both Aberdeen and to Bracknell locations, assuming the same level of both insulation and internal casual gains. In this example there is a large collection area in relation to heated volume. A reduction in collection area or efficiency would again increase the proportion of useful solar gain, but decrease the solar fraction of the heating load, while an increase in collector area would have the converse effect.

2.8. Comparison of Estimates of Monthly Mean Daily Irradiation on South Facing Vertical Surfaces in Various Scottish Locations

Estimates have been made from measured irradiation data on the horizontal surface where available. Where such data is not available, values have been calculated using measured mean data for sunshine and appropriate values for constants 'a', 'b', 'c' and 'd' in the regression equations described in 2.4. Tables 11-15 in Appendix 1, which give predicted results for Eskdalemuir, Glasgow, Aberdeen, Dunstaffnage and Stornoway, indicate what measured data has been used in the prediction. Table 18 gives a comparative summary, and Fig 20 the graphic equivalent. Since values for 'a', 'b', 'c' and 'd' constants used in the regression equations were only available for two locations in Scotland, Eskdalemuir and Lerwick, validations have been made using various values of 'a' and 'b' for two locations where both measured global irradiation on the horizontal surface and sunshine data is available, Aberdeen and

Dunstaffnage. These are shown in Tables 16 and 17, Appendix 1. The results show that values for 'a' and 'b' for Bracknell give a close correlation for Aberdeen, while values for Lerwick give a closer correlation for Dunstaffnage than those of Eskdalemuir. Also, predictions for Eskdalemuir have been carried out, both using measured data for global and diffuse irradiation on the horizontal[7], and using sunshine hours[6] and values for 'a', 'b', 'c' and 'd' constants by Page 1979[10]. The two methods show a very close correlation in all months except November and January (Table 11, Appendix 1). With the aid of these comparative values, the following assumptions have been made:

(a) Glasgow - (Table 12) use climatic constants 'a', 'b', 'c' and 'd' for Eskdalemuir by Page 1979[10], since locations are reasonably similar - inland sheltered valleys.

(b) Aberdeen - (Table 13) use climatic constants 'c' and 'd' for Bracknell by Page 1979, since the corresponding 'a' and 'b' values give good correlation to measured results at Aberdeen (Table 16). It will not be necessary to use constants 'a' and 'b' since global irradiation on the horizontal is measured.

(c) Dunstaffnage (Table 14) constants 'a' and 'b' not required as at Aberdeen, but use Lerwick values for 'c' and 'd' by Page, since corresponding 'a' and 'b' values give close correlation to measured results for global irradiation at Dunstaffnage (Table 17).

(d) Stornoway - (Table 15) - use 'a', 'b', 'c' and 'd' values for Lerwick since the geographical and climatic situation is similar.

Noteworthy from the results illustrated graphically in Fig 20, are the relatively high values for Stornoway and Dunstaffnage, in March, April, May and June, somewhat higher than Glasgow, Aberdeen and Eskdalemuir. Additional values for January to May, based on 1983 measured global and diffuse irradiation on a horizontal surface at Stornoway Airport[16], add a cautionary note, with generally lower values than those predicted with assumed constants. However, the January to March period in 1983 was below average, with particularly high rainfalls in March[17], and the April to May values are significantly greater than those predicted for Aberdeen using long-term measured global irradiation. Lerwick follows a similar pattern, but with generally lower values, decreasing rapidly in winter months. The mainland locations are generally similar, but Glasgow in the west, has slightly higher values than Aberdeen in the east from January to May. The graphs show clearly that apart from the extreme northerly maritime location of Lerwick, the largest variations occur between March and June, with west coast locations being the most favoured, reflecting the well known West Highland and Hebridean early summer. East coast locations can also

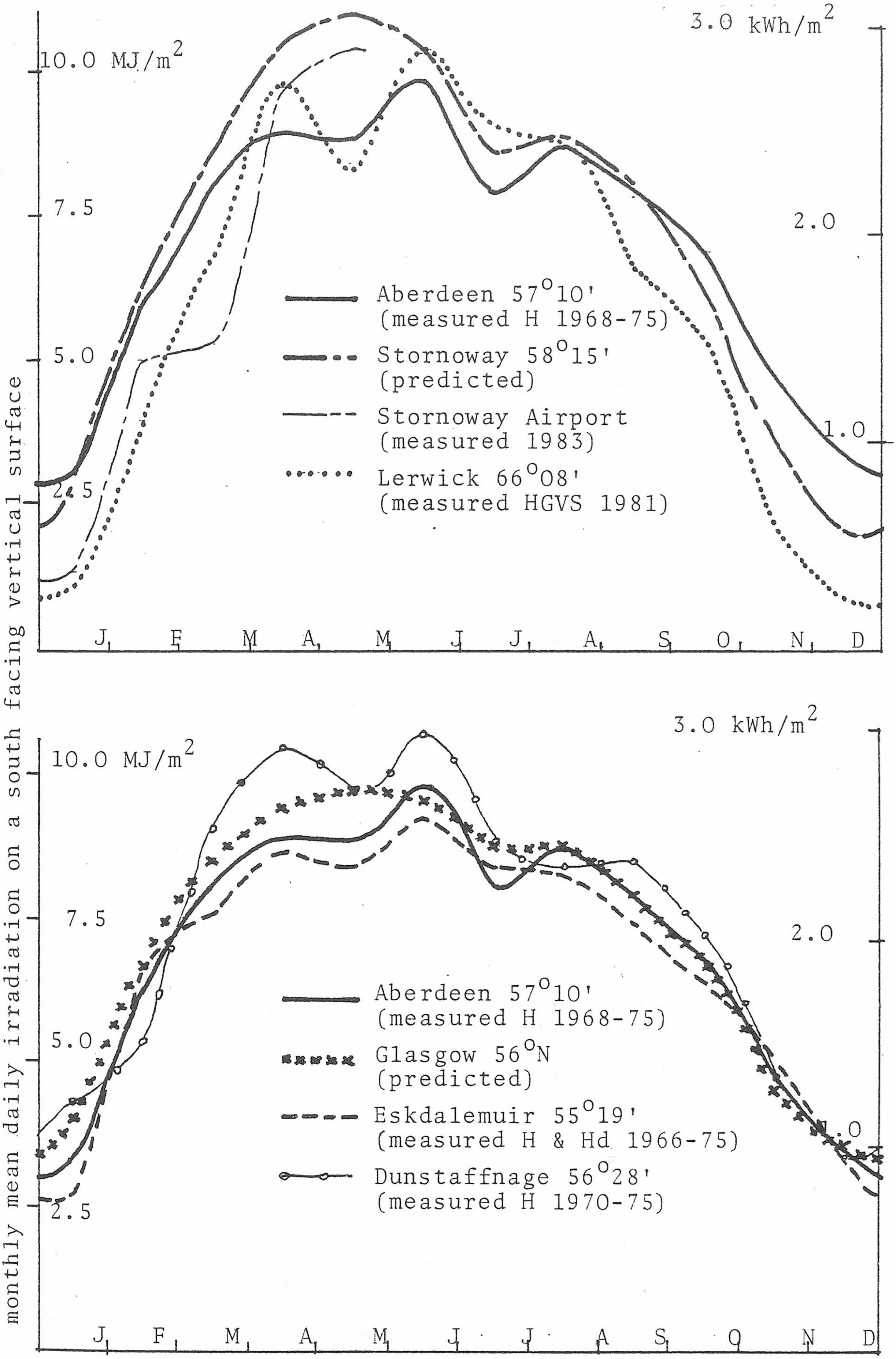


Fig 20 comparison of predicted/measured solar irradiation values for various Scottish locations expect some good weather during these periods, but radiation is probably somewhat reduced due to the incidence of east coast haars, and subsequent higher proportion of the diffuse element, as indicated by the ratios in Table 19, Appendix 1.

2.9 Conclusion

Values indicate that the main climatic differences, both within Scotland and the UK, occur between populated and non-populated regions. This simply confirms that topography suitable for building also tends to enjoy a more uniformly favourable climate. However in one key respect, temperature, there is both a substantial latitude and topographical variation. Corresponding to this fall in temperature and generally higher wind regimes, fuel costs rise disproportionately with UK latitude, compared to the corresponding fall in solar radiation levels. It can be concluded, therefore, that locations in Scotland are in a favourable position for passive solar utilisation. This, therefore, is the economic Scottish incentive to explore simple planning and building methods which use solar gains passively, and at maximum efficiency, in the context of a large public sector housing market.

Section 2.6. shows the relationship between solar radiation and other relevant climatic features for one location in Scotland. If these can in turn be related to specific building characteristics a useful early decision tool could emerge. By taking into account regional and local climatic features together with related constructional variables, housing standards could be established to provide a uniform rate of heat loss per unit volume as suggested in Section 1.1.3. Markus[18] has proposed the development of a 'Climatic Severity Index' for use in cold climates. Such a CSI for a particular housing category in a particular location would be obtained by applying a regional coefficient to the annual heat loss, this in turn derived by synthesis of three linear relationships established between relevant climatic and building characteristics. These are air temperature, solar radiation and wind velocity to insulation/mass, fenestration/mass and permeability respectively. It is not proposed to include rainfall, and hence driving rain, in this index since the effect of rain saturation to porous external surfaces becomes marginal as insulation standards increase. Such an index, assuming it can be validated by field studies and accurate analogue or digital simulations, could make possible comparison of one location with another from the point of view of relevant aspects of climate and hence likely energy demands to maintain stated internal environments in a range of 'model' house constructions.

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SECTION 3

DEVELOPMENT/EXTENSION OF PASSIVE SOLAR TECHNIQUES

3. DEVELOPMENT/EXTENSION OF PASSIVE SOLAR TECHNIQUES

3.1. State of Development Related to 50°-60° Latitude

3.1.1. Passive Solar Design Within an Energy Conscious Framework

55-60% of the UK's primary energy need is used in space and water heating, approximately one half to two thirds of that percentage in housing[1]. The potential for incorporating passive solar design features in housing lies mainly in the sphere of space heating, and must be seen in context as an integral part of a wider design philosophy, aimed at the conservation of energy.

All energy-conscious design is concerned with dynamic heat flux in the modes of radiation, conduction and convection. Transfer by radiation and conduction can generally be conveniently categorised within either planning or construction strategies. The framework of energy planning should be a logical external and internal spatial hierarchy, positively related to energy gains and losses, including short and long-wave radiation exchanges. For example, living rooms can be located on the south side, protected by service and circulation spaces to the north. Constructional strategy is concerned with thermal resistance, capacity and response of building fabric, related to traditional heating plant, casual and solar heating gains. Each thermally distinct zone deserves a strategy appropriate to the particular occupancy profile. Convection exchanges embracing movement of air within the building and associated infiltration/ventilation losses are influenced by both planning and construction decisions. The geometry of spaces and mult-layer constructional relationships affect not only air flows, but is also critical to condensation risk, particularly where no attempt is made to control internal humidity levels.

3.1.2. Estimating Passive Solar System Performance

Useful solar gains are only those which displace heating plant load, and the ratio of useful to total gains is an expression of the efficiency of the building design in terms of collection, storage and distribution. Although the principles involved in energy-conscious design are straightforward, appraisal of system performance in terms of traditional fuel saved in relation to capital outlay on energy measures, is both relatively complex and also serves only as a comparative guide. Actual savings will vary widely due to the human element - different occupancy patterns, expectations and desires as to thermal/ventilation comfort levels, economic priorities and other social factors. However, predictive comparative analysis is a valuable design tool and the more realistic the model, the more productive the synthesis/appraisal process. There are now a multitude of computer simulation programmes available[2]. One that provides a comprehensive, multi-zone, dynamic thermal analysis is ESP, introduced in Section 1.2.3. (v). This programme will be used for the comparative analysis of 4 housing configurations which incorporate passive solar features considered from the findings in sections 1, 2 and 3.1 to be appropriate in a Scottish context.

Although almost all the analysis in this work is by means of ESP simulations, it is worth commenting on one widely recognised simple long-hand, steady-state calculation procedure. This is the 'solar load ratio' (SLR) method devised by Balcomb[3], which was adapted for use in the 1st and 2nd European Passive Solar Competitions of 1980 and 1982. The heating load for each month is first calculated. This is the product of monthly degree days, to a base of actual assumed internal temperature, and the modified building loss co-efficient, found by synthesis of building skin conductance, infiltration and internal casual gains. The total monthly amount of solar radiation absorbed by the passive solar elements is then calculated. This is the product of the radiation on the surface in question, the collector area, and a factor denoting solar absorptance and efficiency. This figure divided by the net monthly heating load gives the SLR, and by reference to charts, the solar heating fraction can be found, thus enabling the auxiliary heat requirement to be calculated.

The method was developed for performance assessment of the Trombe wall[4], but Lebens[5] asserts that it is less appropriate for direct and isolated gain systems. The method assumes that the building is a single zone, with all the air being continually mixed, and the designer cannot determine the effect of increasing or decreasing the area or thermal capacities of primary or secondary thermal mass. With regard to performance prediction for Trombe walls, Lebens[5] also cautions that:

"Validation attempted by researchers at the Centre National de la Recherche Scientifique (CNRS), Odeillo, France, has not obtained agreement between the results of this method and the measurements from the prototype houses there".

3.1.3. Known Passive Solar Heating Techniques and Limitations for Applications to UK and Scottish Public Sector Housing

(i) Direct Gain: Sun > Living Space > Storage Mass

Collection Delivery and Control

The principle of direct gain systems is simply to provide an optimum amount of south facing glazing, using dense floor, wall and ceiling materials internally to absorb and store solar radiation received during the day, giving it up to the living spaces during the evening and night. Fig 13 in the preceding section shows that radiation on a south facing vertical surface in Scottish locations has rudimentary seasonal overheating control provided by increasing solar altitude. However, depending on orientation and tilt, more flexible short-term overheating control may be required, particularly in the spring and autumn periods, with relatively low solar altitude, but high levels of irradiation. Cost and simplicity of occupant operated controls will be key factors in relation to public sector housing. This will favour simple mechanical methods such as curtains, blinds or shutters, rather than high technology solutions. Even then, the potential benefits require to be carefully weighed against costs. Turrent et al[6] have reported that in a highly insulated house in the London area, assuming 0.3 W/m^2K mean U-value for the opaque building envelope, and double glazing plus night insulation, the first 5 m^2 of south window will yield a saving of 200 kWh/year, the next 10 m^2 only 80 kWh/year, and further increases even smaller benefits.

Applications and Limitations

An important limitation with regard to direct gain appliances in public sector housing is the conflict in thermal response requirements between traditional heating plant and passive solar heating. A comparison of mean monthly daily irradiation levels on a south facing vertical surface in UK locations from 50-60°N to a pioneering passive solar location such as Odeillo in the Pyrenees at 42° 29'N in Fig 21, shows the French location to be very favourable. Here the solar supply curve approximately corresponds to seasonal heating demand, while the UK locations have the opposite characteristics with particularly low values from November to February. The traditional heating system will thus continue to take almost all of the burden during this period, the solar input being of maximum benefit during the

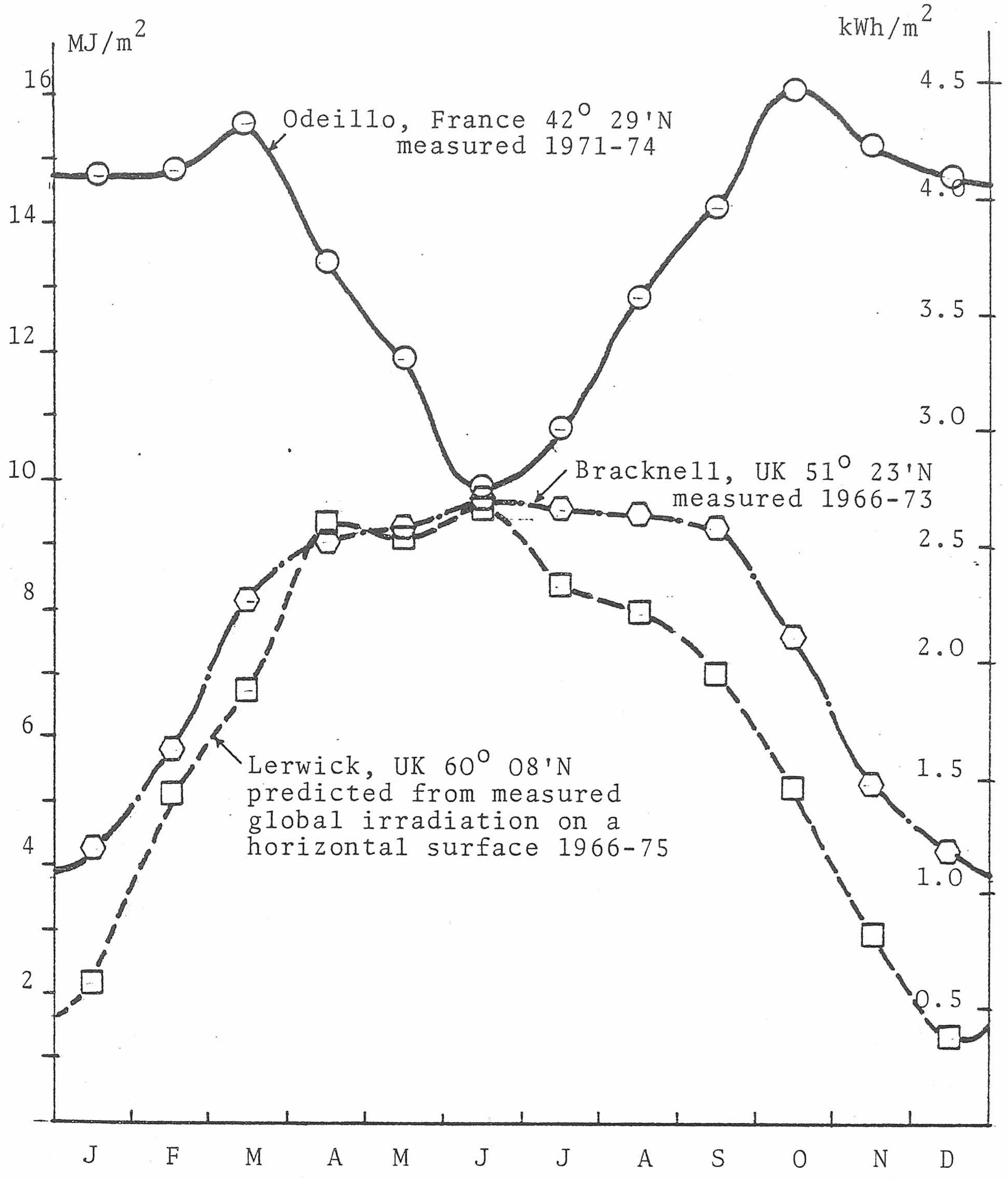


Fig 21 monthly mean daily irradiation on vertical south-facing walls at Odeillo, Bracknell (East Hampstead) and Lerwick, including ground reflected component autumn and spring. According to Burberry[7], analogue studies of insulation position and heating patterns, have shown that where intermittent heating is employed, better economy of the plant is achieved when the insulation is on the inner face of the wall rather than in the cavity. Intermittent heating can be assumed with unknown and varying housing occupancy patterns, unless there is a centrally controlled heating plant. Such district heating would be operated on a more regular cycle, thus ironing out thermal inertia of the building fabric, but will not in itself have the capability of fast response to the solar supply. For maximum efficiency, therefore, all auxiliary regimes used in conjunction with a solar heating system require both heat emitters and surrounding materials capable of a fast thermal response. Even if the former condition is met, for example with a radiant source aimed directly at the occupant(s), the traditional direct gain design, with heavy structural masses internally in the path of solar irradiation, will tend to delay the fabric response and lower mean radiant temperatures. On the other hand if a heavy-weight structural mass around a room is lined with light-weight materials to speed up response, much potentially useful solar gain could be wasted. On sunny days there would be an initial fast build up of temperature to a level where it might be necessary to open, or at least shade windows, in order to re-establish comfort conditions, which will now be at lower temperatures than with exposed heavy-weight linings due to the higher surface temperatures.

Also, regardless of an architect's intentions, there is an inherent lack of control over internal finishes in the sphere of public sector housing, and hence lack of predictability of final thermal performance. For example, if a concrete floor covered with ceramic tiles is specified to optimise solar absorption, it is probable that the occupant might choose to cover the floor with a carpet. Again Burberry[7] confirms that this is of great significance, since a massive construction, if covered with lightweight finishes, will behave initially as a lightweight construction, rapidly absorbing and re-radiating collected energy. This thermal response conflict can be resolved by use of phase-change linings, but specialised materials such as the 'Sol-ar-tile', manufactured for this purpose in the USA, are unlikely to be economic in UK or Scottish local authority housing in the near future. Also there would be no guarantee that an occupant might not cover over these vital surfaces.

Conclusions

It can be concluded that there are serious limitations to the potential efficiency of direct gain as a passive solar collection method for public sector housing in the 50-60^{o} latitude range. The dominant role of intermittent traditional heating points to a thermal response balance, with light and heavy elements juxtaposed in relation to the living function of a particular room. However, it should be remembered that without increasing the size of south facing windows to the maximum permissable or optimum limit for direct gain, simple redistribution of normal glazing areas for all living spaces to the south wall, is in itself a worthwhile conservation measure, and need involve no additional costs.

(ii) Indirect Gain: Sun > Storage Mass > Living Space Collection, Delivery & Control

In the indirect gain concept, a storage mass collects and stores heat directly from the sun, and then transfers heat to the living spaces. Indirect gain systems have been used to considerable effect in lower latitudes, ranging from 30-45^{o}, using both roofs and walls as the storage and distribution medium. The latter is clearly the most appropriate with increasing latitude and decreasing solar altitudes. Prototype houses in Odeillo in the French Pyrenees 42^{o} 29'N, designed by Trombe and Michel[4], gave the name to this system, Trombe-Michel wall; now generally referred to simply as a Trombe wall, and probably the single most researched and validated passive solar technique. The required elements are a large south-facing, glazed collector area, with a storage medium directly behind it. Radiant distribution from the storage mass to the living space is usually delayed up to 12 hours, but could be almost immediate, depending on the density and thickness of the material chosen. Instantaneous heating is also made possible by thermo-circulation of the heated air in the gap between glazing and wall. Hinged insulated flaps are used to control air movement, preventing reverse thermo-siphoning at night, and also some measures are advisable to limit night losses due to excessive conduction and radiation. For example, as a fixed measure, a low emissivity selective surface can be applied to the outer surface of the wall. Mason[9] has shown that a single glazed vertical south facing Trombe wall at latitude 50°N, with a selective surface, will out-perform a double glazed wall with a black neutral surface, providing 62 kWh/m^2 over the heating season as opposed to 17 kWh/m^2. However, the overall result was still negative in January, - 3 kWh/m^2 as opposed to - 9 kWh/m^2.

Applications and Limitations

One problem in locations with much lower winter radiation levels than at Odeillo, is that the presence of thermo-circulation can have a negative effect on comfort conditions, due to the low inside surface temperature. A Trombe wall simulation monitored by Rey et al[10] in Lausanne during January 1981 bears out this contention. Lausanne is located 46° 30'N, approximately 9-14° below the latitude range under examination, with a January mean daily irradiation much lower than Odeillo, but still well above values for Scottish locations. The wall modelled was 280 mm thick, with 4 thermo-circulation vents comparable with those at Odeillo, and with double glazing plus night insulation in the form of an aluminium blind within the air-space. Several combinations of operating mode were simulated - vents always open, open 10.00 am - 6.00 pm, always closed and both with and without night insulation. The conclusion reached was that only the deferred solar heat gains were useful, with no thermo-circulation at all, and provided night insulation is used in addition to double glazing.

Apart from limitations associated with low winter radiation levels in the UK, there is one serious design conflict for public sector housing use apparent in this system. The provision of access, daylight and aspect on the south facade is possible only at the expense of the solar system. This clearly becomes critical in a terraced situation with restricted frontage widths, as defined in section 1.2. However, there is one notable example of a Trombe wall in the UK at Bebington[11] in Cheshire at 53° 25'N - a small, low density, medium frontage, terraced housing scheme for the elderly. The measured data[12,13] for this wall is shown comparatively with measured data[13,4] for the 1967 prototype Odeillo Trombe walls in Table (i) and serves to illustrate the relatively much lower performance levels that can be expected from UK and Scottish locations within the 50-60° N latitude range. However, 15% of the heating load is still a worthwhile gain if it can be achieved at minimal extra building cost. The low proportion of gain attributed to thermo-circulation is significant, bearing out the findings of Rey referred to above, and also pointing to short, carefully detailed ducts.

Conclusions

It can be concluded from the above that the cost effectiveness of indirect systems, such as the Trombe wall in its original form, is reliant on relatively high levels of winter solar irradiation, as shown in Fig 21. Also the thermal transmittance values of such walls are also unlikely to satisfy the Building Standards (Scotland) Amendment Regulations 1982. No trade-offs are permitted from opaque to glazed surfaces, and if the storage wall in a Trombe system is considered to be a dividing

TABLE (i) - Comparative Trombe Wall Data; 1967 Prototype, Odeillo, France to Acorn Close, Bebington, UK

	Bebington	Odeillo
Latitude & Altitude	53° 25' 60 m	42° 29' 1,550 m
Orientation & tilt	163° 90°	180° 90°
Collector Wall Area	19 m^2	48 m^2
Collector Area/Heated Vol.	——— = 0.16	——— = 0.16
Heated Volume	117.5 m^3	300 m^3
Floor Area/Occupancy	50 m^2 1-2P	79.5 m^2 4-5P
Wall material & thickness	Dense brick 225 mm	Dense conc 600 mm
Absorptive surface	Black "	Black acrylic paint
Wall density	2,200 kg/m^3	2,200 kg/m^3
Glazing	Double 4:12:4 mm	Double 3:12:3 mm
Dist. between glass & wall	700 mm	120 mm
Thermocirculation vents	250 x 75 mm 2.2 m apart	565 x 110 mm 3.5 m apart
Active " assistance	Yes, but not used	No
Collector wall U-value	1.21 W/m^{2}K	1.97 W/m^{2}K
Av. bdg. shell U-value	0.60 W/m^{2}K	1.34 W/m^{2}K
Vol. Heat loss	1.28 W/m^{3}K	1.67 W/m^{3}K
°Days to 18.3°C base	2,531	3,942
Global Irradiation on Hor	835 kWh/m^2 yr	1605 kWh/m^2 yr
Annual space htg load	9,100 kWh	27,144 kWh (74-75) (48,000 kWh estimate)
Total annual solar saving	1,300 kWh	19,094 (74-75)
Annual Solar saving per m^2	70 KWh/m^2	400 kWh/m^2
% Thermocirculation	10%	30-35% clear day
Annual Aux. Energy Load (including casual gains)	7,800 kWh (electricity)	8,050 (74-75) (electricity)
Solar Heating Fraction	15%	70%
Efficiency	25%	30%
Wall Time lag	5-7 hours	14-16 hours

wall between a living space and a narrow glazed sunspace, as at Bebington, the maximum U-value permitted, for the opaque wall alone, is 1.0 W/m^2K. Therefore, some modification would be required to the original concept, particularly in terraced houses, where there is a very limited surface area available to satisfy the needs of daylighting, aspect and solar collection. However, it may be that the Trombe effect can be incorporated in situations where there is little or no outlay, for example a sunporch, and/or used in conjunction with other passive solar techniques.

(iii) Isolated Gain: Sun >Collector space >Storage mass >Living space

Collection, Delivery and Control

In the isolated gain passive solar concept, solar collection and storage are thermally isolated from the living spaces of the building. This concept is contrasted with direct gain, where collection and storage are integral with the living spaces, and indirect gain, where collection and storage are separate from the living spaces, but directly linked thermally. The isolated gain concept allows the collector and storage to function somewhat independently of the building surfaces bounding living spaces, while the spaces can draw from storage sources as its thermal requirements dictate.

The thermosiphon convection loop is often used in isolated gain systems, as the means of heat transfer from collector to store, the principle being the same as that for solar water heating. The flow of air through a thermo-siphoning collector is driven by the difference in density between the unheated and heated columns of air. This is a function of the difference in average air temperatures between the two columns and their height, collector performance improving with increasing column height. The cross-sectional area of the flow channel within the collector and the inlet and outlet vents also influences air flow rates and thus collector efficiency. Most research work on thermo-siphoning systems has been done by the CNRS in France and Scott Morris, USA[14], but there is a lack of agreement on optimum or acceptable conditions for collector efficiency. According to Morris a temperature differential of 27.5 - 36K will provide an acceptable flow rate of 0.18 m/s, the design flow rate for active systems; while CNRS found that with a differential of 30K and an air velocity of 0.3 m/s the system has a maximum efficiency of 18%, and only 13% of incident solar energy during the heating season[15]. This would indicate that fan-assisted 'hybrid' systems might be required to improve air flow and hence system efficiency.

Applications & Limitations

An early example of an isolated gain thermosiphon system is the Paul Davies house in Albuquerque[15]. However this is dependent on a favourable south facing slope, and is unlikely to have a general application for UK housing. The most favourable line of development may well be in the field of 'sunspace' and 'double-envelope' solutions, either in combination or independently, in that they do not have the inherent limitations imposed by direct and indirect gain outlined above:

Sunspace: In its simplest form, the attached sunspace is a Trombe wall with an air space sufficiently enlarged to make it a useful annex to the living space. It could thus be regarded as a combination of direct and indirect passive systems. However, the benefits are strongly dependent on the properties of the dividing wall, and it is important to ensure that reverse conduction flow does not make the sunspace a net loser of energy. A refinement is to introduce a well insulated 'store', which is thermally isolated from the living spaces, to cover periods of low radiation. This arrangement then allows the dividing wall to be insulated to a value compatible with building standards. A sunspace can also solve a key problem with respect to control of auxiliary heating in tandem with solar heating, acting as a buffer reservoir between inside and outside. Not only can the sunspace accept higher temperature fluctuations than would be tolerated within the house, but also with a thermally de-coupled store, it can deliver to internal spaces if and when excess energy is available and the demand exists. Although the results of the SHED sun-space project at Sheffield were disappointing, Green[16] has calculated that a solar conservatory coupled to heat storage with fan assisted air circulation could supply 70-80% of the residual space heating load in a well insulated house ie 2,800-3,000 kWh/year or 140-150 kWh/m^2 per year.

Double Envelope: The main elements of a double-envelope thermo-siphon system are:

(a) The south facing 'collection facade' - this would differ from a normal Trombe wall in that the surface behind the glass should be well insulated and thermally light, so that irradiation is not stored in this area. Critical features of the collection facade are the control of unwanted gains, and the reduction of radiated losses.

(b) The 'ceiling duct' - an insulated space between upper ceiling and roofspace, connecting with the north wall. This space must be well insulated to prevent excessive heat flow both outwards, and into the building, and would normally be vented for summer relief.

(c) A 'north wall' comprising an insulated outer skin, air gap and an inner skin, either of high mass and no insulation, or a low mass insulated skin. Air leakage is a critical factor on the north wall, and potential condensation problems must be carefully assessed.

(d) The 'underfloor void', which combines the function of completing the loop, and of thermal storage mass. The main point to bear in mind is that if the slab is not thermally de-coupled from the interior, control of heat input to the interior will be difficult.

Helix Multi-Professional Services have developed this system with certain modifications: The width of air in passage ways is restricted to approximately 50 mm so as to increase the contact with the storage mass; the air flow is controlled by placing one or more fans in the circuit; and the thermal mass in the North wall is increased to constitute a storage element. Two houses in Berkshire are currently being monitored. The south face has a glazed collection surface of 46 m^2, of which 17 m^2 is double glazed window. Radiation is absorbed on panels of minimum thermal mass, lined with 'Maxorb' selective coating. Small air impeller fans are operated by a differential temperature controller which brings them on when the air in the collector exceeds the storage slab temperature by a pre-set amount. The main advantages of this system over a conventional Trombe wall are that there is no longer a restriction on south facing windows, and also by de-coupling the storage from the collection element, re-radiation losses are minimised. Dodson[17] admits that "simulation is complex but that the double envelope house appears to work for human comfort in cold climates, almost no matter how the design principle is applied".

Conclusions

Thermo-syphon systems need to be treated with some caution as the financial outlay could be considerable for a low return in useful solar gain. However, the attraction of an isolated gain sunspace system is that even if the return in useful solar gain is fairly limited, other assets have been purchased such as a practical extension to the living space, and useful climatic buffer zone or thermal lock.

A sunspace is also very flexible in terms of heat collection and distribution, provided it is associated with a well insulated thermal store, and can easily be integrated with other passive solar concepts such as 'double envelope' convection loops. Further, isolated gain systems simplify sychronisation of control of auxiliary heating with useful solar gains[18].

3.1.4. Summary - Prospects for Passive Solar Guidelines for Scottish Public Sector Housing

A passive solar contribution must be assessed in the context of an overall energy conscious framework.

Existing passive techniques have been developed mainly in the field of experimental and individual private houses, whereas public housing implies a considerable degree of additional restriction to design potential, particularly in relation to cost and control.

Radiation levels, in the 50-60° latitude range, indicate that passive gains will not make a significant contribution from November to February. Therefore, traditional heating systems have a much more dominant part to play than in lower latitudes, ranging from 30-45°, where most of the recognised passive solar techniques originated. The balance required between the conflicting needs of passive solar measures and the traditional heating will influence decisions as to the location of high and low thermal capacity materials. It is both important that a heat emitter is capable of fast response to fluctuations in insolation, and that there is some means of storing gains until demand exists - at least over a daily cycle. Well insulated high capacity storage, thermally de-coupled from the main structure, could provide the solution to this thermal response conflict between traditional and passive solar heating. Therefore, a promising line of development for partial passive solar heating in Scotland may lie with compound direct/indirect/isolated gain methods, such as 'hybrid' refinements of the 'sunspace' and 'double envelope'. When assessing cost benefit, it is necessary to apportion mult-purpose aspects of constructional/planning elements. For example, a sunporch can be an essential circulation space, or an added spatial/visual amenity, and in either case a solar collector, which will also serve to reduce the rate of fabric and ventilation losses, even during periods of negligible radiation. Similarly, normal tile cladding substituted for the glazed solar collector skin of a double envelope solution could function as a simple passive solar external insulation medium, without the sophistication of a fan-assisted convection loop.

It is difficult to quantify the energy performance of such features using steady state calculations, and particularly to isolate specific solar fuel savings. However, the use of a spatially multi-zone, and constructionally multi-layer, dynamic thermal simulation engine such as ESP will permit accurate energy flow analysis, from which useful design guidelines can emerge.

3.2. Thermal Analysis of Models

3.2.1. Introduction

The preceding sections have indicated that appraisal of the economic and technical viability of a passive solar space heating contribution for housing will depend on a fine balance of mathematical prediction and pragmatic assumption. For example, internal thermal control is subject to automatic fabric response to solar gains, interfaced with a realistic expectation of physiological response from occupants. The former can only be calculated having made estimates with respect to the latter.

Having established certain primitive passive solar design precepts appropriate to Scottish locations, these are now developed beyond the conceptual stage for more detailed analysis and reappraisal. This is done within the framework of four representative housing models or configurations. It is not the intention to produce a definitive series of passive solar house plans; rather to test the feasibility of various passive solar techniques within limits imposed by specific categories of housing shell, which cover the widest possible spectrum of need and planning flexibility. For example, one of the models analysed is a typical 2 storey terraced family house, using gas or electric heating fuel, and appropriate to an urban to semi-urban setting. Included in Appendix 5 is a rural variation of this house configuration, in a 1½ storey form, using similar passive solar techniques, but related to solid auxiliary fuel. Visually the two house types have very little in common, but the essence of the solar design is identical.

With regard to the specific passive solar gain category, in response to the preceding appraisal, all of the models use a compound of direct, indirect and isolated gain, with thermally de-coupled short-term storage associated with the latter. Again where possible, this is not a special solar provision, rather the enhancement of an essential construction element, such as floor slab or underbuilding. Three of the models use 'active' assistance to transport collected energy to the remote store, the aim being to provide a higher percentage of useful solar gains and minimise risk of overheating; while one, by careful location of the store in relation to the collector, uses the same principles in a purely passive manner.

Accordingly, all four models have certain passive solar features in common, and certain characteristics distinct to the specific housing configuration. All except the live project are designed to minimum housing standards, with no 'solar' floor areas additional to normal requirements. Rather essential elements such as entrance lobbies are enhanced as sun porches, located to act simultaneously as solar collectors and climatic buffer zones between main living spaces and exterior. There may be, therefore, a radical departure from traditional disposition of spaces, but none from current space standards. Also, whilst not precluding recommendations for future amendments to building regulations, such as those outlined in Section 1.1, the configurations are designed to comply with current Scottish standards. This means that, for example, neither maximum U-values for opaque external surfaces, nor percentage of glazed openings in relation to perimeter wall and roof surfaces are exceeded; and where sun porches are located in front of external walls including windows, the opaque dividing wall U-value is met, as well as relevant ventilation requirements. However, in the first configuration where the sunporch has no glazed roof as defined by the Building Standards (Scotland) Regulations 1981, it is deemed to be part of the living space, the inner glazed screen an optional foldaway feature and the outer glazing the living room windows. This is a discretionary interpretation by a particular authority and could be contentious for future similar applications, since from a technical viewpoint the inner screen is essential to the passive solar strategy. In the second configuration the sunporch is also open to interpretation as to whether an inclined surface constitutes a roof or a wall. Such ambiguity could be removed by an amendment whereby the criteria of a sunspace located across the window of a living apartment becomes the maintenance of daylighting standards in that apartment, in the same way that ventilation standards are currently protected.

The aim of the analysis will be firstly to compare the efficiency of specific passive solar collection/storage features, such as sun-porches and rock-bed stores, in relation to the volume of heated space within each configuration. Building construction relationships can be varied during the analysis in order to study the effects of altering factors such as thermal response, storage capacity and conducted losses. Secondly at the planning level, the overall performance of identical houses in different situations, such as intermediate or end-of-terrace, can be compared; and with flats the range can be enlarged to ground, intermediate and upper floors, each in an intermediate or end-of-terrace location. Thirdly by comparing the performance of similar passive solar design features in houses of identical size, but contained in radically different shells - one a medium frontage single aspect north/south terraced house, the other a narrow frontage, dual aspect east/west terrace - it will be possible to test the assumption that north/south orientation $\pm 45^{o}$ is a prerequisite of passive solar planning. Assuming this stage of analysis shows east/west orientation to be viable, the fourth housing configuration will go a stage further in challenging traditional concepts. This is a true single aspect back-to-back terraced house, with one facade facing east or west and with a south facing roof collector and sunwell. Again solar performance can be compared to the north/south terraced house per unit volume.

3.2.2. Housing Configuration 'A': Single Person North-South Flat

(i) General Description

This is a live project in Stornoway, Isle of Lewis by the Western Isles Islands Council, and comprises 22 single person flats located on a sheltered, south sloping site with no significant overshading from adjacent buildings or surrounding terrain. Advantage has been taken of the slope to provide an earth berm half-way up the north side of ground floor flats, and terraces are orientated gable-on to the prevailing westerly wind-sector. The flats are medium frontage, arranged in 2-3 storey, south facing terraces, with a common access stair serving flats on each side.

(ii) Passive Solar Features

Each flat is planned with living spaces to the south, service spaces to the north, and also has a south facing sun-porch entrance connecting to the common stairs and located across the living room window, as shown in Fig 22. The living room receives direct solar gain via the sun porch, and the bedroom through a normal south facing window. Indirect gain occurs mainly by convection from sun-porch to living space and bedroom, but partly by conduction through the dividing construction. The isolated gain system links three collection sources by ducts

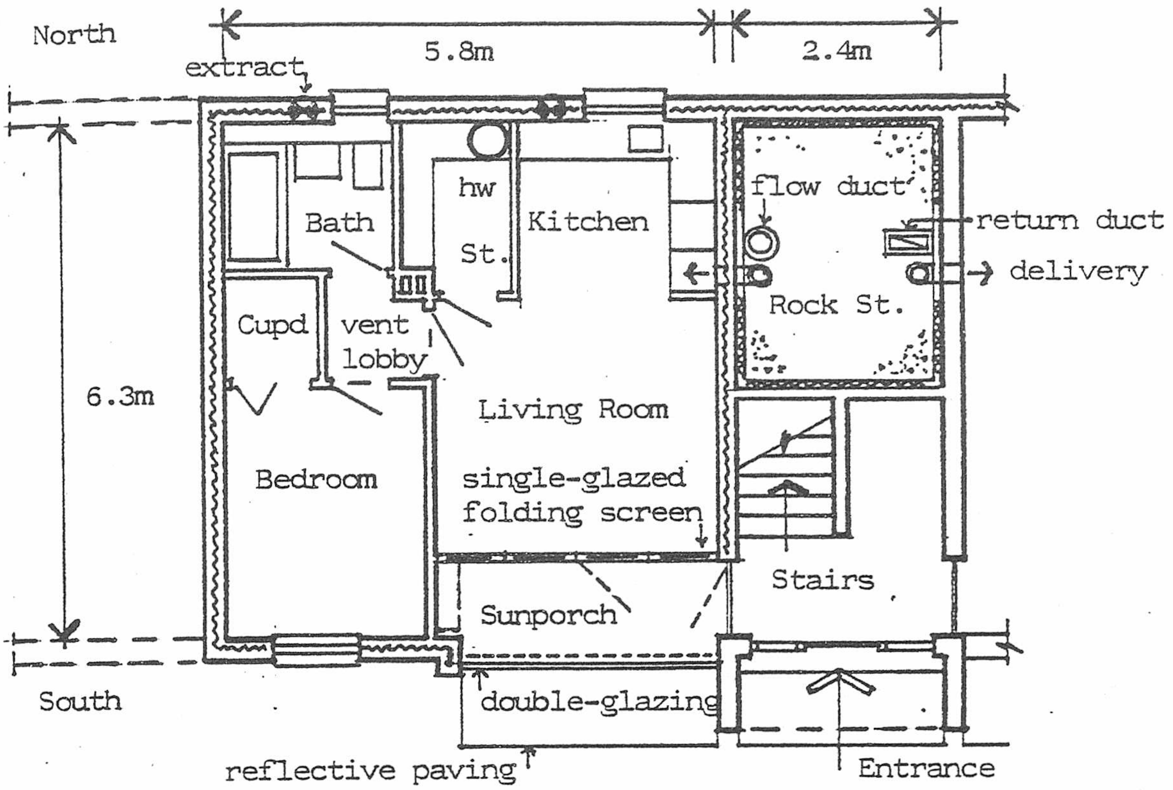


Fig. 22 Plan of typical ground floor passive solar flat

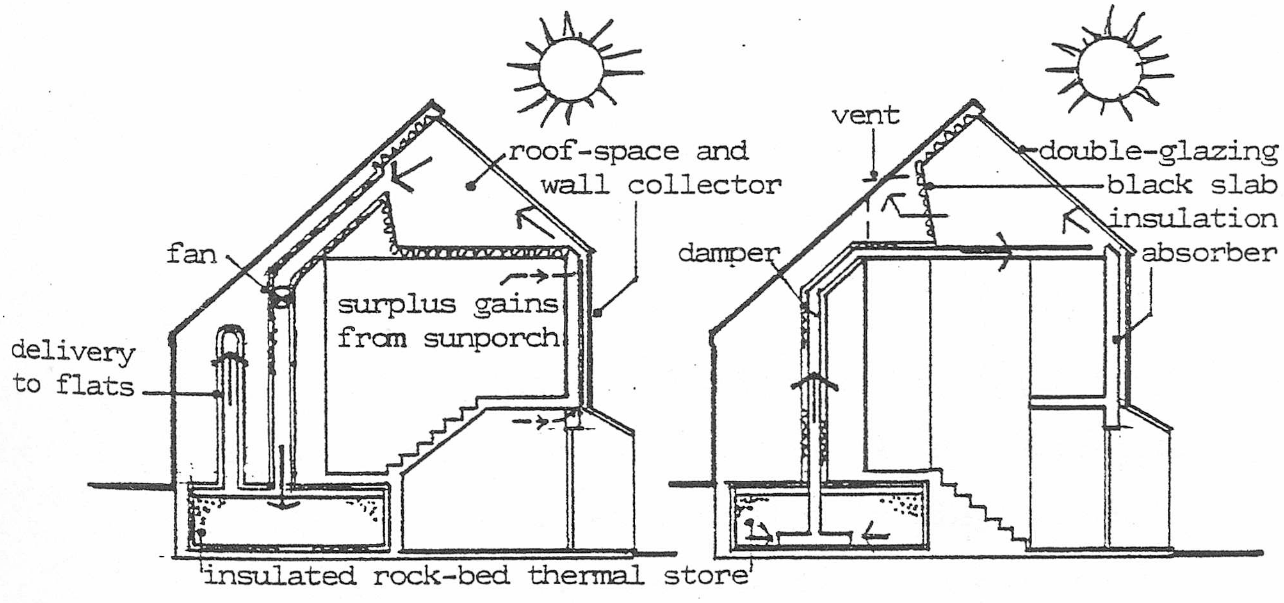


Fig. 23 Sections through stairwell collector system

to a rock bed store in the underbuilding below the stair half landing as shown in Fig 23. The rock store is charged with active assistance, but from the store, delivery to flats is by natural convection, either directly through the wall from the top of the store in the case of ground floor flats, or by short vertical stub ducts in the case of upper floor flats. The three isolated gain collectors are:

(a) the sunporch, where excess gains can be ducted to (b)

(b) a roof space air collector over the common stairs, linked to the rock store with a flow and return duct to provide a closed loop

(c) a south wall collector to the stairwell with thermo-circulation linked to (b)

The latter two sources will also give some radiant/convective transfer indirectly to the stairwell itself, thus reducing losses to this area from entrance porches.

(iii) Control

Convected solar gains from the sunporch to the living area and bedroom can be controlled by adjustable vents in the dividing screen, while a hit and miss device above the entrance door controls the link to the south wall and roof space collector. An occupant can, therefore, preset the system to:

(a) deliver all solar warmed air directly to the living space by opening interconnecting vents or glazed screen and closing vent control to roofspace

(b) store solar gains within the materials surrounding the sunporch and living spaces by closing all vents

(c) deliver excess solar gains from sunporch, and/or living room, by opening vent control to roofspace and opening or closing interconnecting vents as desired.

The success of this control flexibility will be partly dependent on sensible weather anticipation by the occupant, and partly on a public relations exercise by the housing department in explaining the potential cash saving benefit of efficient control to each occupant. Control of gains from the roofspace collector to the rock store will on the other hand be automatic, with the fan switched by a differential temperature sensor. Control of stored heat to the flats is again in the hands of the occupants, with adjustable registers located in the kitchen. When heat is available this will serve to provide a warm air curtain in this area, which is open to the living space, but has a north facing window. Reverse thermocirculation from the store back to the roof space will be prevented by an automatic damper on the fan in the 'flow' duct, linked to another 'damper' in the return duct. No further precautions are therefore required to reduce night losses from the roofspace collector. With respect to the sunporch, a reflective blind on the inside of the outer double glazing will provide both shading control and help to reduce night losses from the sun-porch. Further control of night losses will be at the initiative of the tenant in the form of blinds or curtains inside windows.

The sunporch itself is also the first infiltration barrier and natural ventilation controller to the living space. The sliding-folding screen between the sunporch and living space will be single glazed, but draught stripped, in order to provide a further barrier to infiltration losses from the living area. Natural ventilation can be regulated in the following manner. Vents at the top of the outer sunporch glazing will allow rapid exhaust of unwanted gains in summer. The sliding-folding screen between sun porch and living space can be achieved by adjusting the small vents or louvres. Cross ventilation of the living space is possible by simultaneously opening the kitchen window, the glazed vents in the sun porch and the sliding screen. Mechanical ventilation in both kitchen and bathroom, to allow rapid exhaust of moisture laden air at source, is provided by means of wall extract fans, automatically switched by 'humidstats' when a pre-set level of relative humidity is reached. Permanent ventilation to the internal lobby, living room, bedroom and stores is provided by a plenum located over the lobby and feeding into a vertical, fireproof 'flue', exhausting at roof level. An alternative mechanical ventilation/ heat recovery system, in the form of a standard family house package, modified to serve a group of four flats, and using the same ducts and plenums may be installed on a trial basis.

The auxiliary heating in all flats is electricity, using a fast response fan-assisted storage heater/convector for the living spaces plus low wattage infra-red heaters in the kitchen and bathroom. Although there is a tradition of solid fuel in the form of peat in family housing in the Western Isles, this was considered inappropriate here, where the occupancy will be relatively young single people with intermittent heat requirements. The town gas system did not extend to the site so that electricity was the only practical choice. Construction will give a substantial thermal capacity to the house shell, but with a large proportion of concrete block walls and concrete floors dry-lined with lightweight finishes, together with some stud partitions, to provide an initially fast response to electric heat emitters. Roofs, floors and walls are insulated in compliance with Building Standards (Scotland) Amendment Regulations 1982, Part J. Inert slab insulation is placed against the inner leaf of external and stair party walls and at floor edge situations, and quilt insulation in roofs. The roof collector and rock store are also heavily lined with slab insulation. The advantages of this system of wall insulation are threefold. It contains a substantial thermal storage capacity within the house, cold bridges are avoided at party wall locations, and the risk of interstital condensation, assuming breakdown of the vapour check, is highest on the outer surface of the insulation. By using an inert slab, and allowing for some incidental cavity air movement, any condensation occurring should be able to evaporate outwards without risk of damage to the fabric.

(iv) General Observations

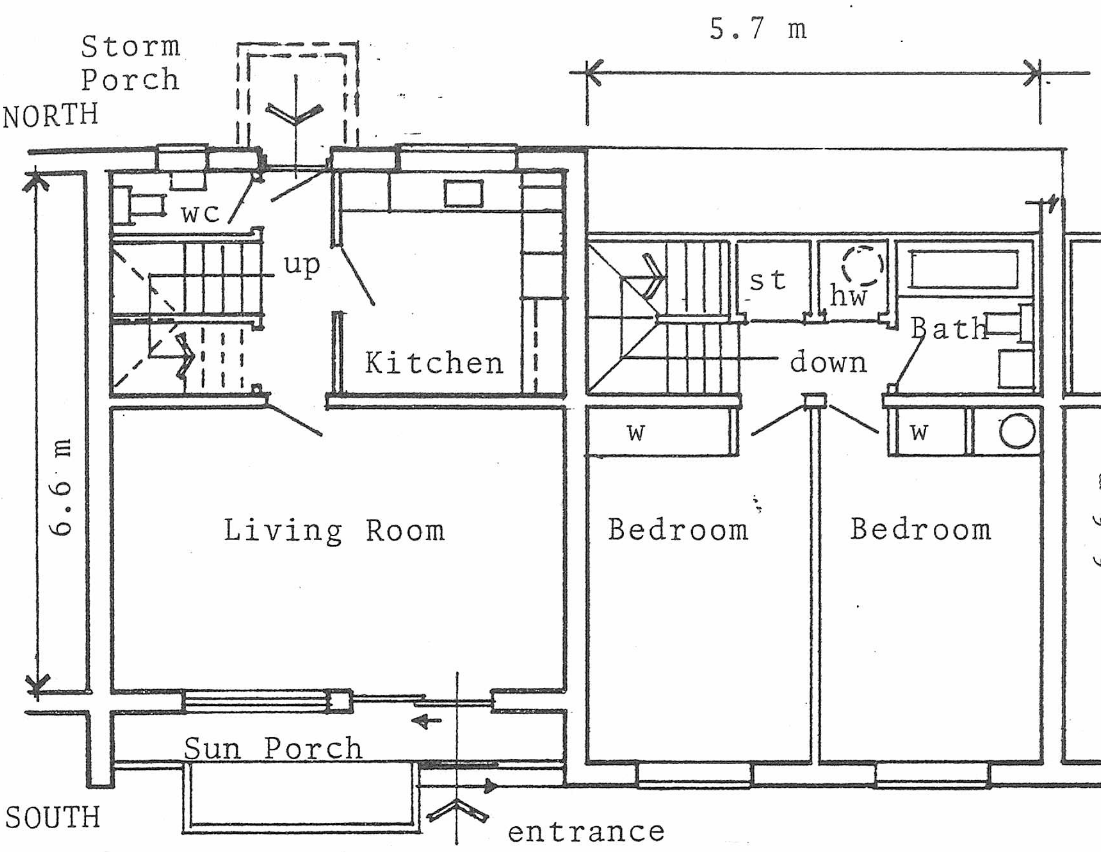
This project is of particular significance as a passive solar field study in an area of Scotland, with a rigorous climate, and located relatively far north at 58^{o} 15'. Building work on site started in June 1983 with completion anticipated early in 1985. The performance/cost analysis (see 3.2.7. below) validates the economic viability of a significant useful solar contribution to the space heating load with a theoretical pay-back period of approximately 8 years.

With regard to relevance of the chosen housing configuration, the tenement flat is still a popular and traditional housing form in Scotland, and clearly not restricted to single persons housing. The system of stairwell and sunporch collection has, therefore, potential for larger dwellings. Also as noted in Section 1, single person households are predicted to rise to 25% of the total stock by 1991, and fuel savings are particularly relevant to the elderly who form the largest proportion of this category. Key data relating to system sizing is in Appendix 2, and further design guidelines with respect to critical ratios emerge from the ESP performance appraisal in Section 3.2.7.

3.2.2. Housing Configuration 'B': 4 Person North-South Terraced House

(i) General Description

This is a typical four person, 2 storey, medium frontage terraced house, oriented north/south, with the plan organised so that all living and sleeping rooms face south. The asymmetric section, shown in Fig 24, has been devised partly to avoid direct solar gain overheating living rooms in summer, and partly to permit the closest possible spacing of parallel terraces for a given radiation loss. Reference to Section 1.2 shows that, assuming a level site, spacing of 18.4 metres would permit orientations from due south ± 30^o, within a 10% radiation loss, providing a net density of 40 houses per hectare, where the ratio of net to characteristic density is 0.7. Dual entrances give planning flexibility, and the plan form is also adaptable for medium-rise maisonette use, with north gallery access or stairs to pairs of dwellings. The house shells are designed to minimum area standards for intermediate terraced houses including the sunporch. This means that for maisonettes, depending on housing policy and budget, the sunporch could become an optional item left to the occupants direction and means, giving potential for individuality as well as energy savings. The same choice could also be left for terraced houses by increasing the living room depth to give the minimum floor area without the sunspace. For the purpose of the simulation models, a standard terraced house of 79.2 m^2, including the sunporch, is assumed as shown on Fig 24 and the heated volume has not been increased for the equivalent model without sunporch. Fig 25 shows a five person variation incorporating a single study bedroom adjacent to the living room at

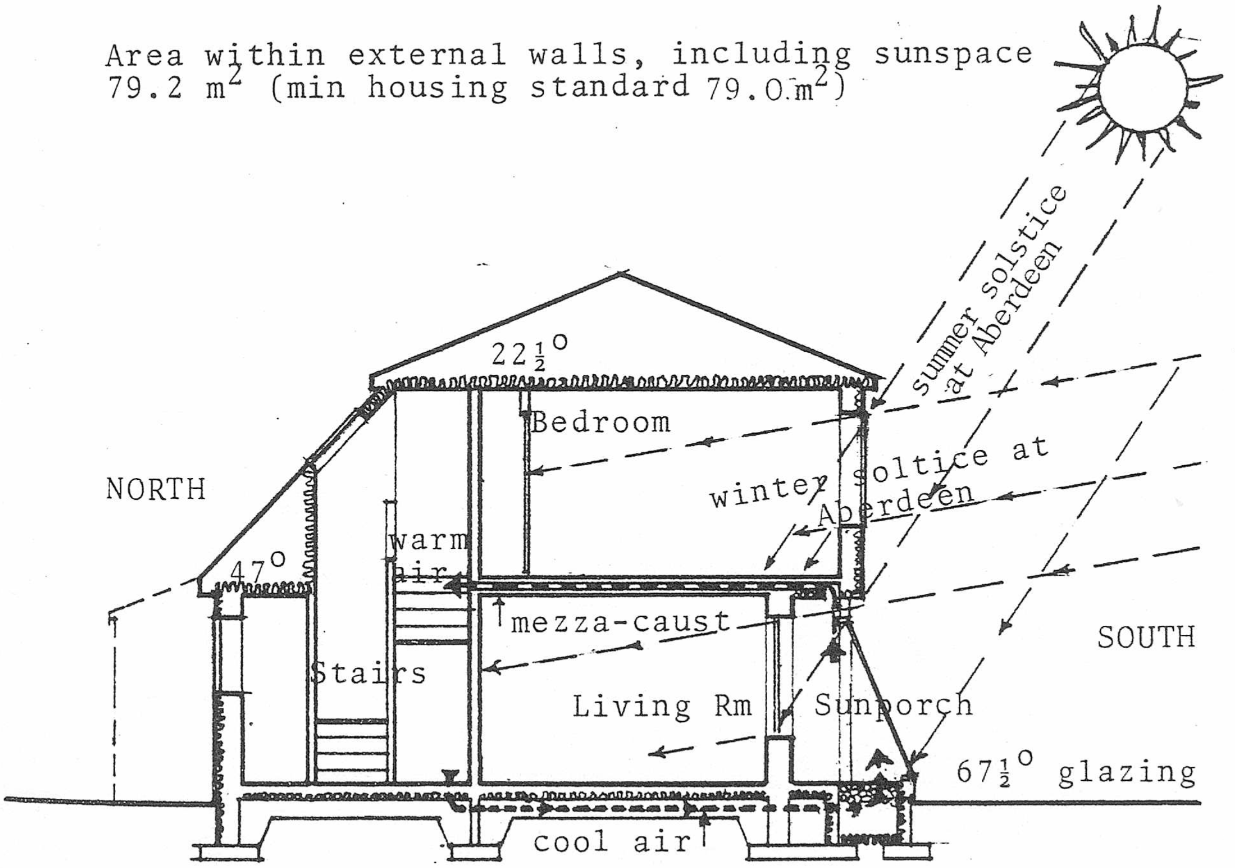


Ground floor plan

First floor plan

Scale 1:100

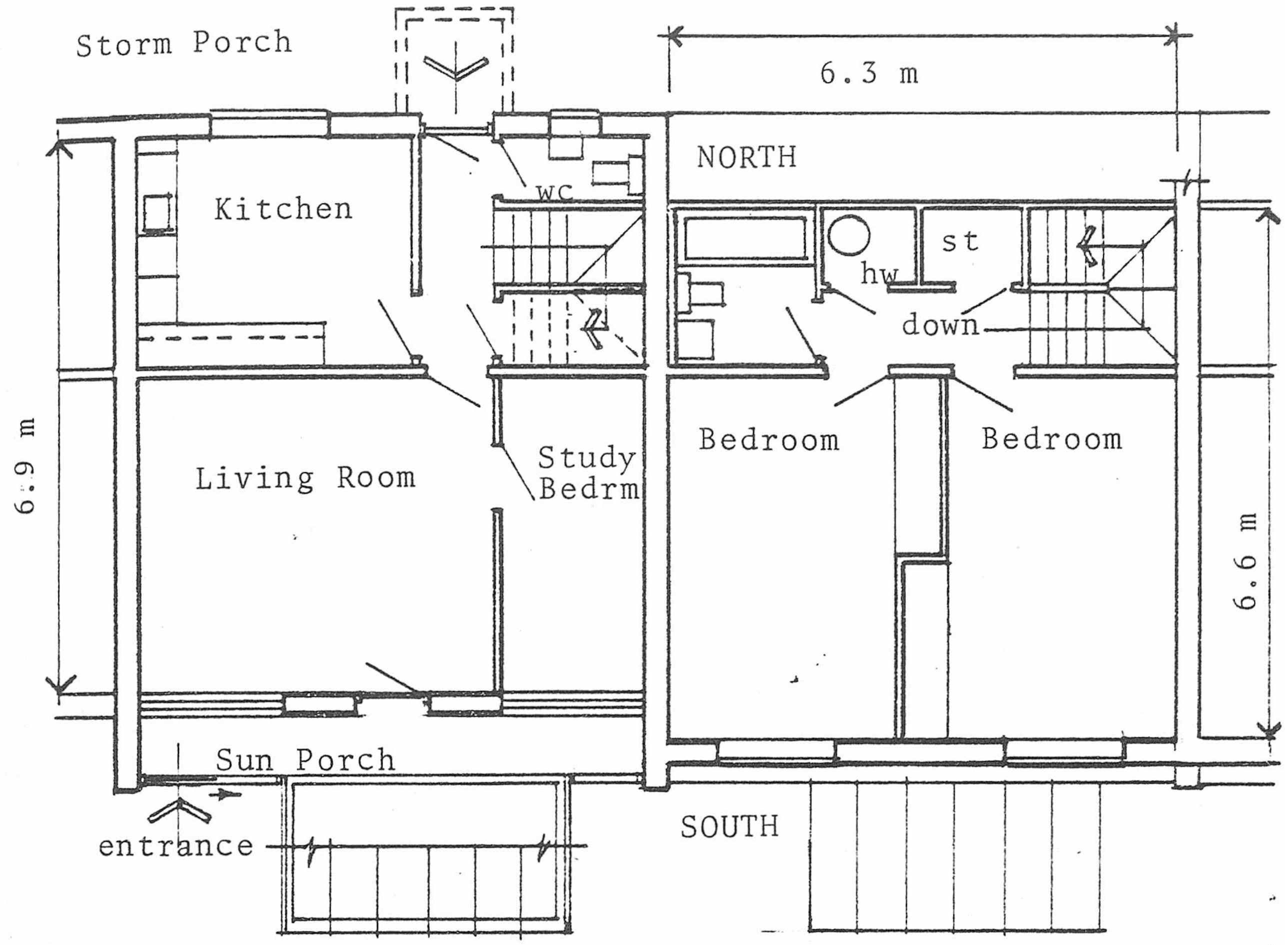
Area within external walls, including sunspace 79.2 m^2 (min housing standard 79.0 m^2)



Cross section

Scale 1:100

FIG 24: Housing Configuration B: 4 person medium frontage, south aspect house in 2 storey terrace.

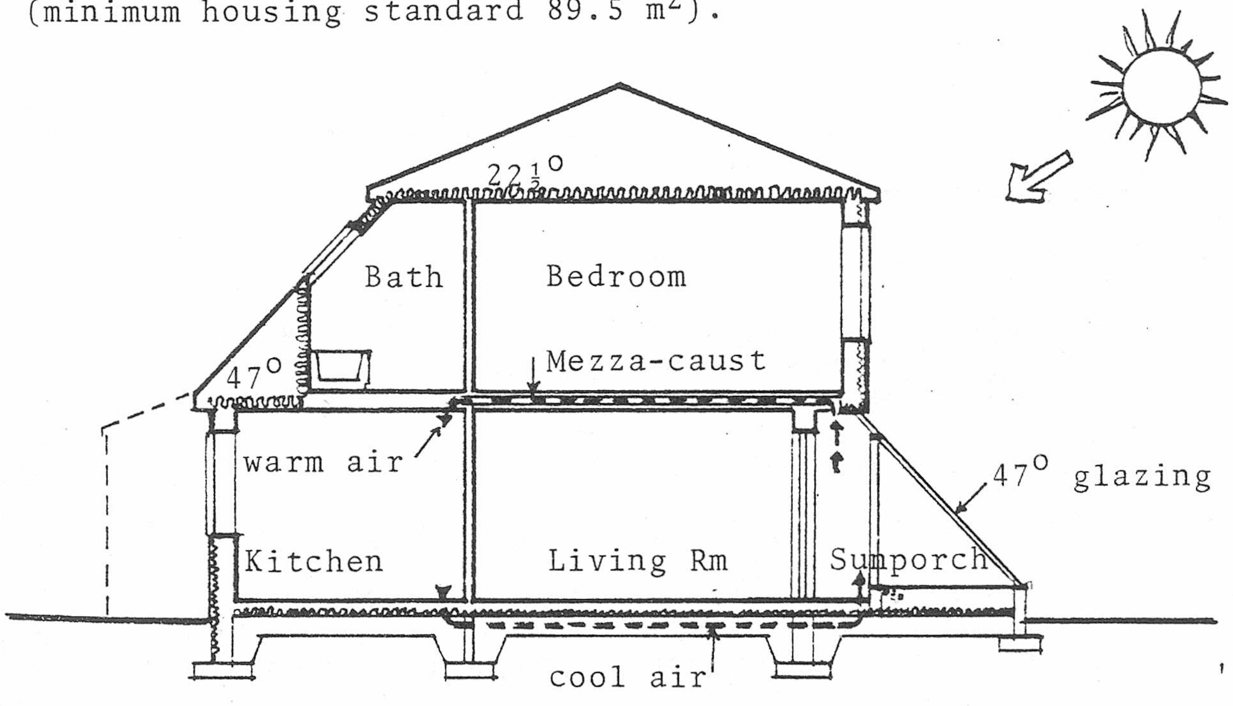


Ground floor plan

First floor plan

Scale 1:100

Area within external walls including sunspace 89.46 m^2 (minimum housing standard 89.5 m^2).



Cross section

Scale 1:100

FIG 25: Housing Configuration B1: 5 person medium frontage south aspect house in 2 storey terrace.

ground level, and with a total area of 89.46 m^2 including sunporch.

(ii) Passive Solar Features

The house is planned in the same manner as configuration 'A', with service areas acting as a buffer to the south. Again the living room receives direct solar gain via the sunporch, while first floor bedrooms have normal south facing windows, and again indirect gain transfer occurs by convection and conduction between the sunporch and living room. The unique feature of this configuration is the isolated gain system, where the thermal store is charged directly by natural convection of warm air generated in the sunspace. The store is a hollow first floor slab of high thermal capacity, with the cavities running from north to south. Warmed air not absorbed in transit through this store can flow into the stairwell, from where there will be a cool air return below the ground floor to the sunspace, thus completing the loop. This is then in essence a simplified version of the 'double envelope' system, with a much shorter travel distance to the thermal store, lying between ground and first floors and therefore central to all parts of the house. It constitutes a 'heated mezzanine' and is thus termed 'mezza-caust' on Figs 24 and 25. Such a floor could be proprietory hollow precast concrete slabs or a hollow clay or concrete pot system, or alternatively a purpose-made system of, for example, pvc pipes set in traditional Scottish 'pugging' between timber floor joists. A hollow concrete floor would provide a thermal capacity of approximately 1.5 kWh/K, approximately one sixth of the entire structure having a capacity of 9.4 kWh/K.

(iii) Controls

Convected solar gains from the sunspace to the living space can be controlled by windows and doors in the dividing wall, while a slot damper controls warm air flow to the mezza-caust. Adjustable register outlets from the mezza-caust would also be provided in the stairwell. If the stairwell overheats, air can simply be exhausted by opening a roof window in the steep north slope. The occupant has therefore the same degree of flexibility as in configuration 'A', although in this case the store is not so remote. The system can also be modified by introducing a fan to accelerate air flow through the mezza-caust, should increased efficiency warrant the active element. Reverse thermo-circulation from the mezza-caust will be avoided by closing the slot damper at night. A range of options are possible in relation to night losses in general, by varying both the mix of double/single glazing and curtains/blinds, between sunporch and living room.

Infiltration and ventilation control is also very similar to configuration 'A'. Permanent ventilation of living and storage spaces will in this case be via the entrance hall/stairwell. Traditional heating is assumed in the model to be either gas or electricity with fast response radiant emitters. Strategy with regard to thermal response is also very similar with lightweight linings to living spaces, and a high capacity structure behind, the ratio of thermal capacity of finishes to structure being 0.16. Reflecting the lightweight finishes, only 5% of the total thermal capacity, 9.4 kWh/K, is primary storage, that is directly insolated at noon on Dec 22; while 67% is secondary storage, that is in radiant 'view' of primary storage, and 28% is remote storage. The external wall construction proposed is a solid concrete block wall, clad in tiles or slates. A U-value of around 0.4 W/m^2K can be achieved using a lightweight load bearing insulating block on its own, or alternatively a dense concrete block can be used with an insulating material externally behind the cladding. This construction will both reduce the evaporative cooling impact of driving rain, and also increase solar absorption on the weatherskin, thus improving the dynamic performance of the wall.

(iv) General Observations

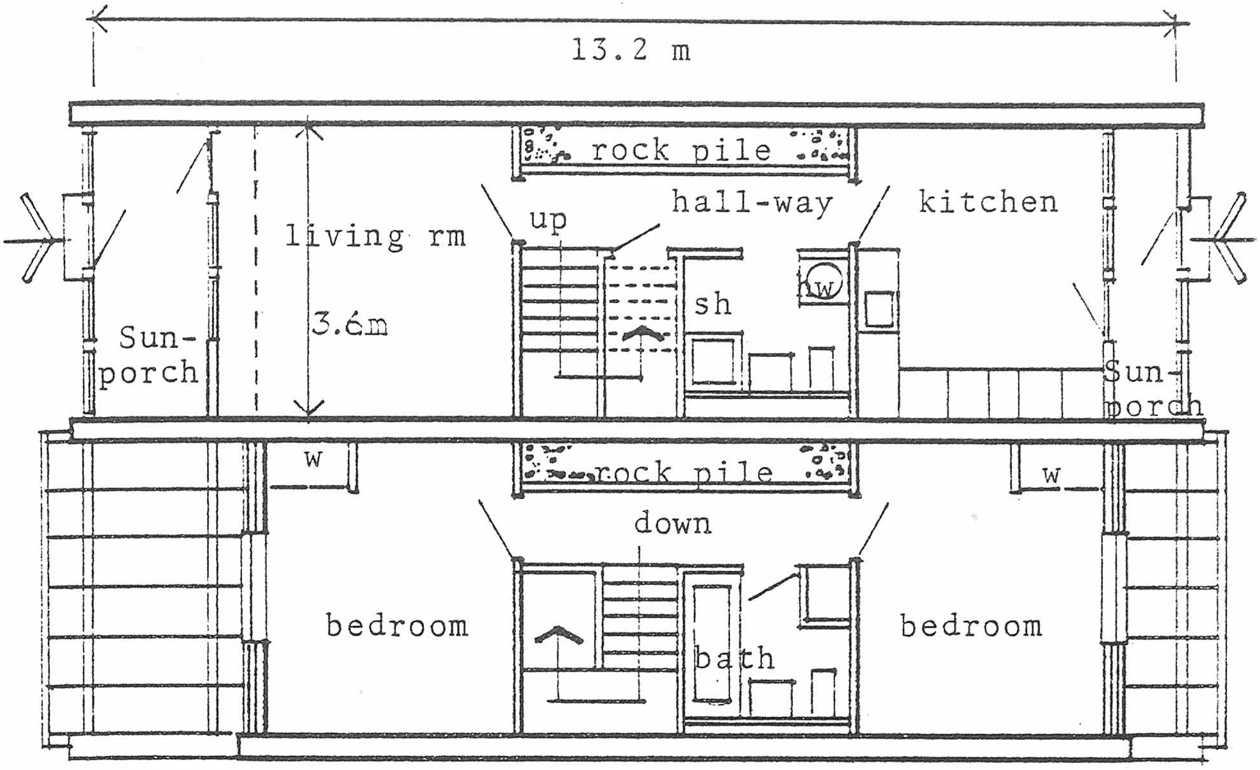
The main attraction of this model is its simplicity and flexibility in passive solar terms. The solar gain principles would be applicable over a wide range of medium density housing in urban, semi-urban, and rural locations, providing both scope for appropriate aesthetic treatment and plan modification by the designer, and also range of choice by the consumer in relation to passive solar features.

Key data comparative to other models are shown in Appendix 2.

3.2.4. Housing Configuration 'C': 4 Person East-West Terraced House

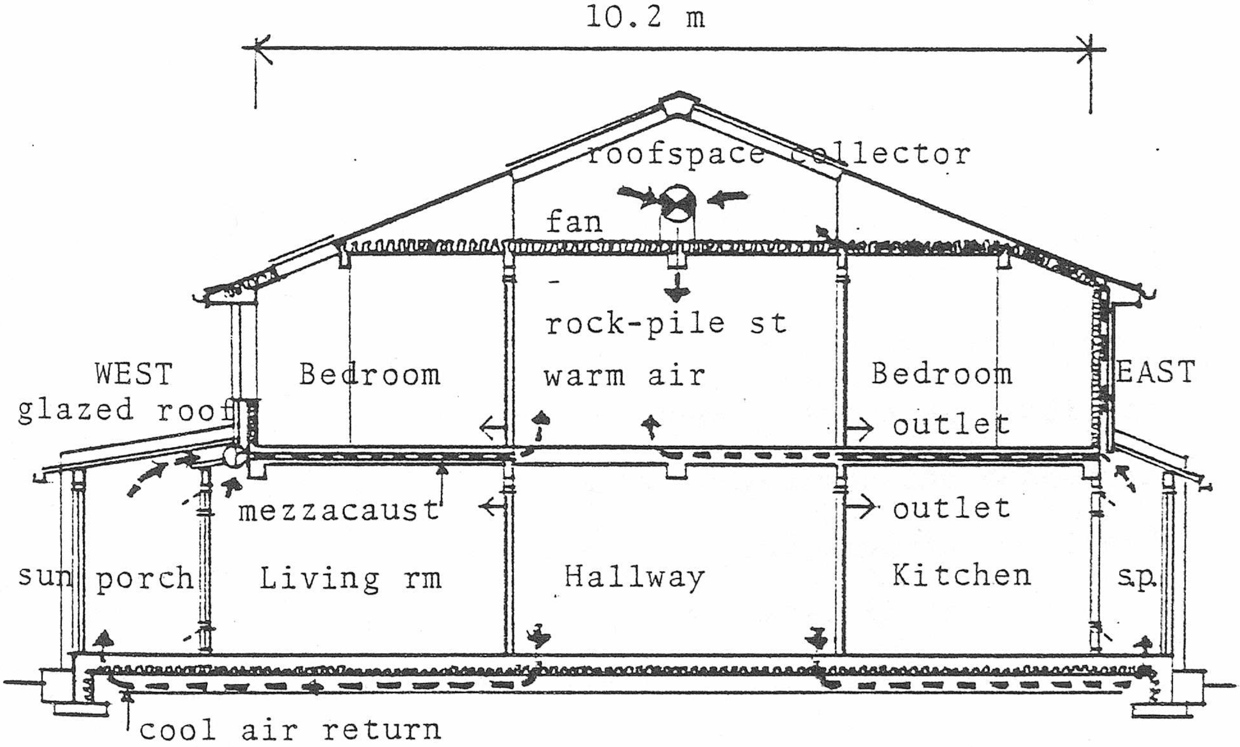
(i) General Description

This is also a four person, 2 storey terraced house, but in contrast to configuration 'B' it is a narrow frontage dual aspect type, oriented east/west. At ground level the living room faces west and the dining kitchen east, and at first floor level one bedroom faces east, the other west, as shown in Fig 26. Although the floor area is identical to configuration 'B', the enclosed volume is marginally greater due to the change in cross-section. The design of the cross-section takes due account of the fact that the roof is the only surface available to southerly radiation, to provide a situation where some passive gain is possible continuously from sunrise to sunset. The narrow frontage permits wider spacing and hence less overshadowing for a given housing density, and the



Ground and first floor plans: scale 1:100

Area within external walls and rock store, including sun-spaces 79.2 m^2.
(Minimum housing standard 79.0 m^2).



Cross-section: Scale 1:100

FIG 26: Housing Configuration 'C': 4 person narrow frontage, east-west house in 2-storey terrace.

model also provides scope for orientation within the sector excluded from configurations 'A' and 'B'. Again dual entrances will give planning flexibility to optimise orientation on any particular site, and exposed north facades will now only occur at one end of terraces.

(ii) Passive Solar Features

Since the house has dual east/west aspect, service areas have in this case been located centrally, and sunporches are located at ground level across both east and west facades. Both sunporches have glazed roofs so that the east porch will not 'cut out' before the west porch 'cuts in'. The west porch is also larger than the east porch, because although radiation levels on west facing surfaces tend to be marginally lower than for east facing[19, 20] in UK locations, from a social point of view, people tend to have more opportunity to sit in such a space in the evening rather than the morning. The living spaces will again receive direct solar gain via the sunporches, while the bedrooms have normal windows, and again indirect gain transfer occurs by convection and conduction through the dividing walls and windows at ground level. The isolated gain system in this case comprises three collectors and two storage elements. Two of the collectors are the east and west sunporches which charge a 'mezza-caust' floor as in configuration 'B'. The third collector which is an independent and optional feature, is a roof air collector, similar to configuration 'A', and using a fan to charge a rockpile thermal store, centrally located along a party wall adjacent to the circulation space. Excess heat travelling through the mezza-caust from either direction can be dumped directly into the stairwell as in configuration 'B'; or the mezza-caust can be by-passed and air convected up solar 'chimneys' behind the first floor east and west facades, to link up within the roof space collector, also as in configuration 'A'. A cool air return duct below the ground floor will connect both rock store and stairwell to the porches thus completing a figure of eight loop.

(iii) Controls

Control of convected gains between west sun-porch, living space, mezza-caust and solar chimney is proposed by means of linear rotating dampers shown in Fig 27, permitting the following regimes:

(a) warm air from sun-porch to living room

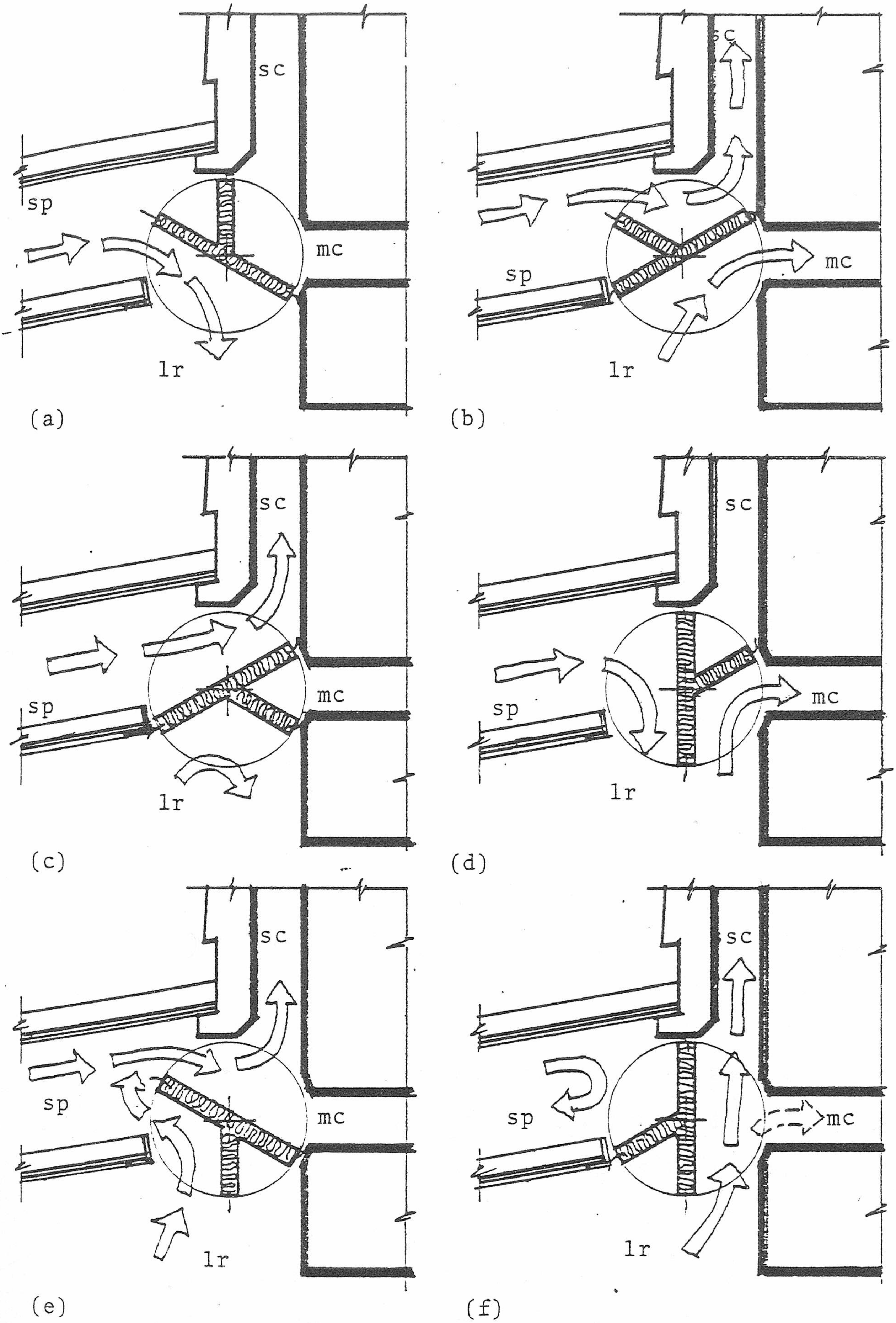
(b) warm air from living room to mezza-caust and warm air from sunporch to solar chimney

(c) warm air from sunporch to solar chimney only

(d) warm air from sunporch and living room to mezza-caust

(e) warm air from sunporch and living room to solar chimney

(f) warm air from living room to solar chimney only.



lr - living room sp - sun porch sc - solar chimney
mc - mezza-caust

FIG 27: Housing Configuration 'C': Damper controls - west sunspace collector.

This is a relatively sophisticated control for optimum use, and although it does provide a very comprehensive range of options to the occupant, it may be too expensive in relation to its likely use and energy return. A much simpler damper flap controlling flow between the east porch, mezza-caust and solar chimney is proposed, with transfer between porch and dining-kitchen through normal window vents only. The control of flow between the roof-space and rock pile store will be identical to configuration 'A', and the outlets will also be by simple adjustable registers to circulation and living spaces. A range of options similar to configuration 'B' are possible in relation to night losses. With regard to overheating some form of shading will be required below the west sunporch roof glazing and also an exhaust outlet from the solar chimney.

Infiltration and ventilation control will also be compatible with configurations 'A' and 'B', with a permanent ventilation source in the roof being required for the central circulation area, and also mechanical extract from kitchen and bathroom, either ducted to a roof outlet or linked to a mechanical ventilation/heat recovery package.

Strategy with regard to traditional heating and thermal response is identical to that of configuration 'B'.

(iv) General Observations

The main interest in this house type lies in validating an east/west orientation for passive solar gain, with the implications of much greater freedom for site layout. The system, however, has a large glazed collection area in relation to heated volume, and is accordingly likely to be more expensive than that of configuration 'B'.

Key data comparative to other models are shown in Appendix 2.

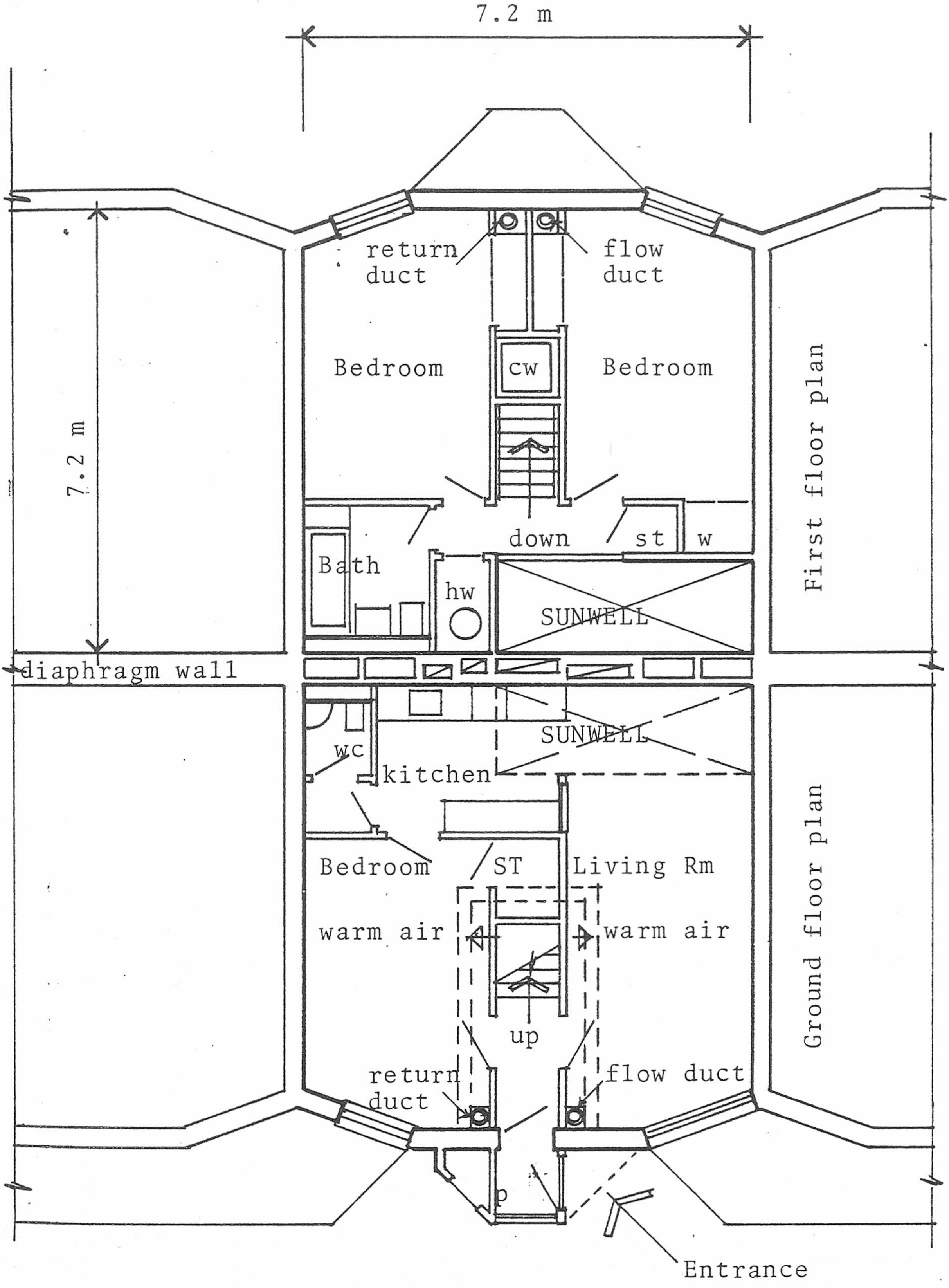
3.2.5. Housing Configuration 'D': 6 Person Single Aspect Terraced House

(i) General Description

The object of this model, is to take the features of configuration 'C' a stage further to a true single aspect house, glazing being restricted to one facade and the roof. This makes possible the use of 'back-to-back' terraces, a common 19th Century form, discarded in a social climate of overcrowding, disease and excessive industrial pollution. The concept is inherently energy efficient, with no exposed north facade, except at one end of terraces, and permitting greater spacing for a given density or higher density for a given spacing. A true single aspect house of this type could also be built against other building categories, such as shops or offices, with the exposed facade facing anywhere between due east and due west. 'Sunwells' adjacent to north/south party walls which incorporate ventilation 'flues' in the diaphragm construction, permit natural light and solar gain to the rear of the house, and efficient cross ventilation. These features can be seen on Figs 28 and 29. The main south facing roof solar collection feature is unlikely to be significantly over-shaded, and should also be self cleansing in a post- Clean Air Act urban environment.

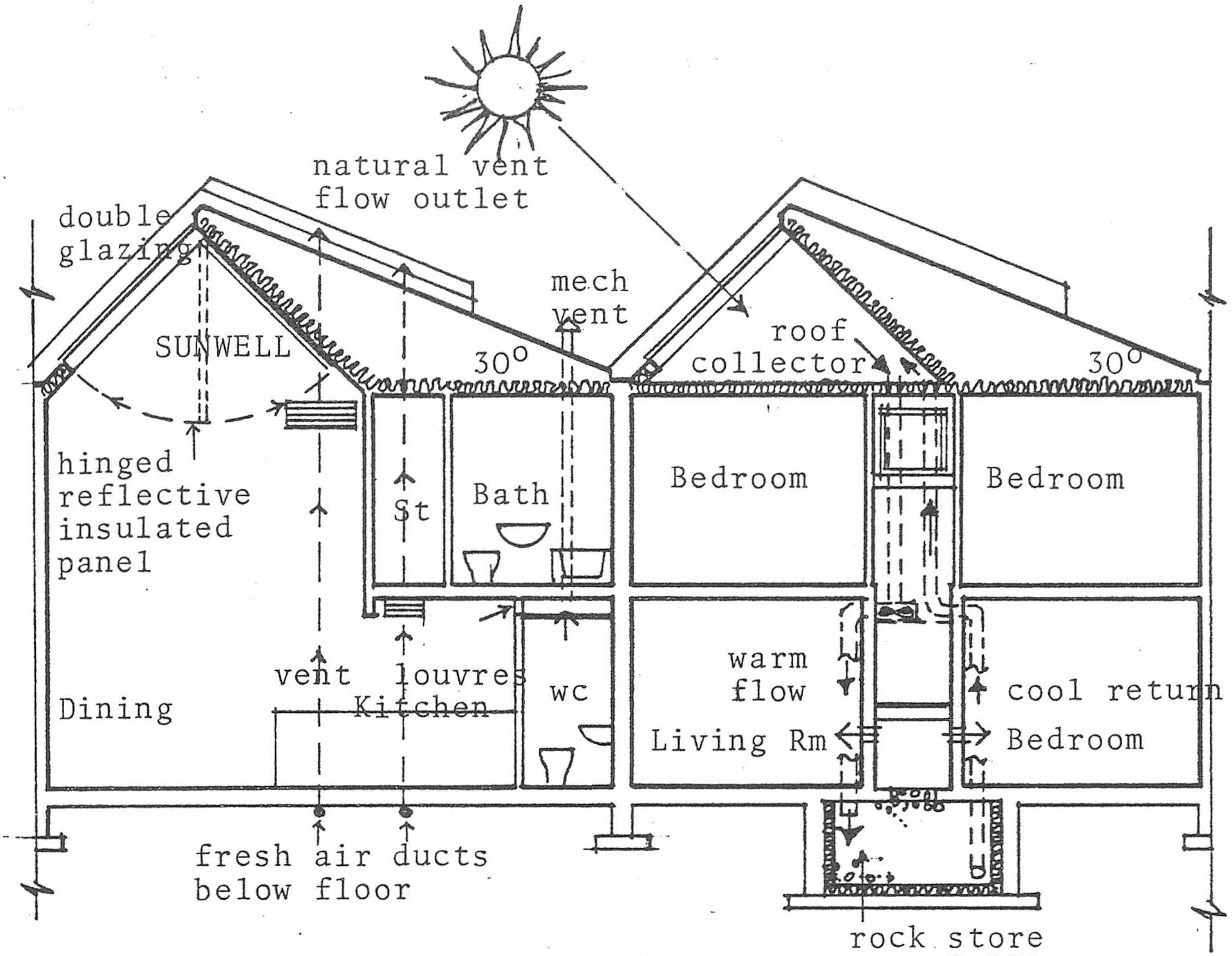
(ii) Passive Solar Features

Since the exposed facade may face either east or west, much emphasis has been placed on the roof for solar collection purposes. The first feature is the 'sunwell', permitting diffused and direct solar gain to the surfaces surrounding this double storey space over the dining-kitchen area adjacent to the north/south party wall. The isolated gain feature, optional as in configuration 'C', comprises a linear roof air collector, the glazing a continuation of the 45^o pitched south facing roof, connected to a rock-bed store below the ground floor. This is very similar to configuration 'A' where a differential sensor operates a fan in a flow duct and a parallel cool air return duct closes the loop. A void between the rock store and the stairs forms a plenum from which adjust-

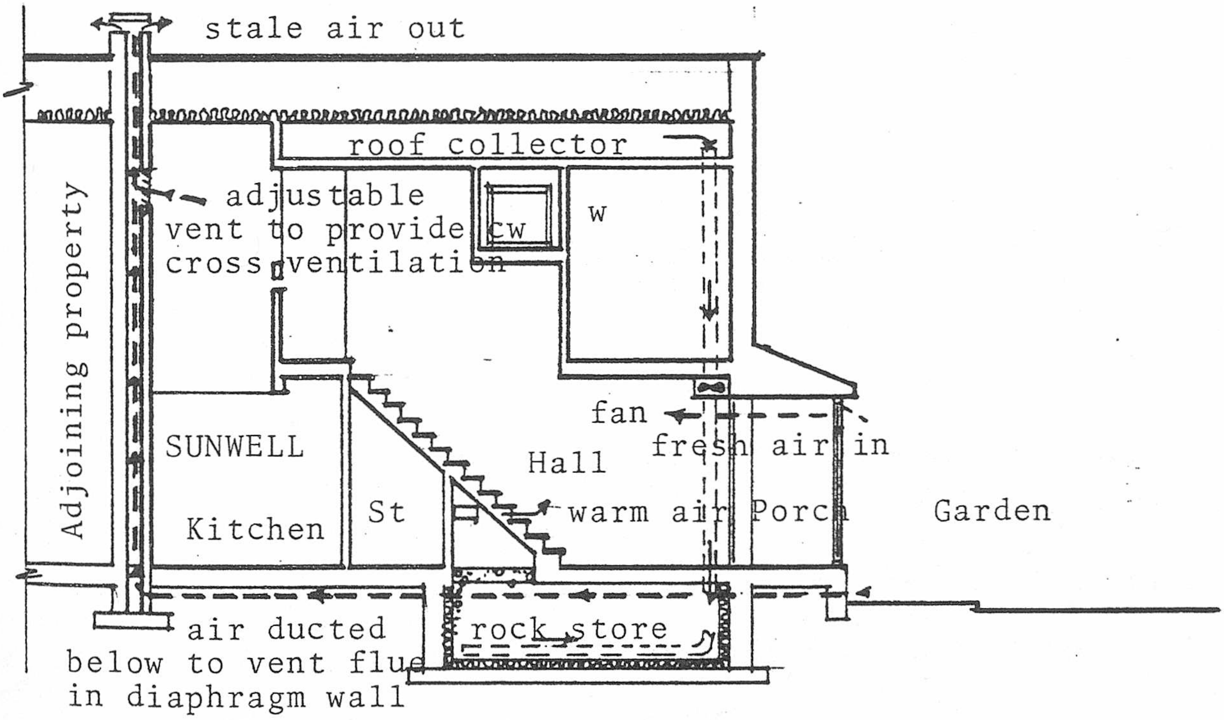


Total floor area within external walls 96.72 m^2 (minimum housing standard 97.0 m^2).

FIG 28: Housing Configuration D: 6 person wide frontage, east or west single aspect, back-to-back 2 storey terraces.



Cross Section looking West Scale: 1:100



Longitudinal section looking North Scale: 1:100

FIG 29: Housing Configuration D

able registers can direct heated air to the stairwell or to either of the two ground floor living spaces. Excess gain generated in the sunwell can be transferred to the roof air collector for storage or exhausted through the passive ventilation system. The only indirect gain feature is a glazed entrance porch, which could at the discretion of the authority or occupant be extended to form a buffer zone across the living room as in configuration 'C'. Warmed air could then be transferred by convection to first floor bedrooms as well as the living space.

(iii) Controls

Control of solar gain, glare and night losses in the sunwell is possible by operation of a hinged reflective insulation panel, using simple pulley and cords. An adjustable vent reached from the stair landing will allow excess warm air to be drawn into the roof air collector when the fan is on. Alternatively adjustable registers to cross ventilation 'flues' incorporated in the diaphragm party wall will permit external exhaust. Controls to the roof collector and rock-bed store are as for configuration 'A'. Windows on the exposed facade will be double glazed, and the reduction of night losses will be at the discretion of the occupant in terms of blinds and/or curtains.

Apart from the roof glazing, infiltration is restricted to one facade, while efficient cross ventilation is possible by simultaneously opening windows and vents to the flues in the opposite diaphragm wall. Additional mechanical ventilation to both kitchen and bathroom will be provided through other vertical ducts set in the diaphragm wall.

Strategy with regard to auxiliary heating and thermal response will be generally the same as other models, with high thermal capacity materials surrounding the sunwell over the dining-kitchen, and lightweight linings to the heavy structural mass in the other main living spaces.

(iv) General Observations

This is a more specialised house-shell than the previous three, but it could have many useful applications particularly within an urban context. It also serves to reinforce the hypothesis that traditional assumptions with regard to housing design may merit re-appraisal in light of changing circumstances.

Again data, comparative to configurations A-C, are shown in Appendix 2.

3.2.6. Climate Data for ESP Analysis

Accepting that all aspects of the climate for any location in Scotland can vary within wide limits at any time of the year, it is nevertheless important for effective analysis of passive solar heating systems for Scottish locations, using the programme ESP[2], to have a climate file for a full year, which can be termed a representative Scottish climate year. This implies that the limits of each climate aspect for any period, usually taken over a month, should not exceed or go below maximum and minimum values recorded over a statistically adequate number of years for the same month for any populated location, and generally should fall within average maximum and minimum values.

Since simultaneous hourly records of all climatic characteristics were not available for any Scottish location in the format required by ESP, a climate file has been compiled by modifying an existing ESP formulated file for a similar EEC location with marine influenced temperate climatic characteristics. Using the programme ESPCLM and records from meteorological stations mainly around Aberdeen, and also from Lerwick and Eskdalemuir in the case of solar radiation, a climate file, ABCLM, has been created. Although there is an east coast bias, this file satisfies the criteria stated above for any Scottish location - that is, as well as high and low values, the monthly means correspond closely to long-term averages for the Aberdeen area, but are equally possible statistics for other Scottish locations. Therefore, although the file may not represent an average year for a specific location such as Stornoway in the case of Housing Configuration 'A', it is nevertheless sufficiently representative for useful comparative analysis.

The following hourly data is required by ESPCLM:

(i) Direct normal incidence solar irradiance W/m^2

(ii) Diffuse solar irradiance on a horizontal surface W/m^2

(iii) External air temperature ^oC

(iv) Wind velocity m/s

(v) Wind direction in degrees clockwise from north

(vi) Relative humidity, percentage where 100% = 1000

(i) Table 1, Appendix 3, gives a comparison of monthly mean daily and high daily irradiation, and maximum hourly values of direct normal incidence irradiation from ABCLM compared to long-term measured data at Kew[19] and 1981 measured data at Lerwick[20]. Fig 30 shows the comparison of a typical April high day for ABCLM with a typical measured April high day for Lerwick.

(ii) Table 2 gives a comparison between mean high day and low day daily values for diffuse irradiation in each ABCLM month to corresponding mean, maximum and minimum daily long-term measured values for Eskdalemuir[19]. The table shows that not only do monthly mean daily values bear realistic comparison, the high-day/low-day figures fall well within the Eskdalemuir maximum/minimum limits. Also maximum hourly values for ABCLM correspond well with long-term maximum hourly values 99% of the time for Eskdalemuir.

(iii) With respect to temperature, Table 3 shows the close fit of ABCLM data to averages of daily maximum, minimum and mean temperatures for the Aberdeen area,

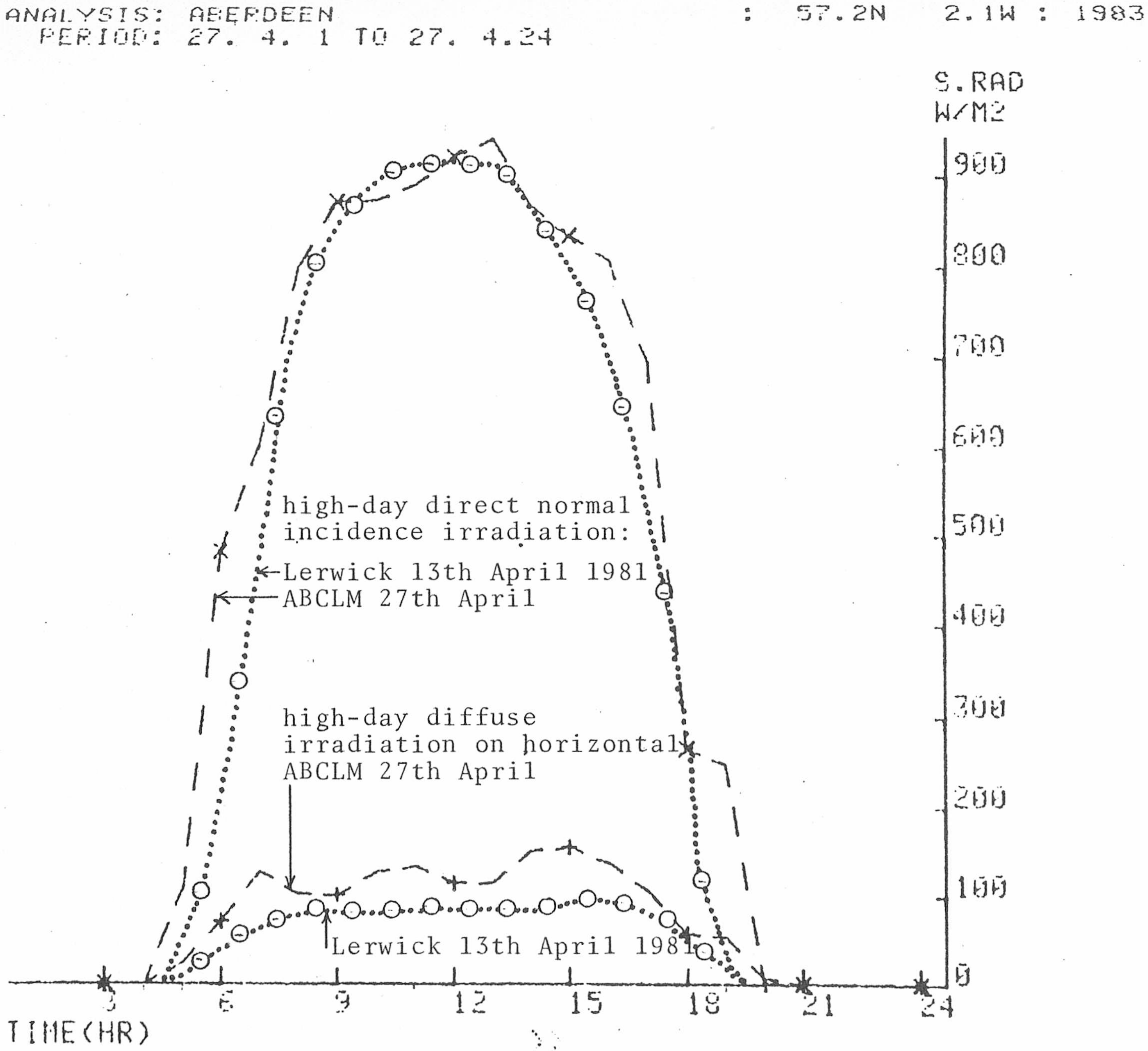


FIG 30: comparative high-day direct and diffuse irradiation: Lerwick 1981 and ABCLM

and Table 4 the corresponding close fit between ABCLM and Aberdeen monthly degree days to a base temperature of 15.5 °C. Figures for Dyce, Aberdeen are provided by Plant[21]. Table 5 gives a comparison of monthly lowest and highest, as well as low-day and high-day values for ABCLM to measured data for various locations around Aberdeen. In all cases the ABCLM lowest values fall within the Aberdeen mean low range. Similarly ABCLM highest monthly values generally fall within the Aberdeen mean high range, and never exceed the highest limits.

(iv), (v) & (vi) ABCLM wind speeds, direction and relative humidity also fall within the long-term measured range for locations around Aberdeen, as shown in Tables 6, 7 and 8. With respect to wind speed, not only are the monthly mean values very close to Aberdeen data, but the frequency of winds in certain speed bands also accords with long-term measured data for the Aberdeen area, and in no case is the maximum speed outwith average limits. Frequency of wind direction varies much more with location. For example the difference between an east and west coast location is noticeable in comparing frequencies in the north-east and south-east sectors, Table 7. Also Plant's [21 22] data available from Aberdeen and Glasgow only allocates direction to 70-80% of the total, the remainder assumed to be light variable winds. In the ABCLM data all wind is given a direction and it can reasonably be assumed that a substantial proportion of the 20-30% light variable wind occurs in the southern sector, explaining the generally higher ABCLM frequencies from these directions. This gives a reasonably strong bias to the south-west sector, in accordance with typical UK prevailing winds, with occasional emphasis in the eastern sector such as in August, coinciding with a typical North-Sea fair weather anti-cyclone. With respect to relative humidity, although the diurnal values for the three summer months are below long-term means for both Aberdeen and Glasgow, they still fall within a substantial percentage frequency band. Values in the remaining nine autumn, winter and spring months are very close to long-term means for both east and west coast locations.

Also included in Appendix 3 is a sample printout of hourly data from ABCLM and detailed analysis of temperature and solar irradiance for a particular month.

3.2.7. ESP Energy Analysis - Housing Configuration A

(i) Input Data for Simulation Models - ESPIMP

In order to obtain useful comparative data within this particular housing development, two flats have been modelled, both in the west terrace. The first is a ground floor, intermediate-terrace flat, the second a first floor end-of-terrace flat on the exposed west gable. Each flat has been divided into four thermal zones, the first the sunporch, the second the living space including kitchen and hot water cylinder store cupboard, the third the bedroom and wardrobe, the fourth the bathroom and ventilated lobby. The first floor flat also has the roof space as a fifth zone. Only zones two, three and four are regarded as heated volume, the sunporch functioning as a solar collector. The limits placed by the programme ESP on the size of the simulation, made it necessary to model the stairwell, with south wall collector, roof space collector and rock store, separately.

ESPIMP, the input management programme, requires four data files - a geometry file, a construction file, a project file and a shading/insolation file. The first two give a complete and accurate description of the building geometry, and the thermal properties of each layer of construction for the bounding surfaces of each zone including windows and doors.

There are some limitations to the construction input facility. For example, the geometry and construction of the roof collector can be accurately described and hence it is possible to determine the solar energy load in the collector as well as the air temperature profile; but, although data can be input in the project file to transfer heated air from the collector to the rock store, it is not possible to realistically simulate the movement of warm air through the voids in the rock-bed, and hence derive the heat exchange between air and pebbles. Also the construction data file does not have the facility to input night insulation to windows. Although this could have been improvised using a separate 'blind control' input file, unpredictability of occupant usage in this respect suggested that omitting this feature had the merit of precluding over-optimistic results.

In carrying out simulation studies, Porteous[23] has found that infiltration/ventilation losses may typically be 50% higher than window/opaque surface conduction/convection losses. The timetable of air change rates, required in the project file for each zone, has therefore considerable influence on the overall energy balance. Ventilation rates will vary widely in response to severity of exposure, constructional/design standards and occupant use/demand. Hence they constitute indeterminate variables which set high margins of error to both prediction and monitoring of energy loads. For this model each zone has been allocated pragmatically derived mean rates of air change, given in Table (ii). These take into account the location and use of each zone, the standard of draught stripping and local climatic/human factors. With respect to the latter, there is fortunately a general tendency on the island due to the dominant wind feature of the climate to only open windows for short periods for specific ventilation tasks. Whilst it is acknowledged that these values could be exceeded due to either poor construction or occupant usage, in general they err on the high side in relation to design standards given by Uglow[24]. They, therefore, constitute a realistic base for comparative analysis in this particular application.

TABLE (ii) Housing Configuration A: Mean Air Change Rate Profile

Zone	Time	Air Changes	Notes
1 Sunporch	0-8	1.0 ach	Main entry space with
	8-24	2.0	high glass: volume ratio
2 Living/R	0-24	1.0	Well protected by sunporch
3 Bedroom	0-8	2.0	High rate for sleeping
	8-24	1.0	Low day-time rate
4 Bathroom	0-8	0.75	Low night-time rate
	8-24	1.5	Related to one-person use

The project file also contains information with respect to casual gains from people, cooking, water heating, lighting and other appliances, some continuous such as a refrigerator, and some intermittent such as a television. Since these gains will displace solar gains, it is important to input a credible profile. Casual gains from washing operations are discounted since extract fans switched by humidstats will automatically remove warm moist air from baths and showers. Gains from lighting and occupants in the bathroom/lobby zone are also considered to be negligible as occupancies will be short, intermittent and coincidental with periods of extractions.

TABLE (iii) Housing Configuration A: Casual Gains, Daily Totals Compared to Values of Uglow

Gain Description	Sensible Gain kWh	Net Gain kWh	Mean Value from Uglow kWh
Occupant 1 N^{o}	1.34 x 1 =	1.34	1.3 (m/f in/out)
Cooking (electric)	2.15 x .8 =	1.72	1.74(2.6 x .67)
Water Heating	1.25 x .8 =	1.0	1.0 (.25 + .4)/.65)
Lighting, T.V. etc	3.80 x .8 =	3.04	2.95(4.4 x .67)
Daily Total	8.54 .85	7.10	6.99

Profiles, summarised in Table (iii) above, for the living room and bedroom have been created with values based on the work of Uglow[24], using appropriate factors to take account of the single occupancy. The table does not indicate the timetable of gains, which assumes a regular cycle of day-time occupancy and does not allow for seasonal variations.

In order to compile a shading/insolation file for the three south facing zones, the sunporch, living space and bedroom respectively, it is first necessary to create a geometry file for obstructions. In this case there is a building to the south of the development which will cause some shading to the ground floor during winter months. Using the programme ESPSHD mean shading for each month on opaque and glazed surfaces is determined. This information is then used in programme ESPINS to calculate levels of insolation on internal surfaces for each month, and the combined information is stored in a shading/insolation file via programme ESPIMP. For the north-facing and roof zones shading information is not required, and a default mechanism will establish values for insolation directly through ESPIMP, assuming the floor plane, unless otherwise specified, to receive any direct insolation.

A fifth configuration file lists preceding files and inputs the connectivity of bounding surfaces to zones within the simulation, zones outwith the simulation such as the stairwell and adjoining flats, and the exterior. Representative ambient climatic/

environmental conditions for exterior surfaces are provided by ABCLM for each hour of each month, but ambient conditions of adjacent zones outwith the simulation are not as determinate. Therefore, in order to provide a reasonable base for comparative analysis, the following assumptions have been made:

(a) that adjoining flats have identical environmental conditions to the flat undergoing simulation.

(b) that the surface between sunporch and stairwell connects directly with exterior conditions.

(c) that, when simulating the living space, the stairwell has a mean temperature of 9°C and the dividing wall zero radiation on the stairwell face.

(d) that when simulating the staircase, the adjacent flats are assumed to have an identical environment.

With respect to the latter two assumptions, the resultant temperatures in the stairs will be slightly depressed since they take no account of the conduction losses from the flats as gains; while there will be occasions when the mean stairwell temperature will both fall below and rise above the mean value of 9°C given in the configuration file for the flats. However, test simulation runs indicated that slight variations to the assumed mean conditions for this surface do not have a significant effect on the total energy load predicted for the flats in any one month.

(ii) Control Strategy for Dynamic Thermal Simulation - ESPSIM

Fig 31 illustrates the complex dynamic thermal exchanges calculated by the simulation engine of the ESP suite of programmes, ESPSIM. In order to establish a breakdown of the energy load for each flat into heating plant load, useful casual load and useful solar load, simulations were carried out using three different control strategies:

(a) The first strategy defines minimum and maximum temperatures for zones 2-4, calling on heating plant; but places no effective upper limit to temperatures, since there is no cooling strategy to reduce temperatures raised above the design maximum by excessive solar gains. This is therefore an effective simulation to ascertain gross space heating energy load, heating plant load, casual load and solar load, but cannot isolate useful casual and solar loads. There is no upper or lower temperature limit nor plant defined for zone 1, the sunporch, which is therefore designated 'free floating'.

(b) The second strategy again defines minimum and maximum temperatures for zones 2-4, but this time introduces a theoretical cooling plant to prevent excess solar and casual gains raising the temperature above

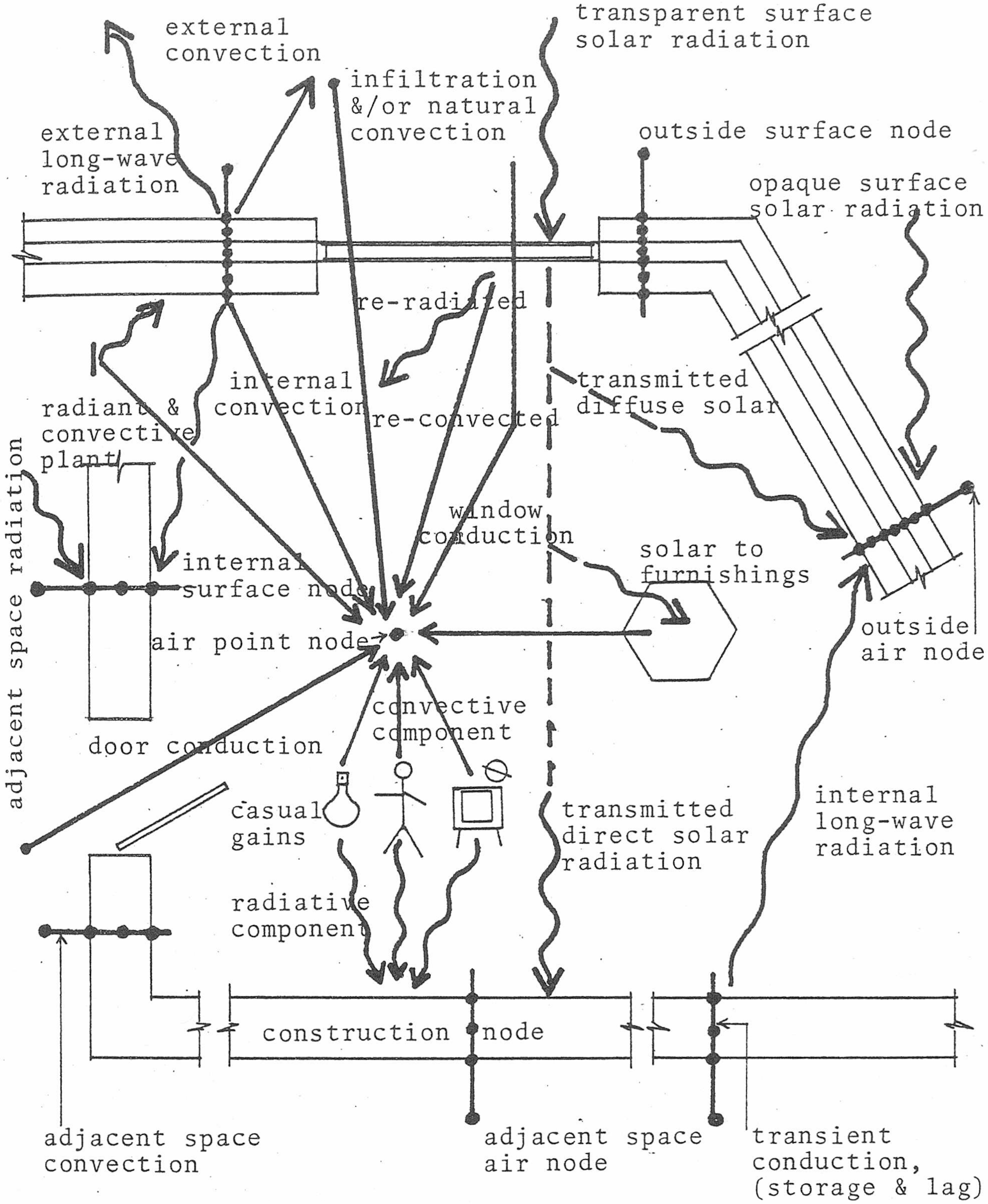


FIG 31: zone energy flowpaths ESPSIM

$20^{o}C$. Zone 1 is allowed to remain 'free floating'. This simulation thus isolates any surplus casual and solar gains in zones 2-4, on the assumption that no action is taken to control temperature swings in zone 1, the solar collector.

(c) The third strategy maintains the limits of (b) for zones 2-4, and also introduces a cooling strategy to zone 1, setting a maximum temperature limit of $24^{o}C$. This simulation isolates surplus solar gains from both zones 1 & 2, which could be transferred via the roof collector system to the rock store for later use.

These control strategies are summarised in Table (iv). The simulation for the stairwell is free floating in order to ascertain the total solar load in the collector and modified Trombe wall. However the fan, switched by differential sensor, will in practice act as a temperature 'brake' to the collector, transferring warm air to the rock store when it reaches a predefined level.

Table (iv) Housing Configuration A: Design Temperature Profile

		control strategies a, b & c		control strat. b	control strat. c
Zone	Time	Htg Plant min ti	max ti	Cooling	max ti
Sunporch	0-24	None	None	None	24 ^{o}C
Living/K	0-8	14	16 ^{o}C	20	20
	8-24	18	20	20	20
Bedrm	0-8	15	18	20	20
	8-22	14	16	20	20
	22-24	16	18	20	20
Bathrm	0-8	14	16	20	20
	8-22	16	18	20	20
	22-24	14	18	20	20

(iii) Analysis of Simulation Output - ESPOUT

Results of simulation for a ground floor intermediate terrace flat indicate a gross annual space heating load of 6,019 kWh or 77.56 kWh/m^3 heated volume, including surplus solar and casual gains. The simulation using control strategy (b) shows that without control the temperatures in the sunporch could exceed 50°C in June, July and August. This is unlikely to be acceptable even in a buffer zone, and confirms the presence of a potentially useful surplus solar load. By setting an upper temperature limit to this zone in simulation (c), the net annual energy load for the heated zones is slightly increased compared to (b), and the solar surplus in the living zone reduced. However, proportionately the useful solar contribution of 16% to the net space heating energy load is the same for both simulations.

The south glazing collection efficiency of a flat can be expressed as: $\frac{Q\ sol}{HGVS \times u \times Ag}$ where 'u' is a utilisation factor and 'Ag' is the net glazed area. In the case of the ground floor flat, this value is 25%. Analysis of results from the simulation of the stairwell roof and south wall collector shows that together with the surplus established from the sunporch and living zones, and assuming the same 25% efficiency calculated for the south glazing of the flat, a further useful solar load of 4% can be added to each flat.

Results of the ground floor flat simulations are summarised below in Table (v). Appendix 4, Table 1 gives the detailed monthly multi-zone breakdown, Table 2 a monthly analysis of volumetric heat loss, Table 3 the efficiency analysis outlined above. Table 4 gives a detailed breakdown of solar irradiation on the south facade, and Table 5 analyses the added contribution from the rock storage system.

Fig 32 shows the monthly mean daily energy breakdown over a full year. It is significant that a proportion of the casual load is displaced, as well as the solar load, during the summer months, leaving a solar contribution in the 33-50% range during this period. This is because the simulation is multi-zone, taking into account the energy load and respective heating plant, casual and solar contributions for each thermally distinct zone. This effect may in practice be enhanced further in favour of solar gain. This is because the casual gain profile has been designed round winter conditions in respect of occupancy and lighting; and rather than give over-optimistic results for the solar/casual split, this was standardised for each month of the year. The predicted summer solar contribution thus accords with actual experience in Scottish locations, but not with results from theoretical single-zone models, where nearly all the solar contribution in the summer months is apparently displaced by casual gains. This effect is indicated by the horizontal broken line in Fig 32.

The sunporch is instrumental in keeping living room heating plant loads at a modest level, reaching a

TABLE (v) Housing Configuration A: Annual Energy Breakdown Summary for Ground Floor Intermediate Terrace Flat

Simulation Model

z1 = sunporch
z2 = living room
z3 = bedroom
z4 = bathroom

1 Annual mean daily load kWh
2 Annual/m^3 heated volume kWh
3 Percentage

	Simulation Model		Net Energy load Q	Heating Plant Qhtg	Useful Casual Qcas	Useful Solar Qsol
	z1 24°C	1	14.6	6.4	5.2	3.0
	z2-4: 14-20°C	2	68.79	30.13	24.66	14.00
(c)	+ load from rock st	3	100%	44%	36%	20%
	z1 24°C	1	14.6	7.0	5.2	2.4
	z2-4: 14-20°C	2	68.79	32.96	24.66	11.17
(c)	no load from rock st	3	100%	48%	36%	16%
	z1: no limit	1	14.2	7.0	4.9	2.3
	z2-4: 14-20°C	2	66.65	32.96	22.99	10.70
(b)	no load from rock st	3	100%	49.5%	34.5%	16%

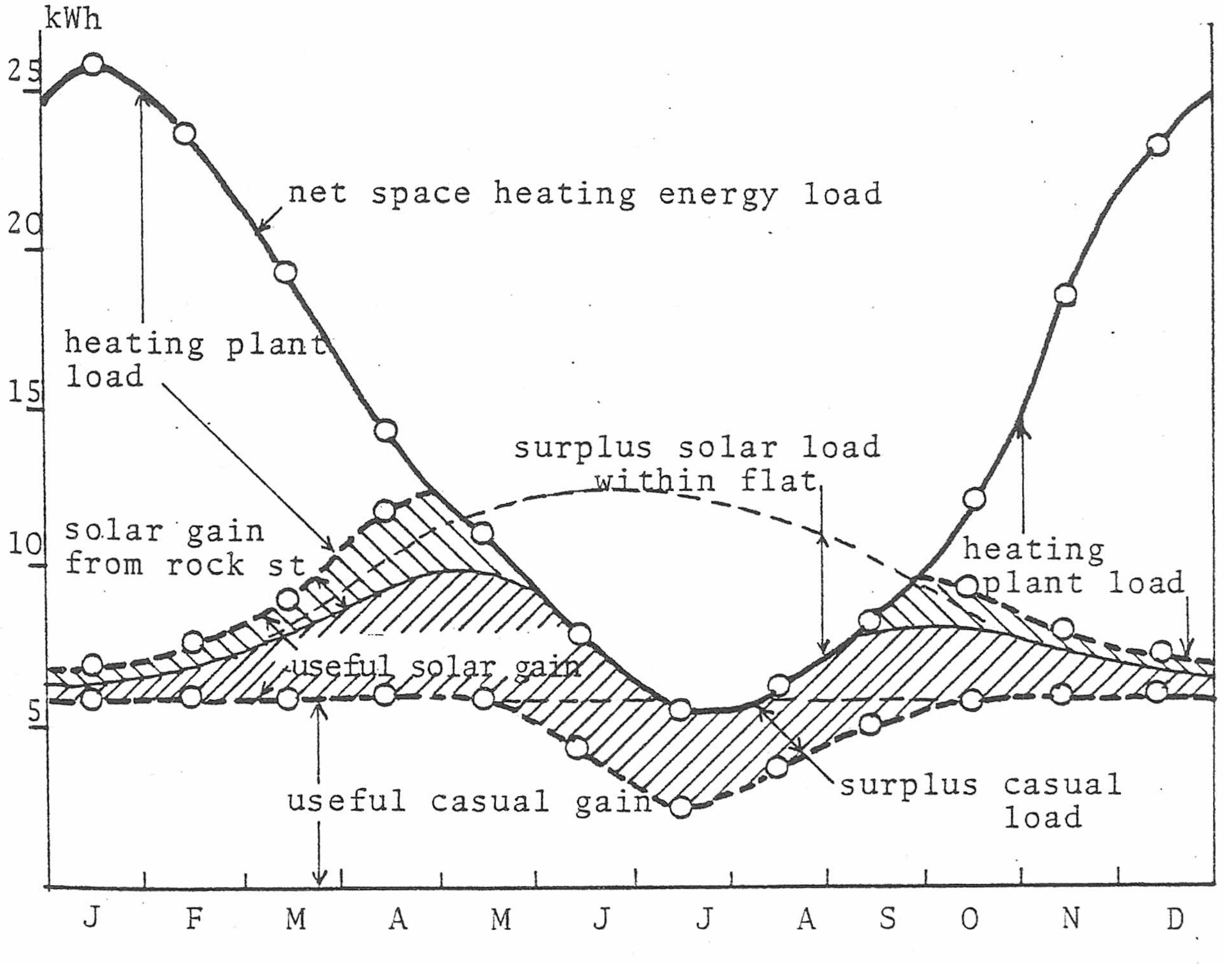


FIG 32: housing configuration A: monthly mean daily space heating energy load breakdown for ground floor intermediate terrace solar flat

maximum of 1.0 kWh in January as shown in Table 6, Appendix 4. The equivalent load without sunspace would be 1.4 kWh, an increase of 40%. Table 6 also defines the internal temperature range in the sunporch with no heating or cooling strategy, and in living spaces with heating but no cooling, compared to mean temperatures when upper limits are imposed.

When comparing the performance of the first floor gable-end flat with the ground floor intermediate terrace flat, the final loads are not significantly different, although there are distinct performance characteristics. The annual breakdown for this flat using control strategy (c) is summarised, Table (vi), below and the monthly mean daily breakdown shown graphically, Fig 33, in relation to an equivalent hypothetical non-solar flat. Compared to the ground floor flat, the net annual energy load reduces from 5338 kWh to 5202 kWh, the heating plant load is virtually identical, and both the casual and solar loads are marginally down. In this case the rock store is estimated to add a further 4.3%, making a total solar contribution of 19.7%, 0.3% less than that for the ground floor flat. The first floor flat receives a greater quantity of solar energy, but a smaller proportion of it is useful, 63.6% compared to 67.3%. Expressed as useful solar load per m^2 south facing glazing, the annual figure is marginally higher than the ground floor flat at 201 kWh/m^2 or 226 kWh/m^2 taking into account the useful contribution from the rock store. The overall efficiency is marginally lower

TABLE (vi) Housing Configuration A: Annual Energy Breakdown Summary for First Floor End-of-Terrace Flat

z1 = sunporch
z2 = living room
z3 = bedroom
z4 = bathroom

1 Annual mean daily load kWh
2 Annual/m^3 heated volume kWh
3 Percentage

	Simulation Model		Net Energy Load Q	Heating Plant Qhtg	Useful Casual Qcas	Useful Solar Qsol
	z1 24°C	1	14.2	6.4	5.0	2.8
	z2-4: 14-20°C	2	67.04	30.19	23.66	13.18
(c)	+ load from rock st	3	100%	45%	35.3%	19.7%
	z1 24°C	1	14.2	7.0	5.0	2.2
	z2-4: 14-20°C	2	67.04	33.09	23.66	10.28
(c)	no load from rock st	3	100%	49.3%	35.3%	15.3%
	Non-solar flat	1	18.1	10.0	5.7	2.4
	14-20°C	2	77.62	42.82	24.57	10.23
	no load from rock st	3	100%	55.2%	31.7%	13.1%

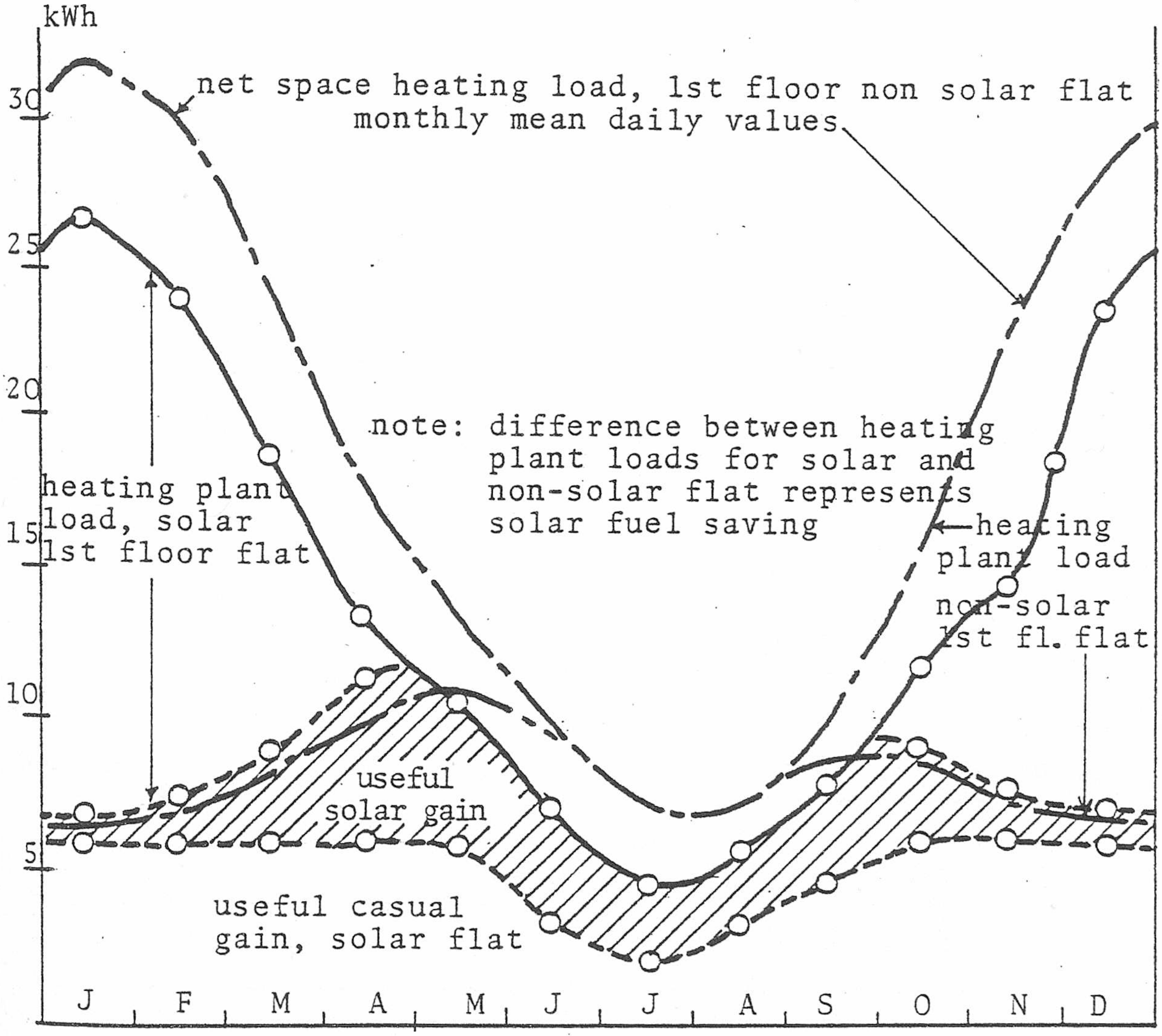


FIG 33: configuration A: comparative solar/non-solar energy loads

at 24% and the annual volumetric heat loss is 0.99 W/m^3K. The heat load for individual zones reflects their location, with zones 3 and 4 adjacent to the gable-end with higher loads than the ground floor equivalent, and zone 2 with a lower load due to the reduced heat loss through the floor and slightly increased solar load. The implications of the comparison with a hypothetical non-solar flat are discussed in the cost analysis section below.

The ESP results correlate well with another design appraisal tool, GOAL[25]. This is not a fully dynamic energy model, and has not such a comprehensive input facility as ESP. For example, all internal dividing walls are treated as opaque, so that it is not possible to define the glazed opening between sunporch and living space. Therefore, a flat was modelled both with and without the sunspace. Although GOAL gives a heavier emphasis for solar in relation to casual gains, and conduction in relation to ventilation losses, the average of total losses and total gains for the two models compare very closely to ESP results as shown below (Table (vii)).

TABLE (vii) Housing Configuration A: GOAL/ESP Comparative Results

Annual Totals kWh	GOAL	ESP (Ground)
Net Energy Load (Conduction/Ventilation Losses)	5415	5338
Useful Energy Gains (Solar/Casual)	2831	2781
Heating Plant Load	2575	2557

(iv) Steady-state Analysis of Stair Collector/Storage System

Since it was not possible to accurately model the heat transfer and exchange from collector to rock store, it was necessary to make some rudimentary steady-state calculations to check energy input from September to May against system losses, and time taken to charge the store over a range of temperature differentials. Monthly totals of collected solar irradiation have been established using ESP. However, to check the effectiveness of the system, it is necessary to use a typical high-day input, rather than the monthly daily means. Factors for typical high-days are obtained by interrogation of ABCLM data using programme ESPCLM. Mean daily system losses during a period from September to May have been estimated, and results are summarised on Table 7, Appendix 4. Applying the resultant loss factor to mean high-day inputs for the 9 month period, estimates have been made of time lags to charge the store through a range of temperature differentials. These are shown on Table 8. This analysis validates system sizing, and charging periods varying from 5½ - 15½ hours indicate that heat output from the store could be called on from early afternoon to night-time, depending on time of year and conditions. There will of course be low-days in each month where insufficient solar radiation is absorbed to charge the store. In September for example, approximately one third of the days are 'high' and one third are 'low'. The optimum time for delivery is likely to be during the evenings, but low levels of input could be utilised by the occupant leaving the delivery vent open before retiring to bed. The above analysis does not, however, provide a guideline 'store volume to collector area ratio' which could be readily applicable to other projects, since it includes surplus from the sunporches, and collector surfaces are 42° sloping and vertical in the proportion 1.5:1. Therefore, the net monthly mean high-day hourly solar energy available to the rock-store has been further analysed per m^2 collector area from September to May as follows:

(a) Combined 42° sloping and vertical collector in ratio 1.5:1

(b) Combined 42° sloping and vertical collector in ratio 1:1

(c) 42° sloping south-facing collector

(d) Vertical south-facing collector

Comparative values are shown graphically on Fig 34. Mean monthly high-day insolation time-lags to raise the rock store temperature through 10 and 15 K have been calculated for store volume to collector area ratios corresponding to the above collector configurations as follows: (a) .35 (b) .33 (c) .4 and (d) .3. Table 9, Appendix 4, shows that these ratios give closely corresponding charging periods within a 5 - 12½ hour range, with the exception of December. The ratios therefore constitute useful design guidelines appropriate to short term daily storage.

The design of the ducting between collector and store is based on an air flow rate of 0.01 m^3/s per m^2 collector area, arriving at a value of 0.15 m^3/s. The input duct is 250 mm diameter with one bend. The

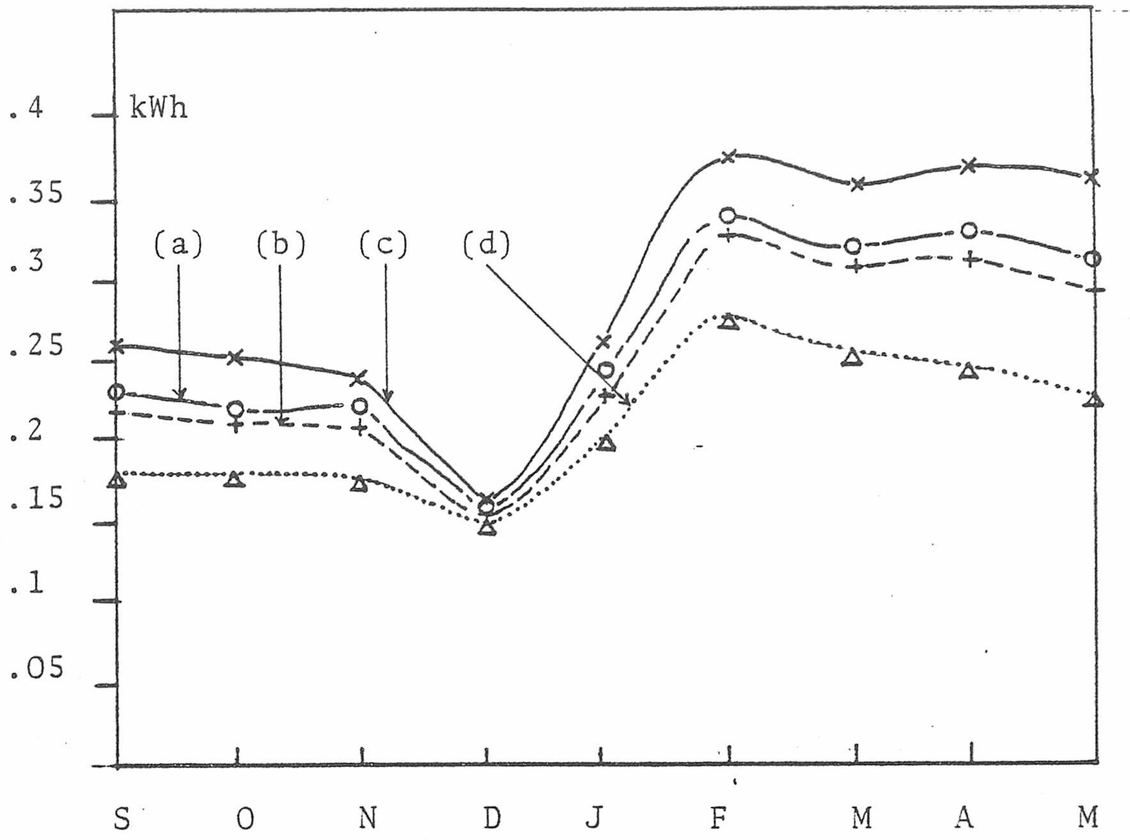


FIG 34 net monthly mean high-day solar energy to rock store per m^2 various roof/wall collectors during 9-month season

return duct has the same cross-sectional area and is routed to the glazed eaves section to promote good mixing of air within the collector space (Fig 23, 3.2.1). Duct flow/pressure loss and fan power data is shown below (Table (viii)).

TABLE (viii) Housing Configuration A: Stairwell Collector/Store Circulation

flow rate m^3/s	system pressure N/m^2	air power W	efficiency %	fan motor power W
0.10	33	3.3	25	13
0.15	75	11.3	30	38
0.20	133	26.6	35	76
0.25	208	52.0	40	130

Since noise is not an important factor due to the stairwell location, it is proposed to use an axial flow or propellor fan, simply located within the supply duct. The fan operation would be switched by differential temperature controller, sensing an appropriate difference between representative locations within the roof collector space and the rock-bed store. The two ducts will be fitted with dampers to prevent reverse thermo-circulation, probably designed to open by air pressure when the fan starts.

(v) Cost Analysis

Since there is a priced bill of quantities, it is possible to allocate an exact figure against each item of builderwork and apportion contractors preliminaries on a 'pro rata' basis. However, an obstacle to objective assessment of the passive solar on-cost is quantitative and qualitative decision making with respect to the substitution of non-solar building elements. In this case the total cost of identifiable solar elements is £2,532 per flat and the estimated cost for substituting traditional construction only £674, leaving an apparent net solar on-cost, excluding share of preliminaries, of £1,858 per flat. On this basis it can be concluded that the passive solar design strategy is not economically viable. However, scrutiny of each solar element shows that the cost of the patent glazing, specified by the client, is disproportionate and excessive accounting for £1,098 per flat. The square metre rate is £162.25 or an on-cost of £100.50 over the estimated traditional construction cost of £61.75/m^2. The solar design did not require such an expensive specification - traditional timber windows would suffice for vertical fenestration and cost of roof glazing could be reduced using proprietory plastics such as 'Filon' or 'Tedlar'. Therefore, the solar on cost has been analysed for glazing within two alternative budgets. The actual cost and the two reduced figures have in turn been related to discounted costs for heating systems, which it is reasonable to assume might have been specified in a project without a solar heating system, arriving at three realistic figures for the net solar on cost (Table (ix)).

TABLE (ix) Analysis of Solar Oncost

Alternative glazing strategy specification	cost/ m^2	discounted cost/flat	heating system	discounted cost/flat	solar oncost
0 As specified	£162.25	£0.0	as specified	£0.0	£1858
1 " "	£162.25	£0.0	solid fuel	£1,500	£ 358
2 within budget	£100.00	£680	oil (central boiler)	£ 750	£ 428
3 " "	£ 61.75	£1098	electric (warm air unit)	£ 400	£ 360

The solar contribution to the net space heating energy load has been estimated as 1086 and 1023 kWh respectively for the two simulations. This is not the net fuel saving afforded by these particular solar features, since any south facing flat will receive passive gains. Therefore, a comparison of the heat plant load established by a further simulation of a hypothetical flat - without sunporch and stairwell collector, with the same floor area and hence increased heated volume - to the heat plant load for an equivalent solar flat, will give an estimate of the true energy saving afforded by the solar design features. The annual plant load for a first floor gable-end flat is 3640.75 kWh, indicating a saving of 1297.75 kWh by the equivalent flat with solar features.

The current cost of a kWh unit is 4.23p, giving a current year's value of annual fuel savings of £54.90 per flat. Using the standard method of discounted cash flow analysis[26], assuming the 5% 'real' discount rate favoured by the Treasury for energy studies, and a long-term predicted 4% 'real' rate of increase of fuel prices (ie above rate of inflation), pay-back periods have been estimated for three solar cost strategies, for both net fuel saving and solar contribution to the net space heating load (Table (x)).

TABLE (x) Solar Oncost - Payback Analysis

Solar Oncost + 10% prelims	Fuel Saving £55 x 10 yrs Net Present Value £520	Solar Contribution £43 x 10 yrs Net Present Value £407
£394 (strategy 1)	7½-8 yrs	10 years pay-back
£470 (strategy 2)	9 yrs	12 " "
£396 (strategy 3)	7½-8 yrs	10 " "

(vi) Conclusions from Analysis

The general conclusion to be drawn from the results is that where insulation levels are not designed to greatly exceed mandatory Building Regulation standards[27], a significant solar contribution of approximately 20% can be made to the net space heating energy load. This would reduce the annual mean daily space heating plant load to approximately 6.4 kWh/day from 10.0 kWh/day for an equivalent non-solar flat, representing a fuel saving of 36%.

The use of a 'multi-zone' dynamic thermal appraisal tool such as ESP has been critical in predicting a balanced displacement of solar and casual gains during summer months, a significant departure from results obtained using single-zone methods.

The passive solar system has been shown to be cost effective, provided the specification for glazing is compatible with non-solar construction and an allowance is made for a more elaborate traditional heating system in an equivalent non-solar house. The stairwell system which the analysis has shown only provides 219-225 kWh's annually, also contains the bulk of the solar on-costs, and cannot, therefore, be considered cost effective on its own merit. On the other hand a first floor flat with sunporch would provide an annual saving of 1072.75 kWh for a negligible or even negative solar on-cost, dependent on window specification and allowances for alternative heating plant.

The justification for the roof collector/rock store system lies in its flexibility for storage of day-time surplus gains for use at night. Also the contribution could be substantially larger than shown by the analysis if the assumed characteristic occupant use were changed. For example the design temperature profile infers day-time occupancy. If day-time temperature requirement is lowered, moving the emphasis of heating plant load to after normal working hours, the relative proportions of solar heating provided by direct and indirect gain during the day, and isolated gain from the rock-store during the evening and night, would change in favour of the latter. Similarly increasing day-time ventilation rates would increase the evening heating load. The rock store analysis has shown that from May to September there is more solar energy available than can usefully be used; but if design conditions were changed as described above, a significant summer evening heating plant load would emerge, which could all be met by the rock store. This suggests a useful avenue for extended research, which could be related to detailed monitoring of the two simulated flats with both working and non-working occupancies.

3.2.8. ESP Energy Analysis: Housing Configuration B

(i) Input Data for Simulation Models - ESPIMP

In this typical 2-storey family north/south medium frontage terraced configuration, four situations have been modelled:

(a) Intermediate terrace, without sunspace, heavy construction

(b) Intermediate terrace, with sunspace, heavy construction

(c) Intermediate terrace, with sunspace, light construction

(d) End-of-terrace, with sunspace, heavy construction

Unlike configuration A, in this series of simulations the sunspace is regarded as optional, so that the heated volume for simulation (a) is identical to simulations (b) - (d). The heated volume is divided into three thermal zones, south facing living room and bedroom zones and a north facing service zone, incorporating kitchen, stairs, bathroom and storage. The roof void is a further unheated zone. The air change profile, summarised in Table (xi), is similar to configuration A, with a higher rate of 1.5 ach assumed for the living space in model (a) where there is no protective sun porch.

TABLE (xi) Housing Configuration B: Mean Air Change Rates for Zones in Simulations

Zone Description	Period	Air Changes per Hour	
Model (a)		weekday	weekend
zone 1 Living	0-24	1.5	1.5
zone 2 Service	0-12	1.0	1.0
	12-16	1.25	1.5
	16-20	2.0	2.0
	20-24	1.0	1.0
zone 3 Bedroom	0-9	2.0	2.0
	9-24	1.0	1.0
Models (b)-(d)			
zone 1 Sunporch	0-9	1.0	1.0
	9-18	2.0	2.0
	18-24	1.0	1.0
zone 2 Living	0-24	1.0	1.0
zone 3 Service	0-12	1.0	1.0
	12-16	1.25	1.5
	16-20	2.0	2.0
	20-24	1.0	1.0
zone 4 Bedroom	0-9	2.0	2.0
	9-24	1.0	1.0

The casual gain profile, summarised in Table (xii) below, is again based on the work of Uglow[24].

TABLE (xii) Housing Configuration B: Casual Gains Summary Daily Totals compared to values of Uglow kWh

Gain Description	Sensible Gain	Utilisation Factor	Net Gain	Uglow Mean
Occupants - 4N^o	4.61	1	4.61	4.60
Cooking	3.785	.8	3.00	2.93
Water Heating	3.0	.8	2.40	2.40
Appliances & Lights	5.525	.8	4.42	4.40
Total	16.92	.85	14.43	14.33

The shading/insolation data files in this case assume a parallel terrace of the same design with the north wall 24 metres from the south building face of the simulated terrace. External ambient conditions are again defined by hourly climate data contained in ABCLM, and adjacent houses are assumed to be maintained at the same temperature as the simulation model.

(ii) Control Strategy for Dynamic Thermal Simulation ESPSIM

As with configuration A, the proportions of useful casual and solar gains are established by first running a simulation with lower and upper temperature limits for heating plant, and then introducing cooling strategies to both heated zones and sunporch collector in a second simulation run, as shown in Table (xiii). The intermediate step maintaining a 'free floating' regime within the sunporch only, was considered an unnecessary refinement. The lack of an upper temperature limit in this buffer zone would theoretically lower the heat demand in the adjacent living space, but this condition is dependent on the occupants toleration of unregulated sunporch temperatures.

TABLE (xiii) Housing Configuration B: Design Temperature Profile

Zone	Time	Heating Plant: Min ti	Max ti	Cooling Max ti
Sunporch	0-24	None °C	None °C	24 °C
Living	0-8	14	16	20
	8-24	18	20	20
Service	0-8	14	16	20
	8-22	16	18	20
	22-24	14	18	20
Bedroom	0-8	15	18	20
	8-22	14	16	20
	22-24	16	18	20

(iii) Analysis of Simulation Output - ESPOUT

Results reflect the higher level of insulation compared to configuration 'A' with a 25% lower mean annual volumetric heat loss. The reduction in heating plant load per m^3 heated volume is proportionately greater, 50% less in the case of models without sun porches, and a mean of 37.5% less in the case of models with sunporches. This means that although the useful solar load is still a substantial proportion of the net energy load, varying from 25-18%, and model (b) with a sunporch gives a 23% lower heat plant load compared with model (a), in quantitative terms the annual fuel saving offered by a specific passive solar feature such as the sunporch is quite small - approximately 5 kWh/m^3 heated volume. In cash terms this represents only £38 per annum compared to the saving of £55 p.a. for the less well insulated single person flats.

Predictably, the contribution of casual gains, expressed as a percentage, rises with increased insulation from 5-6%, comparing models without and with sunporches respectively; but again there is a drop in quantitative terms. In the case of intermediate terrace model (b) the useful solar load per m^3 heated volume is 10.8 kWh, almost the same as the 10.7 kWh mean for an equivalent configuration 'A' model, excluding the contribution from stair collector/rock store. However, interestingly in the case of model 'B' (a) without a sunspace, the solar contribution is both proportionately and quantitatively greater than the equivalent configuration 'A' model. The solar load is 4.8 kWh/m^3 greater and the solar contribution 25% of the net space heating load compared with 13%. The main reason for this apparent anomaly lies in the comparative distribution of casual gains between north and south facing thermal zones. Housing configuration 'B' has a high proportion of gains in the north facing service zone, resulting in 54% and 67% useful solar contribution in the living room and bedroom zones respectively, compared to 42% and 60% with configuration 'A'. The configuration 'B' model is also at an advantage in that it is an intermediate terrace model, whereas the non-solar 'A' model is at the end of a terrace.

The configuration 'B' model (a) without sunspace can therefore be regarded as an energy efficient house. Annual heating plant and casual load are each 37.5% of the net space heating load, and the 25% balance is a passive solar gain for zero on-cost. The addition of a sunporch, while lowering the plant load still further and maintaining a useful solar contribution from 18-22% cannot be considered cost effective unless the on-cost is written off against increased amenity value. Using the same expression for south glazing collection efficiency as configuration 'A', model 'B' (a), without a sunspace, achieves a high value of 77.5%. However, this is a misleading comparison, because the utilisation factor has been taken as the ratio of gross to useful solar gains within the two south facing zones, and only 30% of the wall surfaces receiving insolation are glazed. Applying the same expression to the sunporch models, the efficiency drops to a mean of 25.3%.

The relatively high percentages of useful solar gain in all models is also partly due to the assumption of a heating regime compatible with day-time occupancy. This control strategy restricts the role of the 'mezzacaust' as a short-term store for surplus sunporch and living room gains, making possible a potential further reduction of heat plant load only in February, March, April, May and October. Assuming 33% utilisation this would provide no more than a 1.5% increase in the solar contribution or £5.50 p.a. fuel reduction. Also the thermal capacity of the floor would require to be carefully tailored to quantities of available surplus solar energy in each month. Using the simulated hollow precast concrete slab construction, the thermal capacity would be 1.5 kWh/K. The period to raise the temperature by 5K in a 'heavy' intermediate terrace house, using predicted surplus during typical high-day insolation in these five months would then vary between

5 and 16½ hours, as shown in Table (xiv). The thermal capacity could be adjusted by limiting area exposed to warm air circulation and/or using a higher density storage medium, with corresponding reductions to charging periods for a particular temperature range/quantity of insolation. If week-day occupancy were restricted to outside normal working hours, and summer ventilation rates were substantially increased, the mezzacaust's useful season could be extended. With varying occupancy needs this feature cannot be relied on as a significant solar contribution; rather it will constitute a central thermal storage mass, with the capability of raising radiant temperature levels in the sitting and sleeping zones, and circulating warmed air to the north service zone when required.

TABLE (xiv) Configuration B: Mezzacaust Thermal Store Analysis

	Monthly Surplus kWh	High-day Factor	High-day Surplus kWh	Sun-Shine Hours hrs	Gross hourly kWh	Net hourly kWh	Energy to Raise 5K kWh	Time to charge hrs
Feb	16.92	9.3	5.62	9.25	0.61	0.46	7.5	16.3
Mar	35.37	6.02	6.37	11.25	0.61	0.46	7.5	16.3
Apr	216.82	4.03	29.13	13.75	2.12	1.59	7.5	4.7
May	267.91	3.45	29.82	14.25	2.09	1.57	7.5	4.8
Oct	71.53	3.7	8.54	9.5	0.90	0.67	7.5	11.2

Relevant features of the above comparative simulation output are summarised in Table (xv), and Fig 35 illustrates the monthly space heating energy load breakdown for each simulation, using model (b) as a basis of comparison to (a), (c) and (d). The relatively high

TABLE (xv) Housing Configuration B: Annual Energy Breakdown Summary for Comparative Simulation Models

Simulation Model Configuration B Volume 173.2 m^3	Net Energy Load kWh 1 Annual daily 2 " /m^3 vol 3 Percentage	Heating Plant kWh 1 ditto 2 " 3 "	Useful Casual kWh 1 ditto 2 " 3 "	Useful Solar kWh 1 ditto 2 " 3 "	Annual Vol. Heat loss W/m^{3}K	% Useful Solar on S. face	Glazed Collection Efficiency S. face
Intermediate	1 - 28.3	10.7	10.5	7.1	0.88	59.4%	77.5%
No sunspace (a)	2 - 59.5	22.3	22.1	15.0			(direct
Heavy construction	3 - 100%	37.5%	37.5%	25%			gain)
Intermediate	1 - 23.6	8.2	10.3	5.1	0.73	66.9%	28%
Sunspace (b)	2 - 49.7	17.2	21.7	10.8			(indirect
Heavy construction	3 - 100%	34.6%	43.6%	21.8%			gain)
Intermediate	1 - 24.3	9.4	10.3	4.6	0.75	73.6%	23%
Sunspace (c)	2 - 51.0	19.6	21.7	9.7			(indirect
Light construction	3 - 100%	38.5%	42.5%	19%			gain)
End-of-terrace	1 - 23.9	9.5	10.1	4.3	0.74	64.3%	25%
Sunspace (d)	2 - 50.3	19.9	21.3	9.0			(indirect
Heavy construction	3 - 100%	39.6%	42.5%	17.9%			gain)

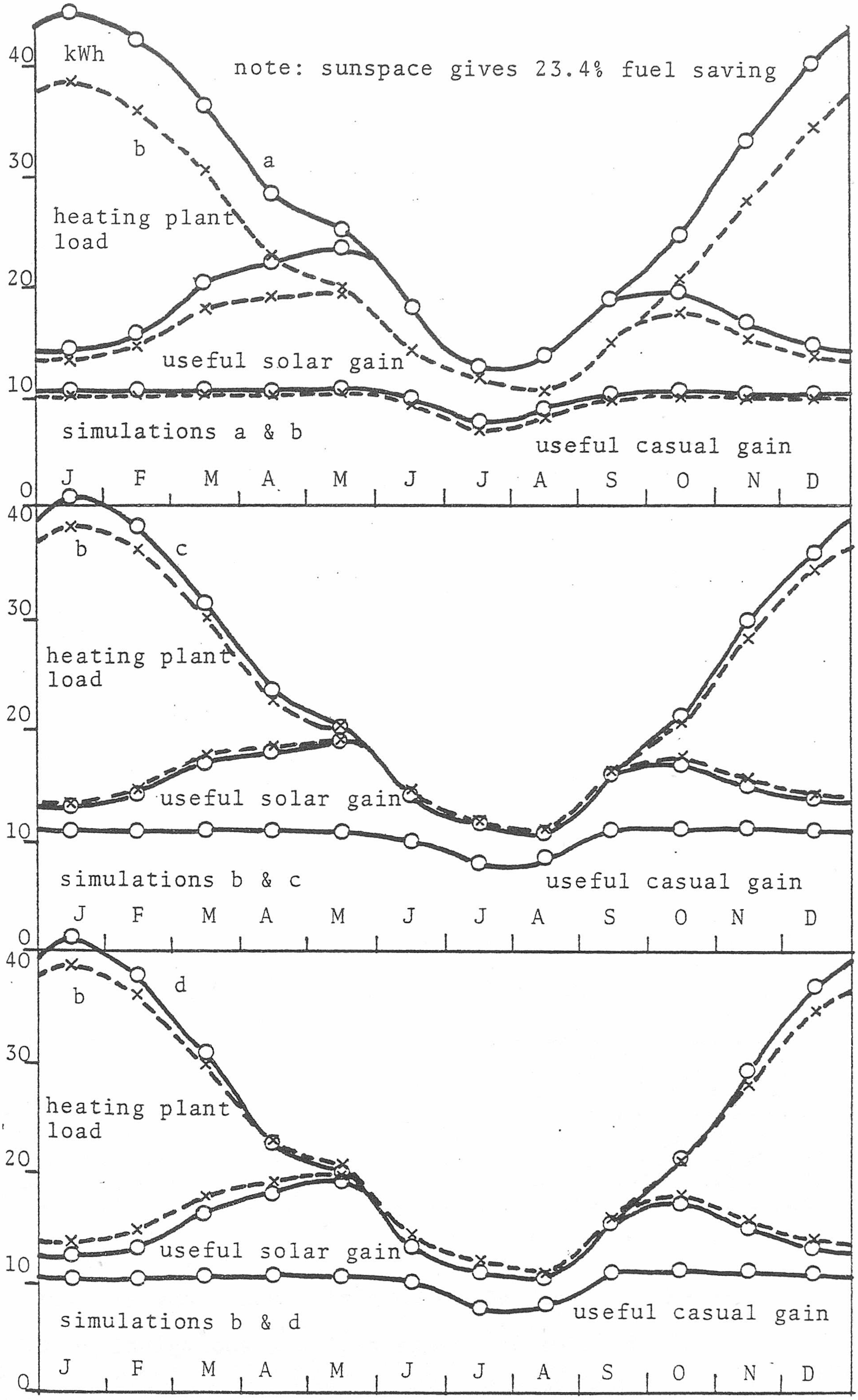


FIG 35: configuration B: monthly mean daily space heating loads

proportion of the solar contribution in simulation (a), where there is a low volumetric heat loss and corresponding low net space heating energy load, merits further comment. As stated there is no apparent solar on-cost, and the findings run contrary to a common contention that a high insulation strategy will economically eclipse a parallel passive solar strategy. Comparison with a single zone energy efficient model with an 11% higher annual volumetric heat loss, identical ambient conditions, and similar temperature and ventilation control strategies, indicates that the relative proportions of heat plant to useful solar gains can vary widely: the former is significantly greater and the latter significantly less. If the configuration 'A' model without sunporch is compared to the same single zone model, in this case a drop in volumetric heat loss of 15%, the heat plant load differential is now marginal and the solar load still substantially down. These comparisons are summarised in Table (xvi). In the single-zone model the

TABLE (xvi) Energy Analysis: Comparative Single-Zone Model

	Q kWh	Qhtg kWh	Qcas kWh	Qsol kWh	Uvol W/m^3K
Annual/m^3	66.06	39.56	21.25	5.25	0.98
comparison to - 'A'	-15%	-7.5%	-14%	-48.5%	-15%
(no sunporch) - 'B'	+11%	+77%	- 4%	-65%	+11%

emphasis was deliberately on maximising the thermal role of an indigenous and free source of solid fuel. South window area was only 20% of opaque south wall surface as opposed to 24% and 30% for the 'A' and 'B' simulations respectively. Also the geometry gives a less favourable volume compactness ratio and the construction restricts heavy thermal storage capacity elements to internal party walls. Results of simulation 'B' (c) also confirm that the light-weight construction, in this case an insulated floating floor and timber-framed north and south external walls, is less favourable than the heavy construction where insulation is located below the floor slab, and north/south walls are tile-clad insulating blockwork. However, the differences are not quantitatively very significant, and the heavy solution is favoured by the assumption of a day-time heating demand with plant operation controlled by thermostat or micro-processor. A less sophisticated and irregular heating regime prevalent in economically depressed housing areas, although difficult to model, may well favour the light-weight construction and this aspect merits more detailed investigation.

(iv) Conclusions

The conclusions from this analysis can therefore be summarised as follows:

Although the quantitative fuel saving of a specific passive solar feature predictably diminishes with increased insulation standards, a simple passive solar strategy considered integrally with high insulation levels can make a further significant contribution to reduction of traditional fuel costs.

The resultant house designs will also provide a more tolerant living environment, permitting both plentiful daylight/sunlight and higher levels of ventilation than are normally associated with energy-efficient houses, without severe penalty to the thermal performance and simultaneously reducing condensation risk.

The model without sunporch is representative of cost effective passive solar design based on optimising south facing glazing to living apartments. However, it is not possible to establish a definitive solar fuel saving for this model. Comparative analysis has shown that the size of solar contribution in well insulated buildings appears to be extremely sensitive to the proportion of south glazing to opaque wall surface, general building geometry and specific thermal resistance/capacity/response relationships in multi-layered construction.

The solar contribution from the sun porch can be quantified, and this feature cannot be considered cost-effective simply as a solar collector. However, it would enhance the property and give scope for storing gains for evening and night delivery. The contribution of both sunspace and 'mezzacaust' would be increased with a more evening orientated heating demand, reflecting a working/school family situation. The oncost of the mezzacaust may also be difficult to justify in purely energy terms, but there could also be structural and/or acoustic benefits in such construction.

3.2.9. ESP Energy Analysis: Housing Configuration C

(i) Input Data for Simulation Model - ESPIMP

This model was set up partly to measure the energy performance of an east/west oriented narrow frontage house against the previous model, and partly to compare collection efficiency of an east/west facing roof space collector with the south facing equivalent in configuration 'A'. The house has been divided into 8 thermal zones, 5 of which comprise the heated volume, living room, dining-kitchen, service core, east and west bedrooms; and 3 of which are collectors, west sun-porch, east sunporch and roof-space collector. The performance of the roof collector and the associated rock-pile store, input as part of the multi-layered wall construction, can be analysed separately in relation to that of configuration 'A'; permitting comparison with configuration 'B' to be based on the size/orientation of equivalent sunporch buffer zones to living spaces, and normal windows to bedrooms. The air change profile, summarised in Table (xvii), is closely matched to configuration 'B'. The casual gain daily totals are identical, with gains to the single service zone in the 'B' models distributed between separate kitchen and service zones, and similarly gains to the single bedroom zone in the 'B' models split between the east and west bedroom zones.

The shading/insolation input again assumes parallel terraces on a level site, this time 18 metres from east and west faces and 5 metres high. Other conditions are identical to the previous simulation.

TABLE (xvii) Housing Configuration C: Mean Air Change Rates for Zones in Simulation

Zone Description	Period	Air Changes per Hour
zone 1 - W. Sunporch	0-24	2.0 ach
zone 2 - Living Room	0-24	1.0
" 3 - E. Sunporch	0-24	2.0
" 4 - Kitchen/Dining	0-8	1.0
	8-20	1.5
	20-24	1.0
" 5 - Service Core	0-8	1.0
	8-9	2.0
	9-16	1.0
	16-24	2.0
" 6 - W. Bedroom	0-8	2.0
	8-24	1.0
" 7 - E. Bedroom	0-8	2.0
	8-24	1.0
" 8 - Roof Collector	0-24	1.0

(ii) Control Strategy for Dynamic Thermal Simulation ESPSIM

The temperature control strategies are also identical to respective zones in the previous simulation models with both kitchen-dining and service core treated as 'service'.

(iii) Analysis of Simulation Output - ESPOUT

The energy breakdown for the east/west intermediate terrace house simulated is a remarkably close match to the equivalent north/south intermediate terrace house. This is summarised in Table (xviii) and Fig 36 below.

The annual volumetric heat loss, 0.69 W/m^3K, and consequently the net energy load are both down by approximately 5%, due to the smaller area of exposed

TABLE (xviii) Housing Configuration C: Annual Energy Breakdown Summary

Uvol 0.69 W/m^3K	Q kWh	Qhtg kWh	Qcas kWh	Qsol kWh	% Qsol E/W	collection efficiency
1 Annual daily	23.08	8.07	9.69	5.32	E 77.3%	
2 " /m^3	47.00	16.44	19.72	10.83	W 76.7%	15%
3 percentage	100%	35%	4.2%	23%	mean 77%	

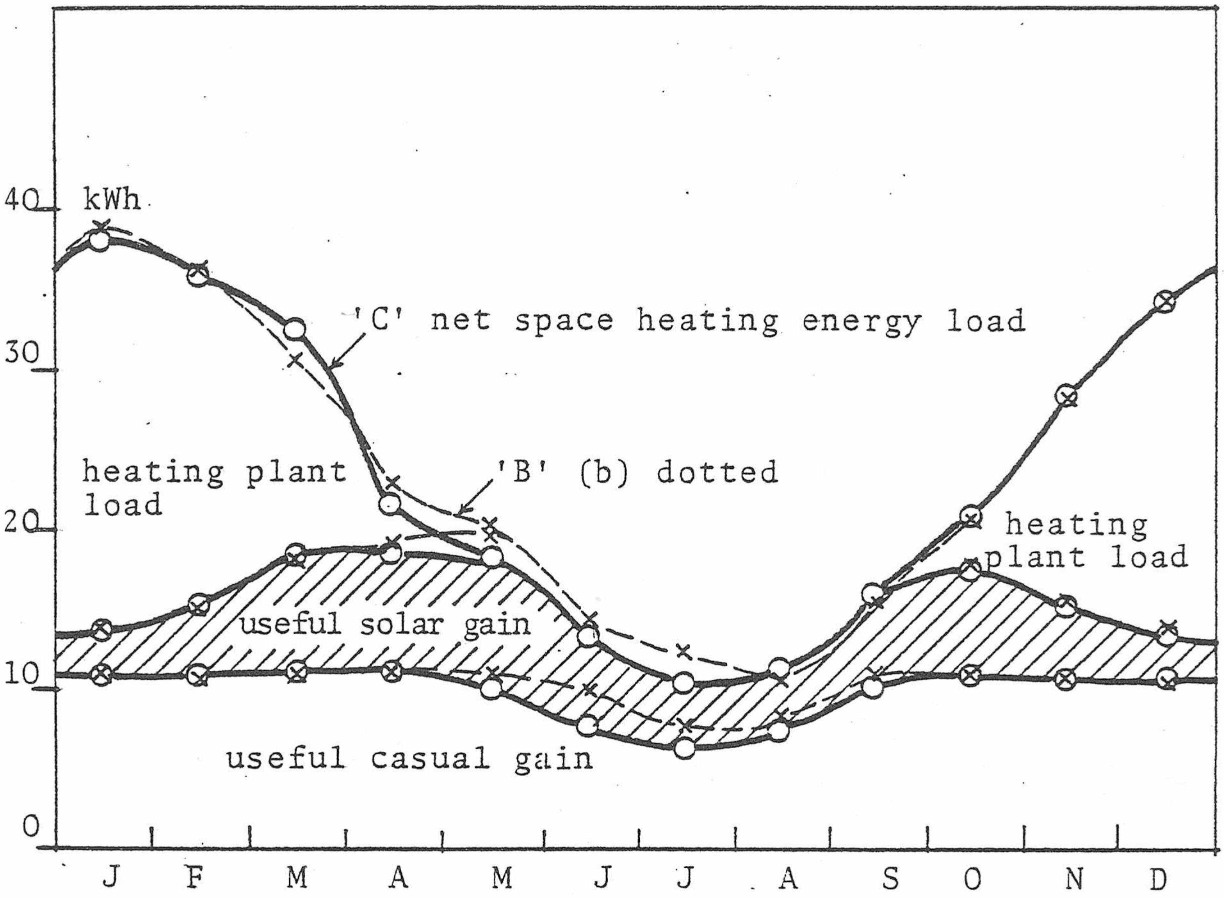


FIG 36: configuration C: monthly mean daily space heating energy breakdown compared to configuration B (b)

external surface. The heating plant load is down by 4%, the useful casual load by 9% and the useful solar load virtually identical at 10.83 kWh/m^3 heated volume and comprising 23% of the space heating load. The simulation shows that it is possible to achieve as great a solar contribution with an east/west design for only a modest increase in glazed area. Proportionately the net glazed area of sunporches and bedrooms to total east/west facade, including sunporch roofs, is 60%, which is identical to the proportion of bedroom windows and sunporch glazing to the south facade on models 'B' (b), (c) and (d). The net quantity of glazing on the east/west facades is 23.5 m^2 corresponding to 16.6 m^2 on the 'B' south facade, but taking into account the balance of north glazing and rooflights, the net increase in configuration 'C' is 3.0 m^2 or 14%. The percentage of useful solar gain within the east and west facing zones is a mean of 77%, 10% higher than with the south facing zones, but the glazed collection efficiency drops, corresponding to the increased glazed area, to 15%. Viewed purely as solar collectors, therefore, the east/west sunporches are less cost-effective than that of the north/south model; but in this case at least one sunporch must be regarded as an essential entrance vestibule, and there are also substantial hidden economies associated with a narrow frontage house, such as reduced drainage and road costs.

The role of the hollow precast concrete 'mezzacaust' floor as a short-term store for surplus sunporch, living and kitchen gains is in this case slightly enhanced. This is because the entire solar load in the kitchen is displaced in every month, but still leaving a heating plant load in this zone from October to April. Reference to Table 10, Appendix 4, shows that during a nine month September to May season, there is sufficient high-day surplus to raise the east mezzacaust through 7.5 °C in periods from 8-12 hours. On the west side, there is sufficient in September, October, April and May, taking from 5½ hours in April to 18½ hours in October. Since in this model there is an alternative route for surplus solar gains to an independent store, it could be advantageous to reduce the thermal capacity of the mezzacaust in order to extend its usefulness beyond a high-day insolation capability. For example, using a hollow woodwool slab construction the thermal capacity could be reduced to 0.2 kWh/K for each mezzacaust. The monthly mean daily surplus for April in the west sunspace and living room could then be sufficient to raise the temperature through 7.5°C in 6¼ hours. In either event the construction would be relatively cheap, have the additional advantage of sound deafening and constitute a useful stabilising thermal mass located centrally between living spaces. As with the configuration 'B' models, further work would be required to establish by how much a working/school occupancy could increase the usefulness of the mezzacaust. However, accepting that the extra cost of a heavy intermediate floor can be justified, the proposed rotating damper on the west side would seem to be too sophisticated and expensive a control element in relation to the quantitative heating contribution. Assuming 33% utilisation of surplus from both living spaces and sunporches the solar contribution would increase to 11.78 kWh/m^3, representing 25% of the net space heating load, an increase of 2% or approximately £7.50 per annum.

The results of the roof collector/rock store analysis show that the low $22\frac{1}{2}^{\circ}$ pitch east/west facing collectors are substantially less efficient than the south-sloping or south vertical collector. This is illustrated in Fig 37.

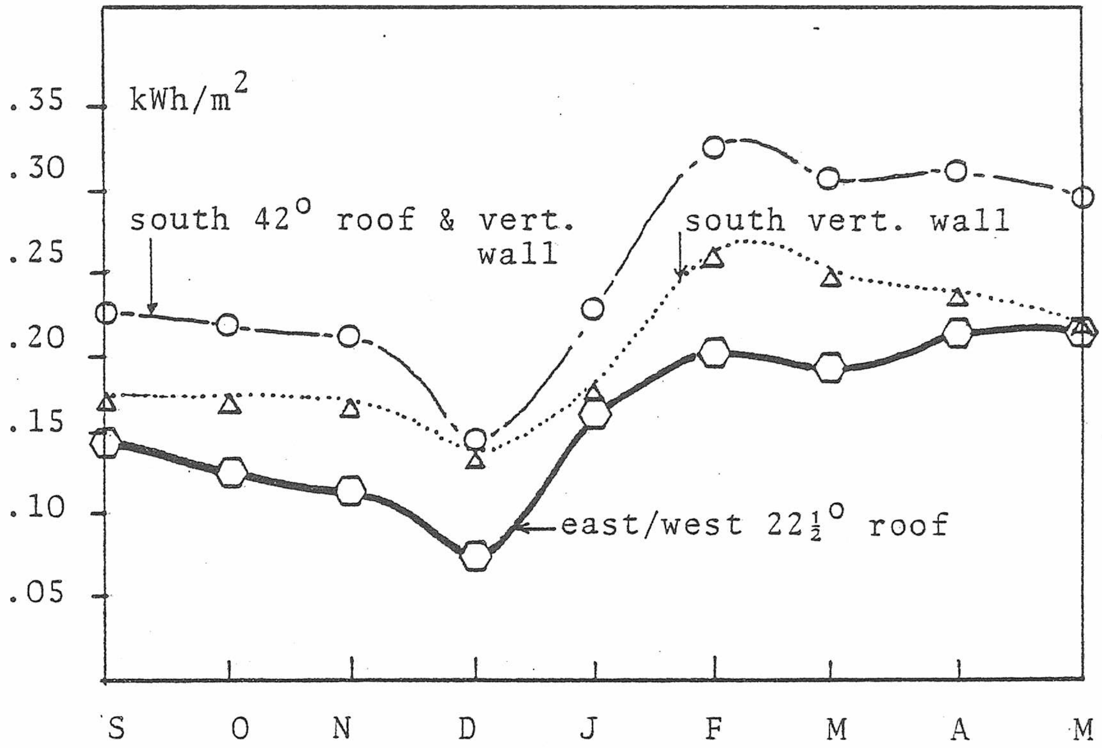


FIG 37: net monthly mean high-day hourly solar energy to rock store per m^2 configuration 'C' roof collector compared to configuration 'A' during a 9 month season

The ratio of rock store volume to collector area at 0.7 is therefore much too high giving theoretical high-day periods to raise the temperature through 10°C, ranging from 15 hours in May to 24 hours in September and almost 48 hours in December. However, if the volume of the rock store were reduced from 10.08 m^3 to 3.6 m^3, reducing the store volume to collector area ratio to 0.25, the system would be comparable with that of configuration 'A'. This is shown in Table 11, Appendix 4, indicating time lags to charge the store appropriate to daily requirements. Relating the roof collector/rock store system to the simulation results without the possible 2% additional mezzacaust surplus, and assuming 25% utilisation of roof gains, the solar contribution would increase by 4% as with configuration A, giving an adjusted annual breakdown as shown in Table (xix). However, the roof collector area is .08 m^2 per m^3 heated volume compared with .05 m^2/m^3 in configuration 'A', representing a performance capital cost increase on the collector of 60%. Assuming only 25% utilisation, therefore, this feature purchases a relatively small further fuel saving of approximately £14 p.a. at current costs for a larger relative outlay than its south facing counterpart. This contribution could increase by direct utilisation of roofspace gains from October till March, by-passing the rock store. Assuming system efficiency is thereby increased to 66.6%, the additional solar fuel saving would rise to £28 per annum or £1.85 p.a. per m^2 collector. These figures suggest containment of collector oncosts within £16-20/m^2 to achieve 10 year pay-back.

TABLE (xix) Housing Configuration 'C' - Annual Energy Breakdown Summary Including Gains from Roof Collector/Rock Store System

Unit kWh	Net Energy Load	Heating Plant	Useful Casual	Useful Solar
Annual Daily	23.08	7.18	9.69	6.21
" /m^3	47.00	14.62	19.72	12.65
Percentage	100%	31%	42%	27%

(iv) Conclusions

This simulation has shown that for a 14% increase in glazed area, representing no more than £250 increased window costs at current prices, an east/west passive solar sunporch solution can match the performance of an equivalent north/south design, with a 23% useful solar contribution to the net space heating load. This would result in a modest annual fuel bill of £125 p.a. at current electricity rates.

Although a separate simulation was not carried out, it is reasonable to assume, as with the north/south design, that the fuel saving afforded by the sunporches specifically may match the solar contribution at around 23%. This will be relatively small in quantitative terms due to the low volumetric heat loss - approximately 880 kWh or £38 p.a. However, the sunporches can be justified on other grounds, and the narrow frontage design is inherently economic in land use.

The merits of the 'mezza-caust' feature as a thermal stabiliser carry the same qualifications as with the previous configuration. It is technically viable, but the energy storage capability in relation to typical high-day solar surplus is quantitatively relatively small. The effect of the east solar buffer zone across the window facade of the kitchen, with a high proportion of casual gains, is interesting. Sufficiently high temperatures are predicted in the kitchen during sunshine hours in each month of the year to displace all the solar load for potential short-term storage.

The unit area of the roof collector, with low pitch and evenly divided east/west glazing, to heated volume requires to be significantly greater than the combined vertical and 42° south-sloping collector of configuration 'A' to achieve the same results. Also the ratio of rock storage volume to collector area requires to be much lower, approximately 0.25 compared to 0.4 for a south-sloping roof.

The roof air collector/rock pile store may be considered as an optional passive solar feature, and in isolation it is difficult to justify economically. However, as an integral part of an overall passive solar package, as with the mezza-caust, it represents a desirable means of aligning solar supply and heating demand more closely.

3.2.10. <u>ESP Energy Analysis</u>: <u>Housing Configuration D</u>

(i) Input Data for Simulation Models - ESPIMP

This final model has only two exposed collection surfaces, a west wall surface and a 45° pitch south-facing roof surface, the purpose being to establish if a passive solar design strategy is compatible with a single aspect house of this type. The majority of the south roof surface is used as a roof space collector, and associated with a low level rock store similar to configuration 'A'. This is again analysed separately for comparison purposes, and also to establish the performance range without the relatively costly feature. Due to the complexity of the geometry, it was not feasible to use a multi-zone thermal model for the heated volume. Therefore the results cannot be assumed to provide as accurate a guide as with previous simulations. Ventilation/infiltration rates have been assumed to be a mean of 1.5 ach between 8-24 hours and 1.0 ach for the remaining period. Casual gains are based on the previous simulations with allowance for the additional occupants and accommodation, mean daily sensible gains totalling 20 kWh. The shading/insolation input again assumes an equivalent parallel terrace with facades 18 metres apart, and identical adjacent roof silhouettes.

(ii) Control Strategy for Dynamic Thermal Simulation ESPSIM

In order to provide a reasonable range of volumetric heat loss for a simple single-zone model, two simulations were carried out. The first has a minimum design temperature of 16°C between 8-24 hours and the second 18°C. The maximum temperature in each case is 20°C during this period, and the minimum and maximum temperatures for the remaining period are 14°C and 16°C respectively for both simulations.

(iii) Analysis of Simulation Output - ESPOUT

The energy breakdown for the west facing, intermediate terrace house for the two design temperature control strategies is summarised in Table (xx). The respective values for annual volumetric heat loss of 0.81 and 0.91 W/m^{3}K lie below that of configuration 'A', but higher than 'B' and 'C', with the exception of the 'B' (a) model without the sunspace. The percentage solar contribution in the 'D' simulations tend towards the upper end of the 'A' - 'C' models which range from 15 - 27%. The mean solar contribution of the two models without the roof collector/rock store at 22.4% is approximately 2.5% lower than the equivalent intermediate terrace 'B' model without a sunporch. The quantity of casual load is almost identical to the mean for the 'B' models while the percentage range is also compatible with the 'A' - 'C' range of 35 - 44%. The mean heat plant load without the roof collector contribution at 24 kWh/m^3 is 7.5% higher than the 'B' model without sunporch, while the percentage load range is again within the 'A' to 'C' range of 31 - 44%.

TABLE (xx) Housing Configuration D: Annual Energy Breakdown Summary

Simulations (heated volume 243.4 m^3)	Net Energy Load kWh	Heating Plant kWh	Useful Casual kWh	Useful Solar kWh
1 16^{o}C design temp.				
Annual Daily	36.38	13.79	14.12	8.47
" /m3	54.55	20.68	21.17	12.70
Percentage	100%	37.9%	38.8%	23.3%
2 18^{o}C design temp.				
Annual Daily	41.05	18.10	14.12	8.83
" /m3	61.56	27.15	21.17	13.24
Percentage	100%	44.1%	34.4%	21.5%
3 16^{o}C + roof coll.				
Annual Daily	36.38	12.45	14.12	9.81
" /m3	54.55	18.67	21.17	14.71
Percentage	100%	34.2%	38.8%	27%
4 18^{o}C + roof coll.				
Annual Daily	41.05	16.40	14.12	10.53
" /m3	61.56	24.59	21.17	15.80
Percentage	100%	39.9%	34.4%	25.7%

As with configurations 'A' and 'C', assuming 25% utilisation, the roof collector adds approximately 4% to the solar contribution. In this case this represents a further fuel saving from £21 - £26 p.a., relatively somewhat higher than with 'C'. Again this contribution could probably be doubled by direct utilisation of day-time gains in winter months. Analysis of the system suggested that the store volume to collector area ratio of 0.5 is on the high side, and that as with configuration 'A', a moderately steep south sloping collector gave the most suitable high-day time lags to raise the temperature through 10-15 K with a ratio of 0.4. As simulated the thermal capacity is 2.9 kWh/K, and with the exception of December this gives time-lags varying from 6-16 hours, whilst the reduced ratio with a thermal capacity of 2.3 kWh/K gives equivalent time-lags from 4½-13 hours. Fig 38

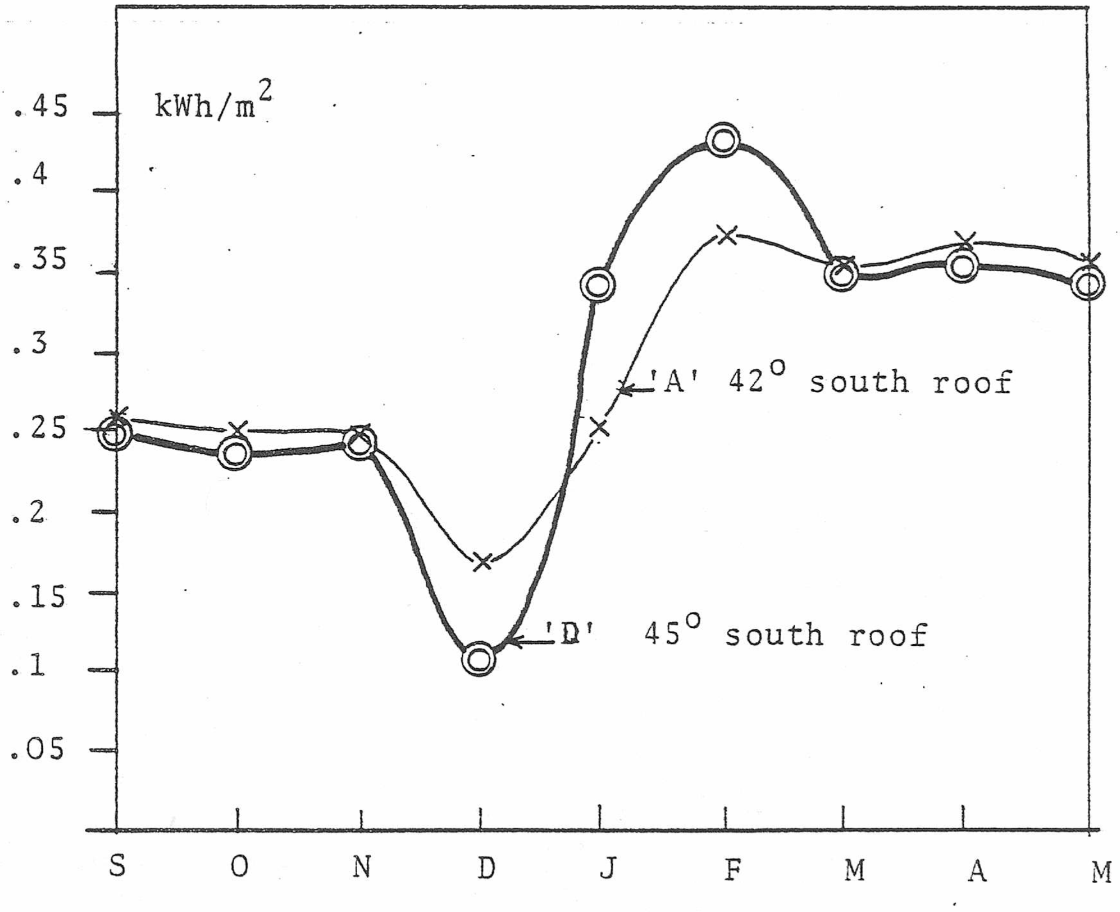


FIG 38: net monthly mean high-day hourly solar energy to rock store per m² configuration 'D' roof collector compared to configuration 'A' during a 9-month season

shows the comparison of the net monthly mean high-day solar absorption within the 45^o south facing collector of configuration 'D' compared with the 42^o collector of configuration 'A'. The very low value in December is accounted for by shading from the adjacent roof while the higher values in January and February are assumed to be due to the geometry of the absorbent surfaces within the collector.

(iv) Conclusions

The specifically single aspect house type is viable as a passive solar model, achieving in the intermediate terrace situation an equivalent performance to normal dual aspect house types for significantly lower quantities of insulation and glazing per unit volume.

Whilst a south-facing roof window for direct solar gain and daylight to the rear of the house is an essential element of the design, the roof collector, as in the previous simulation, is an optional solar feature with a similar percentage contribution of 4% of the net space heating load. This could again be increased by by-passing the store when appropriate, and by assuming proportionately higher evening temperatures.

The negative feature of this relatively high-density urban house form does not lie in terms of the physiological/constructional performance, rather with the psychological/planning restrictions of a house with a single outlook and entrance.

3.3. Conclusions and Guidelines from Passive Solar Models

All simulations have confirmed the viability of a significant passive solar contribution to the heating load within a representative range of local authority house shells, the extended Scottish heating season being a critical factor in utilising some solar energy in each month of the year.

Certain consistent design guidelines have been established with regard to specific passive solar features, such as the sunporch in relation to reduction of the space heating energy load; but the performance of a sunporch as a solar contributor to this reduced energy load is sensitive to several critical design variables. Simulations for configurations 'A' and 'B' have established that a south-facing sunporch, planned as a buffer zone to the main living space, represents an annual net space heating energy saving of 10 kWh/m^3 heated volume, equivalent to a drop in volumetric heat loss of 0.15 W/m^{3}K. This is shown graphically on Fig 39. The contribution of casual gains is also approximately proportional to the volumetric heat loss, a drop of 0.15 W/m^{3}K representing 1.65 kWh/m^3 annual casual load. But the heat plant load and useful solar contribution vary widely with distribution of casual gains in relation to thermally distinct zones, proportion of south glazing to opaque surface and other geometric/constructional factors.

For example, housing configuration 'B' gives a favourable 25% annual solar contribution of 15 kWh/m^3 with 30% direct gain glazing on the south facade. This

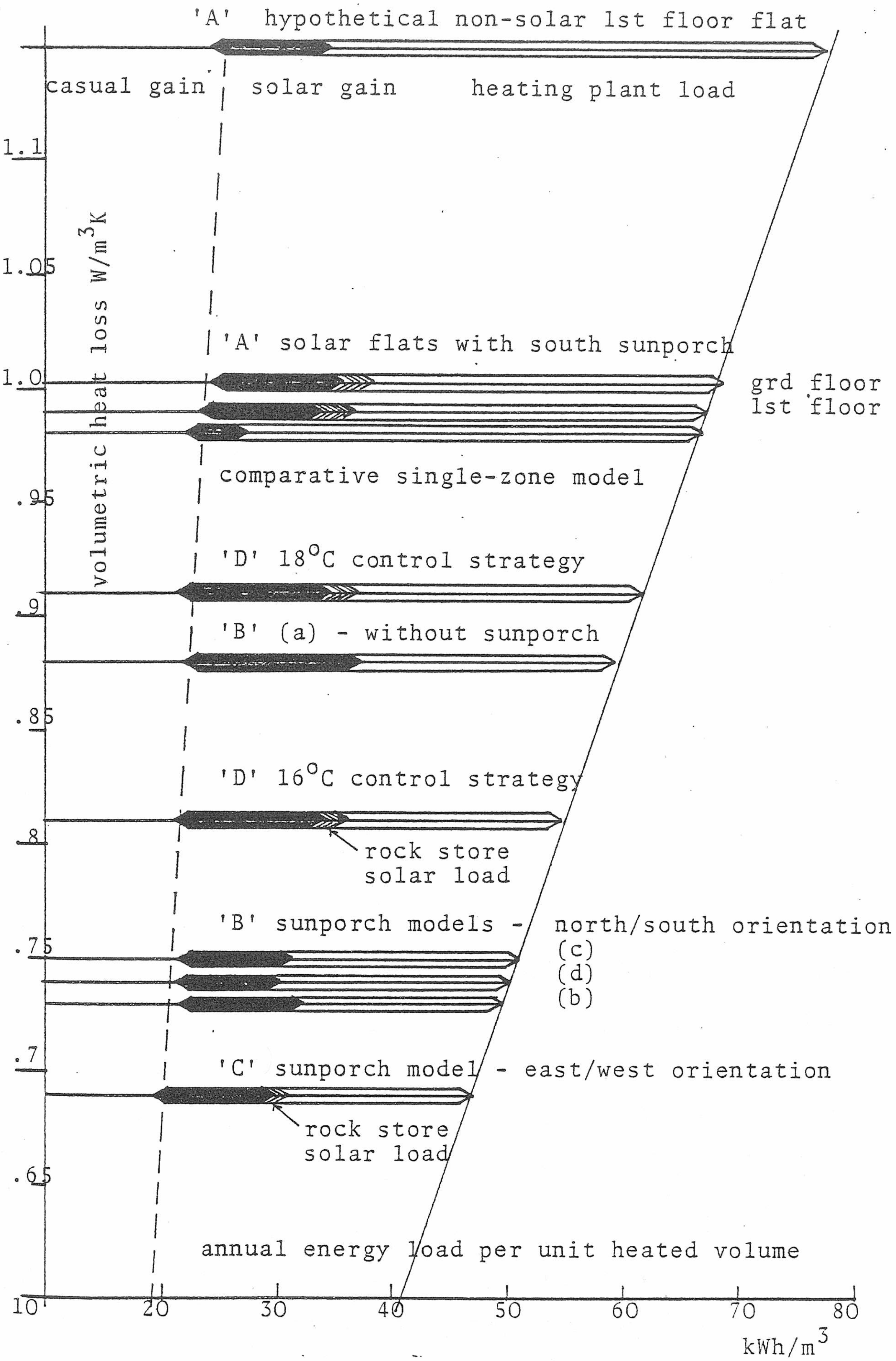


FIG 39: summary of energy breakdown for simulation models

predicted performance is also related to a strategy of concentrating the heaviest casual loads in the north service buffer zone, and assuming a design temperature profile based on day-time occupancy. Comparison to the hypothetical configuration 'A' model without the sunporch, shows that a reduction in direct gain glazing to 24% of the south facade, and more evenly distributed casual gains, will give approximately half the annual solar contribution proportionately. This simulation also predicts a 5 kWh/m^3 lower value quantitatively, even when the net space heating energy load is 18 kWh/m^3 higher. However, in the indirect models, a 50% and 60% proportion of south glazing respectively to configurations 'A' and 'B' give the former an annual solar contribution 2.35 kWh/m^3 greater than the latter, with a fairly large annual differential of 15 kWh/m^3 maintained between net space heating energy loads. The intermediate terrace east/west model with sunporches gives marginally the lowest net space heating energy load and heat plant load of all the simulations. It is also remarkable for its similarity to the equivalent south-facing sunporch model. However, this design is inherently more expensive in terms of glazed collection area required to achieve the equivalent performance, and this would require to be weighed against potential siteworks savings.

Systems with short-term storage are considered to be desirable from a performance flexibility viewpoint, but costs would require to be defrayed against total solar fuel savings. Suitable ratios have been established for thermal rock store volume to collector area: for south sloping 42-45°, south vertical and east/west sloping $22\frac{1}{2}°$, ratios of 0.4, 0.3 and 0.25 respectively give high-day insolation time-lags to raise the store temperature through 10-15 K, in a range from 5-15 hours. The ratios of collector area to heated volume to achieve a 4% additional useful solar contribution to the net space heating energy load are .05 and .08 for the south facing and east/west facing collectors respectively. It is estimated that such a contribution could double by direct utilisation of winter gains, and increase further by assuming relatively higher evening design temperatures and higher diurnal spring/summer/autumn ventilation rates. Such factors may also affect the slightly better performance of a 'heavy' construction, compared to a 'light' construction as simulated in the configuration 'B' models, and merits further detailed investigation (3.4. below).

The models simulated cover a differential in space heating load from configuration 'C' to the hypothetical 'A' model without sunporch of over 30 kWh/m^3. Whether the net energy load is lowered by simple insulation methods, or passive solar planning/construction tactics, at the lower 'B' - 'D' end of 47 - 63 kWh/m^3 the further potential for a solar contribution, although proportionately in the 18% - 27% range, quantitatively only ranges from 9 - 16 kWh/m^3. Since a building without a specific passive solar strategy is liable to give a minimum of 4 kWh/m^3 useful solar load, this represents in the case of a four person family house a maximum solar fuel saving of 5 - 12 kWh/m^3 or £38 - £50 p.a. Added to the fuel contribution of the sunporch of £38 p.a., the total solar fuel saving therefore amounts to

£76 - £88 p.a., compared to £80 for the same house without sunporch; the resultant fuel bills reduced to £126 - £146 and £164 respectively. However, a saving of £20 per quarter at current rates is still worthwhile when achieved for negligible on-cost, and although the 36% or £55 p.a. fuel saving for the less well insulated single-person flat appears more impressive, the resultant fuel bill is also proportionately higher at almost £100.

These findings dispel some commonly held misconceptions by showing that passive solar design in Scottish latitudes of 55 - 60°N can be economically compatible with moderate to high insulation standards, and healthy ventilation levels. Building work on housing configuration 'A' started in June 1983, and this may point the way to future local authority housing policy in Scotland. From the occupants' viewpoint this should respect low economic resources, and generally raise thermal standards, lessening winter spatial shrinkage and condensation risk. From the local authority and central government viewpoint, the passive solar approach will not only reduce the national power bill, but also assist to reduce an excessive housing maintenance bill.

3.4. Suggestions for Further Work

Direction for further research can be found from appraisal of input data in the above simulation models. For example, how representative is the input of real living conditions within the public housing sector, and how could changes to certain key data affect the predicted thermal performance and passive solar contribution?

In the case of heating, upper and lower temperature limits will switch plant on and off during a simulation in exactly the same manner as a thermostat in a real system. This may be reasonably representative for middle income families, particularly where homes are occupied during the day; but heating control in lower income groups is likely to be less predictable, and also where adult members of a family group are working, heating may only be used in the evenings during weekdays, and even then possibly only in the living room. Also the air change profiles used in the simulations, while conforming to standards, may be much more uniform than a real situation, which could vary through a wide range on a daily and seasonal basis.

There is a case, therefore, for introducing much more erratic heating and ventilation control strategies than those used in this analysis. Also it has been stated above that a change of emphasis to evening occupancy, and hence heat demand, would favour the isolated gain passive solar system with short-term thermally de-coupled storage; and that much higher summer day-time ventilation rates could generate a larger evening heat demand which could be met from such a store. A further range of simulations could verify and quantify this effect. At the same time, changes of constructional emphasis, for example the influence of furniture and furnishings, could be related to these more irregular control patterns.

In this way, the representative comparative analysis used in this thesis, would be extended to meet the likely range of occupancy variables, which will inevitably be found during the monitoring stage of a project such as the 22 single person flats in Stornoway. In other words, such additional work will increase the likelihood of meaningful correlation between computer prediction and site measurement.

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Appendix 1 - Climate Analysis

Table 1 Lerwick: Predicted and Measured Values for Monthly Mean Daily Irradiation

Table 2 Lerwick 60° 10'N 1981: Measured Values for Monthly Mean Daily Solar Irradiation

Table 3 'R' Factors Derived from Measured Lerwick Data 1981

Table 4 Aberdeen 57° 10'N: Predicted Values for Monthly Mean Daily Solar Irradiation

Table 5 Measured Daily Totals for Solar Irradiation, March 1983, Scott Sutherland School of Architecture, Aberdeen;

Table 6 Measured Hourly Means for Solar Irradiation, March 1983, Scott Sutherland School of Architecture, Aberdeen

Table 7 Measured Hourly Means for Solar Irradiation 1966-75 Bracknell and 1968-75 Aberdeen

Table 8 Radiation Values for Aberdeen and Bracknell: Comparison of Predicted and Measured Monthly Mean Daily Values

Table 9 Solar Radiation Related to Temperature Wind-speed, Rainfall and Sunshine: Monthly Mean Values for Aberdeen

Table 10 Comparative model: Aberdeen and Bracknell - Heating Load Compared to Solar Supply

Table 11 Eskdalemuir: 55° 19': Measured and Predicted Values for Monthly Mean Daily Irradiation

TABLE 1.1 Lerwick: Predicted & Measured Values for Monthly Mean Daily Irradiation

	Predicted			Measured '81			Measured Mean 1966-1975	
	H	Hd	HGVS *-GRD	H	Hd	HGVS *-GRD	H	Hd
J MJ/m^2 kWh/m^2	0.82	0.63	2.05 0.57	0.82	0.70	1.03 0.29	0.78	0.63
F	2.79	1.90	4.78 1.33	2.64	1.99	3.75 1.04	2.73	1.77
M	5.86	3.87	6.07 1.69	5.83	3.81	6.22 1.73	6.32	3.95
A	11.60	6.92	8.16 2.27	11.29	6.58	8.79 2.44	11.73	7.16
M	14.36	8.60	7.69 2.14	11.76	8.09	7.15 1.99	14.82	8.95
J	16.40	10.47	7.95 2.21	16.34	10.86	8.77 2.44	17.19	10.14
J	13.80	9.23	6.96 1.93	14.25	10.58	7.68 2.13	14.72	9.85
A	11.25	7.47	6.78 1.88	11.74	8.85	7.60 2.11	12.27	7.67
S	7.16	4.64	6.28 1.74	6.55	4.39	5.93 1.65	7.87	5.01
O	3.48	2.41	4.86 1.35	3.57	2.39	5.02 1.39	3.66	2.44
N	1.18	0.89	2.77 0.77	1.28	1.04	1.98 0.55	1.41	1.03
D	0.48	0.39	1.28 0.36	0.50	0.45	0.78 0.22	0.51	0.43
Annual Daily Mean MJ/m^2	7.43	4.78	5.47	7.21	4.98	5.39	7.83	4.92
Annual Total GJ/m^2	2.72	1.75	1.99	2.62	1.82	1.97	2.87	1.80

*Note: Predicted values for HGVS exclude ground reflected radiation in order to correspond to data in Met. 0.912, where this component has been deliberately screened.

TABLE 2.1 LERWICK 60° 10'N 1981: Measured values for monthly mean daily solar irradiation kWh/m^2, excluding ground reflected component

	H	Hd	HGVS	HGVW	HGVE	HGVN	HGLS
J	.23	.195	0.344	0.11	0.155	0.081	0.391
F	.73	.55	1.043	0.40	0.419	0.22	1.20
M	1.62	1.06	1.729	0.878	0.973	0.418	2.17
A	3.13	1.83	2.441	1.729	1.811	0.728	3.469
M	3.27	2.25	1.985	1.832	1.449	0.913	3.043
J	4.54	3.02	2.436	2.134	2.216	1.298	3.955
J	3.96	2.94	2.133	1.84	1.986	1.257	3.421
A	3.26	2.46	2.110	1.686	1.621	0.919	3.166
S	1.82	1.22	1.647	0.914	0.991	0.447	2.166
O	0.99	0.665	1.395	0.496	0.658	0.267	1.603
N	0.355	0.29	0.549	0.204	0.208	0.119	0.607
D	0.139	0.125	0.218	0.069	0.076	0.046	0.235

TABLE 3.1 'R' factors derived from measured Lerwick data 1981:

'R' derived = $(HG - \frac{1}{2}Hd\ (1 + \cos s))/H - Hd$
where 'HG' is monthly mean daily irradiation on a surface, excluding ground reflected component.

	LERWICK 60°N				ABERDEEN 57°N			
	S lat	EV	WV	NV	Slat	EV	WV	NV
J	6.99 (8.125)	.36 (.303)	.36	-.47 (.062)	6.22	.39	.39	-.50
F	4.375 (4.252)	.80 (.484)	.63	-.305 (.255)	3.56	.78	.61	-.30
M	2.455 (2.29)	.80 (.574)	.69	-.20 (.410)	2.07	.77	.66	-.185
A	1.61 (1.35)	.69 (.612)	.63	-.145 (.504)	1.27	.66	.60	-.13
M	1.33 (0.953)	.53 (.631)	.53	-.135 (.560)	0.91	.50	.50	-.115
J	1.11 (0.818)	.46 (.641)	.42	-.14 (.587)	0.79	.42	.38	-.11
J	1.19 (0.877)	.47 (6.36)	.40	-.15 (.574)	0.84	.43	.36	-.12
A	1.65 (1.166)	.50 (.620)	.45	-.19 (.528)	1.105	.46	.41	-.15
S	2.085 (1.858)	.63 (.592)	.52	-.23 (.450)	1.72	.59	.48	-.20
O	3.40 (3.426)	1.00 (.524)	.64	-.30 (.316)	2.99	.97	.61	-.29
N	5.99 (6.759)	.97 (.364)	.83	-.40 (.114)	5.34	.96	.82	-.40
D	10.09 (10.588)	.80 (.201)	.45	-.70 (.004)	7.87	.87	.52	-.70

Note: 'R' factors by Markus & Morris shown in brackets.

TABLE 4.1 ABERDEEN 57° 10'N: Predicted Values for Monthly Mean Daily Solar Irradiation. Unit KWh/m^2

	Measured at Abdn Univ	Predicted using c & d values	Predicted using R values ( )c - CASD Programme ( )GR - excluding ground reflected radiation				
	H HOR	Hd DIF	HGVS VER(S) r = .2	HGVW VER(W) r = .2	HGVE VER(E) r = .2	HGVN VER(N) r = .1	HGLS LAT(S) r = .2
J	0.36	0.25	0.86	0.21	0.21	0.09	0.89
	(0.46)c	(0.28)	(1.05)c	(0.51)	(0.67)	(0.14)	(1.13)
			(0.82)GR	(0.17)	(0.17)	(0.07)	(0.87)
F	9.99	0.63	1.70	0.63	0.92	0.26	1.81
	(0.87)c	(0.58)	(1.08)	(0.69)	(0.69)	(0.29)	(1.28)
			(1.60)	(0.53)	(0.83)	(0.21)	(1.76)
M	2.00	1.20	2.24	1.33	1.42	0.56	2.67
	(2.22)c	(1.14)	(2.37)	(1.36)	(1.58)	(0.57)	(2.97)
			(2.04)	(1.13)	(1.22)	(0.45)	(2.58)
A	3.25	1.91	2.49	2.08	2.16	0.94	3.38
	(3.00)c	(1.85)	(2.18)	(1.49)	(1.61)	(0.93)	(3.11)
			(2.16)	(1.76)	(1.84)	(0.78)	(3.23)
M	4.02	2.45	2.45	2.41	2.41	1.24	3.50
	(4.76)c	(2.49)	(3.03)	(2.15)	(2.12)	(1.24)	(4.65)
			2.05	(2.01)	(2.01)	(1.04)	(3.32)
J	4.89	2.64	2.72	2.37	2.75	1.32	4.03
	(5.28)c	(2.80)	(3.07)	(2.22)	(2.25)	(1.40)	(4.91)
			(2.24)	(1.88)	(2.26)	(1.07)	(3.81)
J	4.20	2.64	2.20	2.30	2.41	1.34	3.54
	(4.37)c	(2.63)	(2.56)	(1.91)	(1.97)	(1.32)	(4.02)
			(1.78)	(1.88)	(1.99)	(1.13)	(3.35)
A	3.54	2.12	2.44	1.99	2.07	1.02	3.37
	(4.07)c	(2.09)	(2.91)	(1.96)	(2.00)	(1.05)	(4.25)
			(2.08)	(1.64)	(1.71)	(0.85)	(3.21)
S	2.32	1.42	2.19	1.38	1.48	0.64	2.77
	(2.42)	(1.43)	(2.09)	(1.34)	(1.47)	(0.72)	(2.79)
			(1.96)	(1.15)	(1.25)	(0.53)	(2.66)
O	1.28	0.79	1.92	0.77	1.00	0.32	2.13
	(1.30)c	(0.82)	(1.49)	(0.84)	(1.05)	(0.41)	(1.80)
			(1.79)	(0.64)	(0.87)	(0.25)	(2.07)
N	0.57	0.38	1.30	0.40	0.43	0.14	1.33
	(0.60)c	(0.37)	(1.08)	(0.65)	(0.62)	(0.19)	(1.17)
			(1.24)	(0.35)	(0.37)	(0.11)	(1.30)
D	0.29	0.19	0.92	0.18	0.21	0.04	0.95
	(0.35)c	(0.22)	(0.76)	(0.48)	(0.39)	(0.11)	(0.82)
			(0.90)	(0.15)	(0.18)	(0.025)	(0.94)
Year) Totals)	845.3	507.0	712.5	489.5	537.8	241.1	892.9
	(906.8)	(509.5)	(722.0)	(476.0)	(501.0)	(255.4)	(1004.1)c
			(628.0)	(405.3)	(447.5)	(198.8)	(885.8)GR

TABLE 5.1 Measured Daily Totals for Solar Irradiation
March 1983, Scott Sutherland School of
Architecture, Aberdeen

Aberdeen 57^{o} 10'N Unit kWh/m^2

Day	H	HGVS	HGVW	HGVE	HGVN	HGLS
	HOR(G)	VER(S)	VER(W)	VER(E)	VER(N)	LAT(S)
1	1.682	0.774	0.503	0.497	0.162	1.452
2/3			no results			
4	2.310	3.545	0.757	1.877	0.305	4.120
5	1.477	1.364	0.470	1.005	0.374	1.703
6	1.483	1.379	0.739	0.561	0.388	1.839
7	1.293	1.002	0.474	0.636	0.345	1.419
8	2.762	4.485	1.689	1.603	0.292	5.201
9	1.645	1.666	0.881	0.689	0.390	2.170
10	0.993	0.703	0.440	0.355	0.287	1.018
11	0.750	0.279	0.238	0.279	0.255	0.541
12	1.178	0.646	0.382	0.538	0.362	1.060
13	1.187	0.830	0.518	0.464	0.327	1.205
14	2.354	2.929	0.899	2.000	0.406	3.594
15	2.116	2.330	1.347	0.869	0.401	2.918
16	1.148	0.813	0.548	0.345	0.295	1.207
17	1.903	1.700	0.852	1.337	0.499	2.253
18	2.161	2.336	0.618	1.419	0.400	2.969
19	2.494	2.816	1.012	0.886	0.381	3.587
20	2.620	3.056	1.444	1.045	0.444	3.883
21	2.811	3.024	1.946	0.872	0.558	3.899
22	3.397	4.151	2.014	1.174	0.455	5.182
23	1.151	0.456	0.416	0.451	0.396	0.850
24	3.385	3.773	1.392	2.313	0.518	4.805
25	2.273	1.989	1.315	0.829	0.496	2.715
26	2.819	2.681	0.655	2.339	0.492	3.559
27	3.368	3.095	1.440	2.006	0.547	4.140
28/29			no results			
30	3.345	2.749	2.142	1.132	0.692	4.167
31		1.123	0.634	0.760	0.366	
TOTAL	54.105	55.603	25.765	28.321	10.671	72.456
March Tot	64.510	63.829	29.582	32.516	12.723	86.390
mean day	2.081	*2.059	*0.954	*1.048	*0.410	*2.786
high day	3.397	4.485	2.142	2.339	0.692	5.201
low day	0.750	0.279	0.238	0.279	0.255	0.541
	measured					
Pred 'R'	2.00	*2.04	*1.13	*1.22	*0.45	*2.58
CASD	2.22	2.37	1.36	1.58	0.57	2.97

*Note: 'Pred' and measured values exclude ground reflected component.

TABLE 6.1 Measured Hourly Means for Solar Irradiation March 1983, Scott Sutherland School of Architecture, Aberdeen (Local Apparent Time)Wh/m^2

	Hour L.A.T.	H HOR(G)	HGVS VER(S)	HGVW VER(W)	HGVE VER(E)	HGVN VER(N)	HGLS LAT(S)
	5-6	0.09	0.01	0.00	0.11	0.03	0.06
	6-7	14.41	7.40	2.65	23.33	4.33	12.76
	7-8	79.35	59.52	15.39	117.11	18.73	74.08
	8-9	150.27	129.01	31.06	155.20	33.50	149.76
	9-10	219.80	208.59	46.11	192.12	32.09	267.20
	10-11	291.04	301.32	60.93	183.89	53.82	406.74
	11-12	317.19	352.62	72.70	128.31	56.29	454.37
	12-13	309.43	343.76	105.63	79.16	55.09	444.94
	13-14	299.25	331.51	242.01	67.58	55.07	429.82
	14-15	194.73	200.86	166.42	48.18	40.90	226.42
	15-16	136.45	127.68	163.75	30.59	30.49	180.18
	16-17	56.38	47.04	92.60	14.17	14.77	67.86
	17-18	12.66	9.79	34.47	2.06	4.25	14.99
	18-19	0.27	0.05	0.37	0.03	0.04	0.25
Daily Total	KWh/m^2	2.1	2.1	1.0	1.0	0.4	2.7

TABLE 7.1 Measured Hourly Means for Solar Irradiation 1966-1975 Bracknell and 1968-1975 Aberdeen (Local Apparent Time)

Unit Wh/m^2

	Hour	H	HGVS	HGVW	HGVE	HGVN	H
	L.A.T.		BRACKNELL	(E. Hampstead)			ABDN
	5-6	0.00	0.00	0.00	2.78	0.00	2.78
	6-7	30.56	16.67	8.33	47.22	8.33	19.44
	7-8	94.44	75.00	25.00	161.11	25.00	77.78
	8-9	180.56	158.33	41.67	233.33	41.67	155.56
	9-10	252.78	225.00	58.33	230.55	55.56	219.44
	10-11	311.11	283.22	72.22	194.44	63.89	266.67
	11-12	333.33	300.00	83.33	127.78	66.67	288.89
	12-13	322.22	288.89	116.67	83.33	66.67	283.33
	13-14	286.11	252.78	172.22	69.44	61.11	250.00
	14-15	236.11	202.78	202.78	55.56	55.56	202.78
	15-16	161.11	136.11	194.44	41.67	41.67	136.11
	16-17	86.11	63.89	136.11	25.00	27.78	66.67
	17-18	30.56	13.89	50.00	8.33	8.33	16.67
	18-19	0.00	0.00	0.00	0.00	0.00	2.78
Daily Total	kWh/m^2	2.3	2.0	1.2	1.3	0.5	2.0

TABLE 8.1 Radiation Values for Aberdeen & Bracknell: Comparison of Predicted and Measured Monthly Mean Daily Values

		H Abdn M Global	H Br'nell M Horizontal	Hd Abdn Pr Diffuse	Hd Br'nell M Horizontal	HGVS Abdn Pr Global	HGVS Br'nell M Vertical
J	MJ/m^2	1.28	2.23	0.97	1.63	2.54	2.94
	KWh/m^2	.36	0.62	0.27		0.71	0.82
F		3.58	4.47	2.40	2.97	5.38	5.36
		.99	1.24	0.66		1.50	1.49
M		7.19	8.36	4.48	4.90	7.14	7.27
		2.00	2.32	1.24		1.98	2.02
A		11.7	11.95	7.14	7.24	7.67	7.73
		3.25	3.32	1.98		2.13	2.15
M		14.46	15.88	9.10	9.49	7.38	7.61
		4.02	4.41	2.53		2.05	2.11
J		17.6	18.80	9.50	9.95	8.06	7.93
		4.89	5.22	2.64		2.29	2.20
J		15.1	16.93	9.94	9.89	7.35	7.67
		4.20	4.70	2.76		2.04	2.13
A		12.75	14.04	7.86	8.15	7.46	7.90
		3.54	3.90	2.18		2.07	2.19
S		8.39	10.51	5.27	6.07	6.90	8.15
		2.33	2.92	1.46		1.92	2.26
O		4.61	6.13	2.95	3.67	6.20	6.84
		1.28	1.70	0.82		1.72	1.90
N		2.06	3.29	1.41	2.09	4.26	4.91
		0.57	0.91	0.39		1.18	1.36
D		1.06	1.91	0.71	1.35	3.23	3.01
		0.29	0.53	0.20		0.90	0.84
Annual Total KWh/m^2		845.3	969.4	522.6	570.9	623.2	653.1

$Hd = cH + dH^2/Ho$ $c = 1.078$ $d = -1.14$
(values for Lerwick)

$HGVS = (H - Hd)R + Hd/2$ (ground reflected component excluded as Table 1)

(M signifies measured value, Pr - predicted value).

TABLE 9.1 Solar Radiation Related to Temperature, Windspeed, Rainfall and Sunshine: Monthly Mean Values for Aberdeen

	Temp °C	Sun-shine hrs	°Days (base 15.5°C)	Rain mm	Wind-speed m/s	Driving Rain Index m^2/s	HGVS MJ/m^2
	MMD	MMD	MMT	MMT	MM	MMT	MMD
JAN	2.4	1.61	406	62.23	4.94	.307	3.09
FEB	2.8	2.82	356	50.29	5.11	.257	6.13
MAR	4.5	3.43	341	48.51	5.50	.267	8.06
APR	6.6	5.09	267	50.04	4.78	.239	8.95
MAY	9.0	5.51	195	60.71	4.63	.281	8.84
JUN	12.0	5.80	105	42.42	4.30	.182	9.81
JUL	14.0	4.96	46	76.45	3.96	.303	7.91
AUG	13.6	4.43	59	67.82	3.82	.259	8.79
SEP	11.7	3.95	114	68.33	4.18	.286	7.88
OCT	8.8	3.02	208	83.31	4.67	.390	6.91
NOV	5.6	1.94	297	82.55	4.67	.386	4.69
DEC	3.7	1.47	366	80.01	5.02	.402	3.32

MM - Denotes monthly mean value

MMD - Denotes monthly mean daily value

MMT - Denotes monthly mean total.

TABLE 10.1 Comparative Model: Aberdeen & Bracknell - Heating Load Compared to Solar Supply

	HEATING LOAD KWh		SOLAR SUPPLY kWh	
	(15.5 - mean to) x 0.1 x 730		26.0 x 0.3 x HGV x 30.4	
	(ti-to)x	kw/K x hrs/mth	Area m^2 x efficiency x kWh/m^2 x days/mth	
	Aberdeen	Bracknell	Aberdeen	Bracknell
JAN	956.3	904.8	168.35	194.4
FEB	927.1	777.6	356.68	353.3
MAR	803.0	698.4	469.50	479.0
APR	649.7	487.2	505.06	509.8
MAY	474.5	273.6	486.09	500.3
JUNE	255.5	117.6	533.52	521.7
JULY	109.5	60.0	483.72	505.0
AUG	138.5	69.6	490.84	519.3
SEP	277.4	144.0	455.27	535.9
OCT	489.1	324.0	407.85	450.5
NOV	722.7	612.0	279.80	322.4
DEC	861.4	784.8	213.40	199.2
ANNUAL	6,664.7	4,647.8	4,850.0	5,090.8
USEFUL SOLAR GAIN			3,656.0 (75%)	2,926.0 (57%)
SOLAR FRACTION OF HEATING LOAD			54.8%	63%

Notes: Monthly Mean external temp., to, from long-term meteorological records

Base internal temperature, ti, assumed 15.5°C

Specific Heat Loss assumed 0.1 kW/K

Area of collection assumed 26.0 m^2

Efficiency of system assumed 0.3

Mean days in month 30.4 days

Mean hours in month 730 hours

TABLE 11.1 Eskdalemuir 55° 19' - Measured and Predicted Values for Monthly Mean Daily Irradiation

		Measured data				Predicted data			
		H	Hd	HGVS -GRD	HGVS	H	Hd	HGVS -GRD	HGVS
J	MJ/m^2				2.70				4.20
	KWh/m^2	0.38	0.28	0.71	0.75	0.47	0.30	1.12	1.17
F					6.69				6.32
		1.11	0.68	1.75	1.85	1.08	0.68	1.65	1.76
M					7.60				7.36
		2.01	1.25	1.91	2.11	1.94	1.20	1.85	2.04
A					8.68				8.67
		3.24	1.94	2.09	2.41	3.24	1.95	2.08	2.41
M					8.45				9.23
		3.90	2.40	1.96	2.35	4.26	2.54	2.14	2.56
J					9.31				9.34
		4.67	2.71	2.12	2.59	4.67	2.79	2.13	2.60
J					8.43				8.21
		4.06	2.51	1.94	2.34	3.95	2.44	1.88	2.28
A					8.28				8.09
		3.42	2.16	1.96	2.30	3.33	2.06	1.92	2.25
S					7.49				7.22
		2.30	1.45	1.85	2.08	2.20	1.37	1.78	2.00
O					6.48				6.48
		1.29	0.81	1.67	1.80	1.29	0.81	1.67	1.80
N					5.20				4.78
		0.65	0.41	1.38	1.45	0.60	0.38	1.27	1.33
D					3.48				3.48
		0.34	0.22	0.93	0.97	0.34	0.22	0.93	0.97

Values for climatically determined constants:
a = .187, b = .67, c = .809, d = .515

TABLE 12.1 Glasgow 56°N: Predicted Values for Monthly Mean Daily Irradiation

	R	n/No	Kwh/m² → H	H/Ho	Hd	HGVS -GRD	HGVS	MJm²
J	5.97	.16	0.41	.29	0.25	1.08	1.12	4.03
F	3.39	.24	1.02	.35	0.59	1.75	1.85	6.68
M	1.72	.27	1.89	.37	1.08	1.93	2.38	8.58
A	.875	.36	3.41	.43	1.84	2.29	2.63	9.48
M	.51	.38	4.51	.44	2.40	2.28	2.73	9.82
J	.395	.37	4.98	.44	2.66	2.25	2.67	9.61
J	.445	.31	4.24	.39	2.37	2.02	2.44	8.79
A	.705	.32	3.56	.40	1.97	2.10	2.46	8.86
S	1.345	.29	2.29	.38	1.29	1.99	2.22	7.99
O	2.72	.25	1.23	.35	0.71	1.77	1.89	6.81
N	5.10	.19	0.52	.31	0.31	1.23	1.28	4.60
D	7.40	.15	0.30	.29	0.18	0.98	1.00	3.62
$H = Ho\ (.\overset{a}{187} + (.\overset{b}{67} \times {}^{n}/_{No}))$ $Hd = H\ (.\overset{c}{767} - (.\overset{d}{531} \times {}^{H}/_{Ho}))$ HGV = (H - Hd) R + Hd/2 + (.2 x H/2) a,b,c, & d values for Eskdalemuir by Page '79 EEC report.[7]						excluding grd reflected component as Met 0.912	including grd reflected component. r = 0.2	including grd reflected component. r = 0.2

TABLE 13.1 Aberdeen 57°10' - Measured and Predicted Values for Monthly Mean Daily Irradiation

	R	← kWh/m² H	H/Ho	Hd	HGVS 1	HGVS 2	→ MJ/m²
J	6.350	0.36	.29	0.25	0.82	0.86	3.09
F	3.580	0.99	.36	0.63	1.60	1.70	6.13
M	1.800	2.00	.40	1.20	2.04	2.24	3.06
A	0.900	3.25	.41	1.91	2.16	2.49	8.95
M	0.527	4.02	.39	2.45	2.05	2.45	8.84
J	0.407	4.89	.46	2.64	2.24	2.72	9.81
J	0.460	4.20	.37	2.64	1.78	2.20	7.91
A	0.723	3.54	.40	2.12	2.08	2.44	8.79
S	1.370	2.33	.39	1.42	1.96	2.19	7.88
O	2.850	1.28	.38	0.79	1.79	1.92	6.91
N	5.550	0.57	.34	0.38	1.24	1.30	4.69
D	8.000	0.29	.35	0.19	0.90	0.92	3.32
H = measured monthly mean data Hd = H (.995 - (.990 x H/Ho)) Bracknell values for c & d used since Bracknell a & b values gave closest correlationship to measured data. (compare results to Table 2). HGVS = H - Hd R + Hd/2 + (.1 x H)					excluding grd reflected component as Met 0.912	including grd reflected component r = 0.2	including grd reflected component r = 0.2

TABLE 14.1 Dunstaffnage 56° 28' - Measured and Predicted Values for Monthly Mean Daily Irradiation

	←		kWh/m^2			→		MJ/m^2
	R	n/No	H	H/Ho	Hd	HGVS -GRD	HGVS	HGVS
J	6.30	.14	0.41	.42	0.25	1.13	1.17	4.23
F	3.55	.24	0.97	.34	0.67	1.40	1.50	5.39
M	1.76	.27	2.23	.44	.129	2.30	2.52	9.08
A	.887	.31	3.76	.47	2.04	2.55	2.92	10.52
M	.552	.35	4.37	.43	2.57	2.28	2.72	9.78
J	.405	.29	5.35	.47	2.90	2.44	2.98	10.72
J	.450	.22	4.36	.41	2.66	2.10	2.44	8.78
A	.720	.26	3.44	.39	2.18	2.00	2.34	8.43
S	1.377	.24	2.50	.42	1.50	2.18	2.38	8.56
O	2.79	.20	1.37	.40	0.85	1.88	2.01	7.25
N	5.23	.16	0.59	.37	0.39	1.26	1.32	4.75
D	7.65	.09	0.32	.35	0.22	0.88	0.91	3.27
						excluding grd reflected component as Met 0.912		including grd reflected component. r = 0.2

H = measured monthly mean data

$Hd = H (1.078 - (1.14 \times {}^{H}/_{Ho}))$

c & d values for Lerwick, as a & b

values gives closest match to measured data.

$HGV = (H - Hd) R + \frac{1}{2}Hd + (.2 \times H/2)$.

TABLE 15.1 Stornoway 58° 15': Predicted Values for Monthly Mean Daily Irradiation

	←		kWh/m^2			→		MJ/m^2
	R	n/No	H	H/Ho	Hd	HGVS -GRD	HGVS	HGVS
J	7.3	.17	0.32	.31	.23	0.77	0.80	2.89
F	4.12	.26	0.96	.38	.62	1.71	1.81	6.50
M	1.90	.31	2.04	.43	1.20	2.20	2.40	8.65
A	.935	.36	3.66	.48	1.94	2.58	2.95	10.61
M	.55	.375	4.93	.49	2.56	2.58	3.07	11.06
J	.425	.33	5.12	.45	2.89	2.39	2.90	10.45
J	.475	.25	4.04	.38	2.60	1.98	2.38	8.58
A	.760	.29	3.55	.41	2.17	2.13	2.49	8.95
S	1.465	.28	2.29	.41	1.40	2.00	2.23	8.02
O	3.09	.24	1.16	.37	0.76	1.62	1.74	6.25
N	6.17	.20	0.44	.34	0.30	1.01	1.05	3.79
D	9.35	.12	0.20	.27	0.15	0.54	0.56	2.01
						excluding grd reflected component as Met 0.912	including grd reflected component. r = 0.2	including grd reflected component. r = 0.2

$H = Ho (.16 + (.87 \times {}^{n}/_{No}))$

$Hd = H (1.078 - (1.14 \times {}^{H}/_{Ho}))$

$HGV = (H - Hd) R + \frac{1}{2}Hd + (.2 \times H/2)$

a,b,c,d values for Lerwick.

TABLE 16 - Aberdeen 56°10'N: Comparison of Predicted H Values To Measured Mean H Using Various Values For a & b Constants

	n/No	H/Ho	H	Predicted H = Ho(a + (bx^n/No))				
J	.23	.29	0.36	0.40	0.40	0.45	0.36	0.46
F	.31	.36	0.99	1.04	1.03	1.19	0.99	1.19
M	.31	.40	2.00	1.87	1.85	2.15	1.80	2.15
A	.37	.41	3.25	3.25	3.25	3.81	3.26	3.77
M	.35	.39	4.02	4.06	4.05	4.74	4.03	4.70
J	.33	.46	4.89	4.40	4.38	5.10	4.30	5.07
J	.30	.37	4.20	4.19	4.15	4.79	4.00	4.79
A	.30	.40	3.54	3.22	3.19	3.68	3.07	3.68
S	.32	.39	2.33	2.24	2.23	2.59	2.17	2.58
O	.30	.38	1.28	1.23	1.22	1.40	1.17	1.40
N	.25	.34	0.57	0.56	0.56	0.63	0.51	0.64
D	.21	.35	0.29	0.26	0.25	0.28	0.23	0.29
Conclusion - Bracknell '79 values for a & b give close correlation of predicted to measured means than Lerwick 77 or '79 values			measured monthly mean daily value - KWh/m^2	a = .188 b = .6 Page's '79 values for Bracknell	a = .17 b = .65 Day's values for Eskdalemuir & Lerwick respectively	a = .16 b = .87 Page's '77 values for Lerwick	a = .09 b = .07 - retaining Page's '77 Lerwick value for 'b' & reducing 'a'	a = .189 b = .774 - Page's '79 values for Lerwick - cf results to '77 value results

TABLE 17 - Dunstaffnage 56°28'N: Comparison of Predicted H Values to Measured Mean H Using Various a & b Constants

	n/No	H/Ho	H	Predicted H = Ho (a + (b x ^{n}/No))			kWh/m^2
J	.14	.42	0.41	0.27	0.29	0.30	
F	.24	.34	0.97	1.05	1.07	1.16	
M	.27	.44	2.23	1.98	2.00	2.18	
A	.31	.47	3.76	3.40	3.39	3.71	
M	.35	.43	4.37	4.73	3.69	5.15	
J	.29	.47	5.35	4.71	4.72	5.14	
J	.22	.41	4.36	3.76	3.85	4.16	
A	.26	.39	3.44	3.36	3.43	3.72	
S	.24	.42	2.50	2.19	2.23	2.41	
O	.20	.40	1.37	1.13	1.17	1.25	
N	.16	.37	0.59	0.47	0.49	0.52	
D	.09	.35	0.32	0.21	0.24	0.25	
Values in this mountainous west coast area with high rainfaill are closer to Lerwick than Eskdalemuir.				a = .16 b = .87 Page's '77 values for Lerwick	a = .189 b = .774 Page's '79 values for Lerwick	a = .19 b = .90 derived from Page's '79 Lerwick values	

TABLE 18.1 Summary Comparison of Values for Monthly Mean Daily Irradiation on a South Facing Vertical Surface For Various Scottish Locations

	Esk'muir	Gl'gw	Abdn	Dun'ge	Stwy	Lerwick	
J	0.75	1.12	0.86	1.17	0.80	0.31	kWh/m^2
	2.70	4.03	3.09	4.23	2.89	1.13	MJ/m^2
F	1.85	1.85	1.70	1.50	1.81	1.11	
	6.69	6.68	6.13	5.39	6.50	4.00	
M	2.11	2.38	2.24	2.52	2.40	1.89	
	7.60	8.58	8.06	9.08	8.65	6.81	
A	2.41	2.63	2.49	2.92	2.95	2.75	
	8.68	9.48	8.95	10.52	10.61	9.91	
M	2.35	2.73	2.45	2.72	3.07	2.32	
	8.45	9.82	8.84	9.78	11.06	8.34	
J	2.59	2.67	2.72	2.98	2.90	2.89	
	9.31	9.61	9.81	10.72	10.45	10.41	
J	2.34	2.44	2.20	2.44	2.38	2.53	
	8.43	8.79	7.91	8.78	8.58	9.09	
A	2.30	2.46	2.44	2.34	2.49	2.44	
	8.28	8.86	8.79	8.43	8.95	8.77	
S	2.08	2.22	2.19	2.38	2.23	1.83	
	7.49	7.99	7.88	8.56	8.02	6.60	
O	1.80	1.89	1.92	2.01	1.74	1.49	
	6.48	6.81	6.91	7.25	6.25	5.36	
N	1.45	1.28	1.30	1.32	1.05	0.59	
	5.20	4.60	4.69	4.75	3.79	2.11	
D	0.97	1.00	0.92	0.91	0.56	0.23	
	3.48	3.62	3.32	3.27	2.01	0.84	

TABLE 19.1 Ratio of Monthly Mean Daily Diffuse To Global Irradiation On The Horizontal For Various Scottish Locations

	Esk'muir	Gl'gw	Abdn	Dun'ge	Stwy	Lerwick
J	.74	.61	.69	.61	.72	.81
F	.61	.58	.64	.69	.65	.65
M	.62	.57	.60	.58	.59	.63
A	.60	.54	.59	.54	.53	.61
M	.62	.53	.61	.59	.52	.60
J	.58	.53	.54	.54	.56	.59
J	.62	.56	.63	.61	.64	.67
A	.63	.55	.60	.63	.61	.63
S	.63	.56	.61	.60	.61	.64
O	.63	.58	.62	.62	.66	.67
N	.63	.60	.67	.66	.68	.73
D	.65	.60	.66	.69	.75	.84

Appendix 2: Comparative Data: Housing Configurations A-D Prior to Computer Analysis - Refer to Table 1

It is interesting to compare certain data from Table 1.2 in this appendix with recommended guidelines for US locations in the 30^{o}-45^{o}N latitude range by Mazria[1].

With respect to direct gain he recommends in cold climates, average winter temperatures - 6.7^{o}C to -1.1^{o}C, a net glazed area of 0.19 to 0.38 m^2 per m^2 of floor area; and in temperate climates, average winter temperatures 1.67^{o}C to 7.2^{o}C, a net glazed area of 0.11 to 0.25 m^2 per m^2 of floor area. It will be seen from item 18, applicable to living areas, that all configurations comply with Mazria's larger areas for cold climates, while ratios applicable to sleeping rooms, fall within Mazria's range for temperate climates.

With respect to indirect/isolated gain from greenhouse collectors, he recommends for cold climates 0.65 to 1.5 m^2 double glazing per m^2 floor area, and for temperate climates 0.33 to 0.9 m^2. It will be seen from items 13-15 that all configurations fall below both these standards when considering total floor area; but when considering living and sleeping areas only, configurations 'A', 'B' and 'C' fall within the range for temperate climates, and when considering living spaces only, all configurations fall within Mazria's limits for both cold and temperate climates. Configuration 'C' gives the highest results, but this proposal has a proportionately higher area of glazing due to its dual east-west orientation. In contrast configuration 'D' has a relatively low glazed collection area in relation to volume, but this will be offset by the inherent energy saving in having only one exposed facade in an intermediate terrace situation.

With respect to rock storage in passive systems Mazria recommends a range of 1.50 to 3.00 m^3 storage per m^2 collector glazing for active systems in cold and temperate climates; whereas a range of .75 - 1.5 is considered suitable for cold climates in passive systems. Configurations 'A', 'C' and 'D' all use active assistance for delivery to the stores and all except 'C' fall well outside Mazria's limits, to compensate for lower solar radiation levels.

Mazria's guidelines are derived from extensive computer validations of passive solar projects in the US, where both latitude range and general climatic conditions are significantly different compared to the UK. However, there is a practical cost-planning limit to areas of collector glazing and storage capacity in relation to floor areas, which are fixed by housing standards. ESP analysis will assist both in validating such general sizing as dictated by public housing constraints in relation to a practical annual solar contribution to the space heating load for Scottish locations, and in verifying optimum proportions for key collection/storage elements. These results can then be usefully compared to the US equivalents.

When comparing the economic efficiency of the various configurations by the ratios of external surface area to volume enclosed, for intermediate terrace situations it will be seen from item 20 that the two north/south examples 'A' and 'B' are very similar, as are the two east/west examples 'C' and 'D', the latter being more efficient. This may go some way to off-setting the higher costs which will be associated with higher glazed areas in the case of 'C', and more complex solar systems in both cases. Item 22, the volume compactness ratio for all wall and roof surfaces, shows all configurations to be very similar; but when only exposed walls and roofs are considered, 'C' performs better than 'B' in an intermediate terrace situation, and a ground floor intermediate terrace flat in example 'A' reaches a very high value - the surface area of a hemisphere enclosing an equivalent volume being 2.88 times as great as the exposed surface area.

Finally it is interesting that if density is expressed as persons per metre run of frontage, the configurations become progressively more efficient from 'A' to 'D', giving another guide to the relative housing densities at which passive solar design is possible.

Reference

[1] Mazria, E. - 'Passive Solar Energy Book', Rodale Press (USA) 1979. Ch.IV pp.66-262

TABLE 1.2: Comparative Data - Housing Configurations A-D Prior to Computer Analysis

	Description of Item	A		B		C		D	
1.	Category of house	1 person, medium frontage, tenement flat - 2/3 storey		4 person, medium frontage 2 storey terraced house		4 person, narrow frontage 2 storey terraced house		6 person, wide frontage 2 storey single aspect house	
2.	Orientation	NORTH - SOUTH		NORTH - SOUTH		EAST - WEST		EAST OR WEST	
3.	Frontage width x depth (inside shell) f_1 x d_1	5.8 x 6.3 m		Grd 5.7 x 7.5 m 1st 5.7 x 6.6 m		Grd 3.6 x 13.2 m 1st 3.6 x 10.2 m		Grd 7.2 x 7.2 m 1st 7.2 x 7.2 m	
4.	Total floor area - a_n (minimum housing standard)	36.5 m^2 (33 m^2)		79.2 m^2 (79.0)		79.2 m^2 (79.0)		96.72 m^2 (97.0)	
5.	a Living & bedroom floor area b Living room floor area)	17.34 m^2 (9.9 m^2)		46.17 m^2 (20.52 m^2)		45.36 m^2 (23.76 m^2)		62.1 m^2 (21.6 m^2)	
6.	Sunspace glazing	7.2 m^2		16.0 m^2		24.8 m^2		3.6 m^2	
7.	Roof system glazing	3.6 m^2 x 4 flats		——		14.4 m^2		11.5 m^2	
8.	Total collector area (6 + 7)	10.8 m^2		16.0 m^2		39.2 m^2		15.1 m^2	
9.	Volume rockstore (ratio 9:7)	6.43 m^3 (0.45)		——		10.08 m^3 (0.70)		5.75 m^3 (0.50)	
10.	Volume mezzacaust (ratio 10:6)	——		3.0 m^3 (0.19)		3.0 m^3 (0.12)		——	
11.	Heated volume	77.6 m^3		173.2 m^3		179.3 m^3		243.4 m^3	
12.	Collector area: colume - 8:11	0.14 m^2/m^3		0.09 m^2/m^3		0.22 m^2/m^3		0.06 m^2/m^3	
13.	Ratio 6: 4 & (8:4)	0.20 (0.30)		0.20 (0.20)		0.31 (0.50)		0.04 (0.16)	
14.	Ratio 6: 5a & (8:5a)	0.42 (0.62)		0.35 (0.35)		0.55 (0.86)		0.06 (0.24)	
15.	Ratio 6: 5b & (8:5b)	0.73 (1.09)		0.78 (0.78)		1.04 (1.65)		0.17 (0.70)	
16.	Insolated windows - living	3.40 m^2 (south)		5.80 m^2 (south)		9.64 m^2 (east/west)		3.40 m^2 (east or west)	
17.	Insolated windows - sleeping	1.20 m^2 (south)		3.50 m^2 (south)		3.00 m^2 (east/west)		5.40 m^2 (east or west)	
18.	Ratio 16: 5b & (16:5a-5b)	0.34 (0.17)		0.28 (0.15)		0.40 (0.15)		0.20 (0.13)	
19.	Area of hemisphere enclosing 11	75.68 m^2		129.55 m^2		131.5 m^2		151.33 m^2	
20.	Exposed surface to volume m^2/m^3	inter ter.	end ter.	inter ter.	end ter.	inter ter.	end ter.	inter ter.	end ter.
	excluding party walls &) ground including ground floor) first	0.80 1.00	1.00 1.26	0.82	1.05	0.72	1.08	0.73	0.90
21.	Volume compactness ratio 1) grd 19:exposed surfaces) 1st	2.88 0.81	1.66 0.59	1.15	0.82	1.43	0.80	1.21	0.91
22.	Volume compactness ratio 2) grd 19:all wall/roof surfaces) 1st	0.70 0.52		0.64		0.56		0.51 m^2/m^2	
23.	Density - persons/metre frontage	0.27 p/m		0.66 p/m		1.00 p/m		1.60 p/m	

Appendix 3: Climate Data for ESP Analysis, ABCLM

Table 1	Direct (Normal Incidence) Irradiation: Monthly Mean Daily Values for ABCLM Compared to Kew and Lerwick
Table 2	Diffuse Irradiation on a Horizontal Surface: Monthly Mean Daily Values and Maximum Hourly Values for ABCLM Compared to Eskdalemuir
Table 3	External Air Temperatures: Comparison between ABCLM and Aberdeen
Table 4	Monthly Degree Days to a Base of 15.5°C: Comparison between ABCLM and Aberdeen
Table 5	External Air Temperatures: Comparison of ABCLM Monthly Lowest and Highest Values to Long-term Data for Aberdeen Area
Table 6	Windspeed: Comparison between ABCLM and Aberdeen Area
Table 7	Wind Direction: ABCLM Compared to Aberdeen and Glasgow
Table 8	Relative Humidity: ABCLM Compared to Aberdeen and Glasgow

TABLE 1.3: DIRECT (normal incidence) IRRADIATION: monthly mean daily values for ABCLM compared to Kew and Lerwick. Unit kWh/m²

	KEW '51-75		LERWICK '81			ABCLM		
	mean daily	daily range	mean daily	high day	W/m² max hourly	mean daily	high day	W/m² max hourly
JAN	0.524	1.02/0.36	0.166	1.35	342	0.362	3.70	720
FEB	0.909	1.62/0.36	0.615	3.07	633	0.672	6.25	870
MAR	1.570	2.34/0.68	1.310	5.75	733	1.190	7.16	813
APR	2.114	3.15/1.10	2.654	9.96	914	2.582	10.41	943
MAY	2.789	3.83/2.06	1.818	6.89	777	2.892	9.97	885
JUNE	3.288	4.89/2.15	1.848	9.17	863	3.216	9.79	889
JULY	2.599	3.41/1.53	1.658	7.65	897	2.671	10.15	803
AUG	2.422	3.30/1.45	1.240	3.74	781	2.505	8.54	812
SEP	2.143	2.78/1.06	1.189	3.73	790	2.129	5.78	716
OCT	1.445	2.45/0.96	0.994	3.58	617	1.245	4.63	760
NOV	0.766	1.32/0.31	0.261	1.36	371	0.734	3.76	589
DEC	0.502	0.82/0.10	0.088	0.87	396	0.468	2.14	451

TABLE 2.3: DIFFUSE IRRADIATION ON A HORIZONTAL SURFACE: Monthly mean daily values and maximum hourly values for ABCLM compared to Eskdalemuir. Unit kWh/m²

	ESKDALEMUIR				ABCLM			
	daily values: mean	max	min	W/m² max hourly*	daily mean	high day	low day	W/m² max hourly
JAN	0.280	0.82	0.02	150	0.238	0.48	0.07	108
FEB	0.683	1.56	0.06	266	0.559	1.42	0.21	243
MAR	1.250	2.44	0.26	333	1.120	2.18	0.41	325
APR	1.936	3.22	0.34	403	2.020	2.83	1.01	383
MAY	2.397	4.24	0.59	486	2.446	3.17	1.32	399
JUNE	2.717	4.23	0.83	505	2.630	3.39	1.55	418
JULY	2.514	4.46	0.51	464	2.635	3.39	1.23	427
AUG	2.161	3.72	0.35	428	2.109	2.77	1.22	413
SEP	1.450	2.66	0.20	339	1.414	2.14	0.70	326
OCT	0.814	1.69	0.14	258	0.785	1.32	0.19	220
NOV	0.414	1.16	0.04	172	0.374	0.80	0.12	157
DEC	0.225	0.53	0.02	108	0.182	0.39	0.06	94

*note - based on 99% occurrence

TABLE 3.3: External Air Temperatures: Comparison between ABCLM and Aberdeen - Averages of daily max, min and mean (½ (max + min)) °C

	ABERDEEN (DYCE) 1931-60			ABCLM		
	Max	Min	Mean	Max	Min	Mean
JAN	4.9	-0.2	2.4	3.95	0.47	2.4
FEB	5.7	0.0	2.8	5.26	0.05	2.8
MAR	7.8	1.1	4.5	6.86	2.30	4.5
APR	10.5	2.8	6.7	10.78	3.40	7.0
MAY	12.8	5.2	9.0	12.30	5.05	8.8
JUNE	16.0	8.0	12.0	15.67	5.97	12.0
JULY	17.6	10.1	14.0	18.24	9.58	14.2
AUG	17.6	9.6	13.6	17.97	9.00	13.6
SEP	15.5	7.8	11.7	15.30	8.66	11.7
OCT	12.0	5.6	8.8	11.86	5.98	8.8
NOV	8.3	2.9	5.6	7.78	3.06	5.6
DEC	5.9	1.4	3.7	5.46	1.59	3.7

TABLE 4.3: Monthly Degree Days to a base of 15.5°C: Comparison between ABCLM and Aberdeen

	ABERDEEN	ABCLM
JAN	406	406.74
FEB	356	356.43
MAR	341	341.21
APR	267	255.90
MAY	195	208.38
JUNE	105	116.13
JULY	46	67.78
AUG	59	79.28
SEP	114	117.36
OCT	208	207.08
NOV	297	297.98
DEC	366	365.29
ANNUAL	2760	2819.56
SEASONAL	2550 exc J,J & A	2556.37 exc J,J & A

TABLE 5.3: External Air Temperatures: Comparison of ABCLM monthly lowest and highest values to long-term data for Aberdeen area

	ABERDEEN (measured) °C highest and lowest temps - various locations around Aberdeen				ABCLM °C representative climate year			
	Lowest	Highest	Mean Low	Mean High	Lowest	Highest	Low-Day	High-Day
JAN	-18.8/-9.4	13.3	-9.4/-5.0	11.1/10.0	-7.6	10.0	-6.2/-0.8	10/5.0
FEB	-20.5/-8.9	16.1/14.4	-7.8/-4.4	11.67/11.1	-6.7	9.0	-5.7/2.4	9/5.7
MAR	-17.8/-8.3	20.5/20.0	-6.1/-2.8	14.4/13.3	-3.7	12.8	-2.1/0.6	12.8/7.7
APR	-6.7/-2.2	21.7/20.6	-3.3/-0.6	17.8/15.6	-3.2	17.8	-0.9/5.0	15.8/8.6
MAY	-3.9/0.6	23.3/21.1	-0.6/+0.6	19.4/17.8	0.1	21.8	2.7/8.6	21.8/6.0
JUNE	0.0/1.7	28.9/25.6	2.8/3.3	22.8/21.1	3.0	21.3	5.4/9.9	21.3/10.1
JULY	0.0/1.7	28.3/26.7	3.9/5.6	23.3/22.2	4.4	24.3	8.6/14.6	24.3/14.0
AUG	0.0/333	27.2/26.7	2.8/5.0	22.2/21.1	4.2	22.8	4.8/13.1	19.8/13.7
SEP	-2.8/0.0	25.6/25.0	1.7/3.9	21.1/20	3.6	20.3	3.6/12.1	20.3/12.1
OCT	-6.1/-1.1	22.8/20.0	-1.7/1.1	17.8/16.7	-1.7	17.8	2.8/6.9	17.8/10.0
NOV	-11.7/-5.0	16.7/14.4	-5.6/-1.7	13.3/12.2	-3.5	11.0	-3.5/1.7	11.0/9.6
DEC	-13.3/-7.8	15.6/13.3	-7.2/-3.3	11.7/10.6	-5.0	10.5	-5.0/-1.9	10.5/5.9

TABLE 6.3: Windspeed: Comparison between ABCLM and Aberdeen Area

Month	mean wind speed m/s		% frequency of wind speed 5.4 m/s (12 mph)		% frequency of windspeed 5.4 m/s (highest)	(11-17 m/s)
	ABCLM	ABDN	ABCLM	ABDN	ABCLM	ABDN
JAN	4.9 m/s	4.94 m/s	61.3%	59.6%	38.7% (15.0 m/s)	40.4% (3.7%)
FEB	5.2	5.11	57.1	59.1	42.9 (12.4)	40.9 (4.2%)
MAR	5.5	5.50	48.4	52.4	51.6 (11.5)	47.6 (5.1%)
APR	4.7	4.78	63.3	62.4	36.7 (11.5)	37.6 (2.8%)
MAY	4.5	4.63	67.7	63.0	32.3 (10.1)	37.0 (2.7%)
JUNE	4.3	4.30	70.0	69.2	30.0 (14.6)	30.8 (1.3%)
JULY	4.0	3.96	74.2	71.8	25.8 (12.5)	28.2 (1.0%)
AUG	3.8	3.82	77.4	73.7	22.6 (9.3)	26.3 (1.0%)
SEP	4.1	4.18	73.3	71.7	26.7 (10.5)	28.9 (1.9%)
OCT	4.7	4.67	64.5	64.5	35.5 (16.3)	35.5 (3.6%)
NOV	5.0	4.67	63.3	64.1	36.7 (15.5)	35.9 (3.1%)
DEC	4.8	5.02	61.3	58.0	38.7 (16.6)	42.0 (3.6%)

TABLE 7.3: WIND DIRECTION: ABCLM Compared to Aberdeen and Glasgow

Month		0-90°	90-180°	180-270°	270-360°	light/ variable	
JAN	ABCLM	16.1%	32.5%	32.5%	19.4%	-	100%
	ABDN	5.35	17.15	23.4	29.3	24.8	100%
	GL	14.3	10.45	32.05	12.9	30.3	
FEB	ABCLM	28.5	25.0	32.0	14.5	-	
	ABDN	5.5	20.7	25.15	27.55	21.2	
	GL	18.85	12.85	28.2	13.3	26.8	
MAR	ABCLM	3.2	6.4	67.8	22.6	-	
	ABDN	4.8	24.05	27.85	24.9	18.4	
	GL	29.1	22.65	23.05	8.6	20.9	
APR	ABCLM	20.0	13.3	50.0	16.7	-	
	ABDN	9.45	23.5	20.15	22.7	24.2	
	GL	20.0	12.2	30.85	16.05	20.9	
MAY	ABCLM	3.2	25.8	51.6	19.4	-	
	ABDN	8.8	23.8	16.25	25.65	25.5	
	GL	23.4	11.35	30.5	16.95	17.8	
JUN	ABCLM	10.0	36.7	46.7	6.6	-	
	ABDN	5.75	23.7	22.7	23.25	24.6	
	GL	18.45	9.6	36.65	18.2	17.1	
JUL	ABCLM	3.2	32.3	58.1	6.4	-	
	ABDN	8.2	16.2	18.3	29.3	28.0	
	GL	12.25	9.15	35.0	19.35	24.25	
AUG	ABCLM	32.25	32.25	29.0	6.5	-	
	ABDN	7.25	15.85	18.05	28.55	30.3	
	GL	15.65	6.3	35.0	19.3	23.75	
SEP	ABCLM	3.3	46.7	46.7	3.3	-	
	ABDN	5.15	18.6	25.0	21.85	29.4	
	GL	16.45	12.05	32.4	13.0	26.1	
OCT	ABCLM	6.45	25.8	61.3	6.45	-	
	ABDN	4.6	21.55	31.1	17.45	25.3	
	GL	16.85	10.25	39.4	11.6	21.9	
NOV	ABCLM	3.3	26.7	50.0	20.0	-	
	ABDN	6.0	17.5	25.3	25.1	26.1	
	GL	18.5	13.2	27.35	11.05	29.9	
DEC	ABCLM	35.5	3.2	28.7	22.6	-	
	ABDN	2.55	13.9	28.65	31.0	33.9	
	GL	14.9	13.0	33.3	9.5	29.3	

Note: ESPCLM analysis designates orientation to all winds including light/variable, which it is reasonable to assume are mainly in the southern sector - hence higher % frequencies for ABCLM in these sectors.

TABLE 8.3: RELATIVE HUMIDITY: ABCLM (1) Compared to Aberdeen (2) and Glasgow (3) means - Time GMT

		000	0300	0600	0900	1200	1500	1800	2100	Daily mean
JAN	(1)	84.6	84.0	84.1	84.5	84.4	83.8	85.0	85.0	84.4
	(2)	86	86	86	86	82	82	85	86	84.9
	(3)		88		89		82		87	86.5
FEB		85.6	85.8	86.0	85.0	80.0	75.0	81.7	84.6	83.0
		85	86	86	85	79	78	84	85	83.5
			87		86		76		84	83.2
MAR		82.8	83.3	83.5	82.4	77.9	75.6	79.2	82.3	81.0
		85	86	86	81	73	73	79	84	83.5
			87		84		71		83	81.2
APR		86.6	88.0	88.4	78.5	71.2	68.0	72.1	83.2	79.6
		87	88	88	77	69	69	75	85	79.8
			87		78		65		80	
MAY		86.1	91.3	88.3	76.4	68.3	63.1	65.9	79.3	77.5
		88	89	87	75	70	70	74	84	79.6
			88		75		63		77	76.2
JUN		80.1	89.2	85.4	66.8	56.3	*54.9	57.3	67.7	69.6
		87	89	86	73	69	68	73	82	78.4
			89		75		64		77	76.2
JUL		84.6	90.1	88.2	73.2	63.7	+61.0	63.3	76.5	75.0
		88	89	88	76	70	70	75	84	80.0
			89		79		68		81	79.2
AUG		83.7	86.3	88.4	71.8	57.5	°52.8	60.4	76.0	72.1
		90	91	90	79	72	72	78	87	80.0
			91		82		70		84	81.8
SEP		88.7	90.3	91.2	86.4	74.8	68.9	76.5	84.9	82.8
		89	90	91	82	72	73	81	87	83.1
			91		85		72		86	83.5
OCT		88.0	89.5	90.7	88.8	75.4	72.2	81.1	86.8	84.0
		88	89	89	86	78	77	85	88	85
			90		87		77		87	85.2
NOV		85.5	85.1	84.4	85.4	81.9	80.8	85.5	85.4	84.2
		86	86	87	86	80	81	85	88	84.9
			89		89		81		88	86.8
DEC		83.8	84.6	85.6	87.0	84.6	82.1	84.2	84.4	84.6
		86	86	86	86	83	83	86	86	85.2
			88		89		84		87	87.0

Note: Low values for ABCLM are not outwith representative range eg
June: * 16.7% frequency 50-60 RH compared to 29% 70-70 RH
+22.9% frequency 60-70 RH compared to 25.5% 70-80 RH
°10.8% frequency 50-60 RH compared to 25.1% 60-70 RH

Appendix 3: Climate Data for ESP Analysis, ABCLM

Typical Interrogative Output from ABCLM using Programme ESPCLM

```
DAY  7 OF MONTH 12

HR D.B. TEMP. DR.N. RAD. DF.H. RAD.
      DEG.C       W/M!2       W/M!2

 1         6.80          0.          0.
 2         6.60          0.          0.
 3         6.20          0.          0.
 4         5.40          0.          0.
 5         5.20          0.          0.
 6         5.50          0.          0.
 7         5.90          0.          0.
 8         6.00          0.          2.
 9         6.20          0.         10.
10         6.20          0.         11.
11         6.70          0.          5.
12         6.50          0.         29.
13         6.80          0.         31.
14         6.90          0.         23.
15         6.90          5.          3.
16         6.70          0.          0.
17         6.70          0.          0.
18         6.50          0.          0.
19         6.50          0.          0.
20         5.50          0.          0.
21         4.40          0.          0.
22         4.50          0.          0.
23         3.70          0.          0.
24         3.30          0.          0.


CONTINUE WITH ANOTHER DAY ?
>0
```

WD. VEL. M/S	WD. DIR. DEG.F.N.	REL. H. %
6.70	240.	840.00
7.20	250.	840.00
7.20	250.	860.00
6.20	240.	860.00
6.20	240.	870.00
6.70	240.	870.00
6.20	240.	860.00
6.20	240.	860.00
8.80	250.	870.00
7.70	240.	880.00
7.20	280.	890.00
8.30	290.	890.00
8.30	300.	890.00
7.70	320.	880.00
7.20	340.	870.00
9.80	340.	860.00
7.20	350.	840.00
6.70	350.	840.00
9.30	360.	840.00
8.80	360.	880.00
7.20	360.	820.00
7.20	360.	760.00
6.20	360.	800.00
7.20	360.	790.00

```
CLIMATE ANALYSIS: ABERDE
              PERIOD:  1. 1.
DRY BULB TEMPERATURE

 D   M   T              MIN     T
 1,  1   1-24           3.2 @24
 2,  1   1-24           2.8 @24
 3,  1   1-24           1.9 @24
 4,  1   1-24          -2.2 @24
 5,  1   1-24          -3.0 @ 1
 6,  1   1-24          -6.8 @24
 7,  1   1-24          -6.2 @ 5
 8,  1   1-24          -7.6 @ 6
 9,  1   1-24           0.0 @ 8
10,  1   1-24           0.6 @ 4
11,  1   1-24           5.2 @21
12,  1   1-24           2.5 @ 7
13,  1   1-24           5.0 @ 5
14,  1   1-24           4.9 @22
15,  1   1-24           1.5 @21
16,  1   1-24           2.8 @ 1
17,  1   1-24           2.8 @19
18,  1   1-24           2.7 @ 6
19,  1   1-24           4.0 @ 1
20,  1   1-24           3.8 @24
21,  1   1-24           2.1 @ 6
22,  1   1-24           2.0 @18
23,  1   1-24          -0.3 @22
24,  1   1-24          -0.3 @ 1
25,  1   1-24           0.6 @ 8
26,  1   1-24           0.9 @ 1
27,  1   1-24          -3.5 @18
28,  1   1-24          -1.5 @ 1
29,  1   1-24           0.1 @24
30,  1   1-24          -2.6 @16
31,  1   1-24          -0.8 @ 1
```

```
N                                 :   57.2N    2.1W  :  1983
 1 TO 31.  1.24
 DEG C

            MAX       1              MEAN
         5.5 @ 1           4.4
         5.4 @14           3.8
         3.6 @12           3.0
         3.7 @14           1.1
         0.8 @12          -0.6
        -1.2 @ 4          -2.6
        -0.8 @13          -4.0
         1.8 @19          -2.1
         2.7 @13           1.2
         6.8 @24           3.9
         8.1 @13           6.8
         6.9 @22           5.0
        10.0 @17           7.5
         8.6 @ 1           7.2
         4.5 @15           3.0
         4.5 @12           3.9
         4.3 @11           3.7
         3.8 @15           3.2
         6.5 @16           5.6
         6.9 @14           5.3
         4.0 @12           3.2
         2.8 @ 4           2.4
         1.9 @ 1           0.7
         1.9 @17           0.7
         1.5 @ 1           1.0
         5.2 @11           3.3
         2.4 @ 1          -1.3
         3.1 @16           2.0
         3.3 @ 5           2.6
        -0.8 @ 1          -1.8
         6.8 @24           1.6
```

```
CLIMATE ANALYSIS: ABERDEEN
           PERIOD:  1. 1. 1
MONTH  1           : DRY BULB

   HR       MIN       MAX
    1      -4.7       8.6
    2      -5.2       8.5
    3      -5.7       8.5
    4      -6.4       8.4
    5      -6.8       8.1
    6      -7.6       8.1
    7      -6.7       7.9
    8      -6.8       7.7
    9      -7.4       7.9
   10      -5.7       7.8
   11      -2.2       8.0
   12      -1.7       8.1
   13      -1.8       8.5
   14      -1.8       9.4
   15      -1.9       9.6
   16       2.6       9.8
   17      -3.3      10.0
   18      -3.9       9.4
   19      -4.4       9.1
   20      -4.7       9.0
   21      -5.0       9.1
   22      -5.7       9.1
   23      -6.2       8.9
   24      -6.8       8.8

MIN        -7.6       7.7
MAX        -1.7      10.0
MEAN       -4.8       8.7
```

```
                                        :  57.2N   2.1W : 1983
TO 31. 1.24
TEMPERATURE        DEG C

MEAN     DEV.N         LODAY     HIDAY
 2.0       3.2          -4.7       6.8
 2.0       3.1          -5.0       6.2
 1.9       3.1          -5.4       5.7
 1.9       3.1          -5.7       5.2
 1.9       3.2          -6.2       5.0
 1.9       3.2          -5.4       5.0
 2.0       3.0          -4.5       5.4
 1.9       3.2          -5.4       5.5
 1.9       3.2          -5.2       5.7
 2.2       3.1          -5.4       6.2
 2.7       2.7          -2.2       6.4
 3.0       2.7          -1.6       7.4
 3.2       2.8          -0.8       8.4
 3.3       2.9          -0.8       9.4
 3.2       2.9          -1.3       9.6
 2.9       3.0          -2.6       9.8
 2.7       3.0          -3.3      10.0
 2.5       3.0          -3.9       9.4
 2.5       3.1          -4.4       9.1
 2.3       3.1          -4.4       9.0
 2.3       3.0          -4.3       9.1
 2.3       3.1          -4.4       9.1
 2.2       3.2          -4.5       8.9
 2.2       3.4          -4.5       8.8

 1.9
 3.3
 2.4                    -4.0       7.5
```

```
CLIMATE ANALYSIS: ABERDE
              PERIOD:  1. 1.
DIRECT NORMAL RADIATION

 D   M   T            MIN      T
 1,  1   1-24         0.0  @  1
 2,  1   1-24         0.0  @  1
 3,  1   1-24         0.0  @  1
 4,  1   1-24         0.0  @  1
 5,  1   1-24         0.0  @  1
 6,  1   1-24         0.0  @  1
 7,  1   1-24         0.0  @  1
 8,  1   1-24         0.0  @  1
 9,  1   1-24         0.0  @  1
10,  1   1-24         0.0  @  1
11,  1   1-24         0.0  @  1
12,  1   1-24         0.0  @  1
13,  1   1-24         0.0  @  1
14,  1   1-24         0.0  @  1
15,  1   1-24         0.0  @  1
16,  1   1-24         0.0  @  1
17,  1   1-24         0.0  @  1
18,  1   1-24         0.0  @  1
19,  1   1-24         0.0  @  1
20,  1   1-24         0.0  @  1
21,  1   1-24         0.0  @  1
22,  1   1-24         0.0  @  1
23,  1   1-24         0.0  @  1
24,  1   1-24         0.0  @  1
25,  1   1-24         0.0  @  1
26,  1   1-24         0.0  @  1
27,  1   1-24         0.0  @  1
28,  1   1-24         0.0  @  1
29,  1   1-24         0.0  @  1
30,  1   1-24         0.0  @  1
31,  1   1-24         0.0  @  1
```

```
EN                                 :   57.2N    2.1W  :  1983
 1  TO  31.  1.24
 W/M2

              MAX        1             MEAN
       560.0 @11         110.8
       190.0 @10          31.3
       398.0 @14          47.4
       720.0 @12         154.0
       105.0 @15           4.5
         1.0 @ 9           0.3
         0.0 @ 1           0.0
         0.0 @ 1           0.0
         0.0 @ 1           0.0
         0.0 @ 1           0.0
         0.0 @ 1           0.0
         0.0 @ 1           0.0
         0.0 @ 1           0.0
         0.0 @ 1           0.0
       102.0 @15           6.8
         1.0 @11           0.1
         0.0 @ 1           0.0
         0.0 @ 1           0.0
         0.0 @ 1           0.0
         0.0 @ 1           0.0
         0.0 @ 1           0.0
         0.0 @ 1           0.0
         0.0 @ 1           0.0
         0.0 @ 1           0.0
         0.0 @ 1           0.0
         1.0 @11           0.3
       584.0 @10         111.6
         0.0 @ 1           0.0
         0.0 @ 1           0.0
         0.0 @ 1           0.0
         0.0 @ 1           0.0
```

```
CLIMATE ANALYSIS: ABERDEE
            PERIOD:  1. 1.
MONTH   1          :'DIRECT

   HR        MIN        MAX
    1        0.0        0.0
    2        0.0        0.0
    3        0.0        0.0
    4        0.0        0.0
    5        0.0        0.0
    6        0.0        0.0
    7        0.0        0.0
    8        0.0        0.0
    9        0.0      421.0
   10        0.0      584.0
   11        0.0      672.0
   12        0.0      720.0
   13        0.0      703.0
   14        0.0      611.0
   15        0.0      351.0
   16        0.0      109.0
   17        0.0        0.0
   18        0.0        0.0
   19        0.0        0.0
   20        0.0        0.0
   21        0.0        0.0
   22        0.0        0.0
   23        0.0        0.0
   24        0.0        0.0

MIN          0.0        0.0
MAX          0.0      720.0
MEAN         0.0      173.8
```

```
EN                                   :  57.2N   2.1W : 1983
 1 TO 31. 1.84
 NORMAL RADIATION  W/M2

    MEAN    DEV.N        LODAY    HIDAY
     0.0      0.0          0.0      0.0
     0.0      0.0          0.0      0.0
     0.0      0.0          0.0      0.0
     0.0      0.0          0.0      0.0
     0.0      0.0          0.0      0.0
     0.0      0.0          0.0      0.0
     0.0      0.0          0.0      0.0
     0.0      0.0          0.0      0.0
    23.3     78.8          0.0    119.0
    57.7    151.1          0.0    521.0
    68.4    175.1          0.0    672.0
    64.2    174.9          0.0    720.0
    55.6    157.7          0.0    703.0
    52.5    140.0          0.0    611.0
    34.5     83.5          0.0    351.0
     5.5     21.7          0.0      0.0
     0.0      0.0          0.0      0.0
     0.0      0.0          0.0      0.0
     0.0      0.0          0.0      0.0
     0.0      0.0          0.0      0.0
     0.0      0.0          0.0      0.0
     0.0      0.0          0.0      0.0
     0.0      0.0          0.0      0.0
     0.0      0.0          0.0      0.0

     0.0
    68.4
    15.1                   0.0    154.0
```

Appendix 4 - ESP Energy Analysis: Simulation Output, Housing Configurations A, B, C & D

Table 1 Housing Configuration A: Ground Floor Intermediate Terrace Flat - Monthly Space Heating Load Breakdown from Mult-zone ESP Simulation

Table 2 Housing Configuration A: Ground Floor Intermediate Terrace Flat - Estimate of Heat Loss per Unit Heated Volume

Table 3 Housing Configuration A: Ground Floor Intermediate Terrace Flat - South Glazing Collection Efficiency, Sunporch and Bedroom

Table 4 Housing Configuration A: Ground Floor Intermediate Terrace Flat - Solar Radiation on South Facade and Surplus Available for Rock-bed Store

Table 5 Housing Configuration A: Ground Floor Flat - Added Solar Load from Rock Store

Table 6 Housing Configuration A: Ground Floor Intermediate Terrace Flat - Heat Plant Loads and Internal Temperatures in Zones 1,2 & 3

Table 7 Housing Configuration A: Mean Daily Losses from Stairwell Collector and Rock-bed Store, September - May

Table 8 Housing Configuration A: Stairwell Collector/ Rock-bed Store System. High-day Loads and Charging Periods, 10-20 K Temperature Range

Table 9 Housing Configuration A: Analysis of Suitable Rock Store Volume to Collector Area Ratios in Relation to Net Monthly Mean High-day Solar Loads, September - May

Table 10 Housing Configuration C: East/West Mezzacaust Analysis, Using Solar Surplus from Sunporches and Living/Kitchen

Table 11 Housing Configuration C: Roof Collector/Rock Store Analysis, Using Modified Rock Store Volume of 3.6 m^3

TABLE 1.4: Housing Configuration A: Ground Floor Intermediate Terrace Flat - Monthly Space Heating Load Breakdown from Multi-zone ESP Simulation kWh ($z1$ upper temp. limit $24^{o}C$ & $z2$-4 14-20 ^{o}C)

	Gross Energy Load Qg	Surplus Energy Load Qs	Net Energy Load Q	Heating Plant Load Qhtg	HTG %	Gross Casual Load Qg.cas	Useful Casual Load Q.cas	CAS %	Gross Solar Load Qg.sol	Useful Solar Load Q sol	SOL %
2	418.86	0.0	418.86	248.05	59%	162.58	162.58	39%	8.18	8.18	2%
3	165.89	0.0	165.89	142.34	86%	20.71	20.71	12%	2.84	2.84	2%
4	215.65	0.0	215.65	203.45	94%	0.0	0.0	0%	12.27	12.27	6%
J	800.40	0.0	800.40	593.84	74%	183.29	183.29	23%	23.29	23.29	3%
2	340.87	0.0	340.87	180.57	53%	147.28	147.28	43%	13.00	13.00	4%
3	136.85	0.0	136.85	109.93	80%	18.70	18.70	14%	8.22	8.22	6%
4	184.07	0.0	184.07	171.38	93%	0.0	0.0	0%	12.87	34.09	7%
F	661.79	0.0	661.79	461.88	70%	165.98	165.98	25%	34.09	34.09	5%
2	306.06	0.0	306.06	118.41	39%	161.62	161.62	53%	26.03	26.03	8%
3	121.20	0.0	121.20	78.19	65%	20.71	20.71	17%	22.31	22.31	18%
4	169.67	0.0	169.67	149.34	38%	0.0	0.0	0%	20.33	20.33	12%
M	596.93	0.0	596.93	345.94	58%	182.33	182.33	30.5%	68.67	68.67	11.5%
2	244.01	17.67	226.34	34.96	15.5%	159.48	159.48	70.5%	49.56	31.90	14%
3	96.87	8.48	88.19	32.23	36%	20.04	20.04	23%	44.40	35.92	41%
4	113.74	0.0	113.74	75.87	67%	0.0	0.0	0%	37.87	37.87	33%
A	454.42	26.5	428.27	143.06	33.5%	179.52	179.52	42%	131.81	105.69	245%
2	226.06	46.11	179.95	6.24	3.5%	162.34	162.34	90%	57.88	11.37	6.5%
3	91.12	9.36	81.76	9.84	12%	20.71	20.71	25%	60.57	51.21	63%
4	88.89	0.0	88.89	26.90	30%	0.0	0.0	0%	61.95	61.95	70%
M	406.07	55.47	350.60	42.98	12%	183.05	183.05	52%	180.40	124.53	36%
2	214.71	110.66	104.05	0.0	0%	156.84	104.05	100%	57.87	0.0	0%
3	82.49	22.29	60.20	0.35	0.5%	20.04	20.04	33.5%	62.10	39.81	66%
4	73.06	0.0	73.06	0.67	1%	0.0	0.0	0%	72.39	72.39	99%
J	370.26	132.95	237.31	1.02	0.5%	176.88	124.09	52.5%	192.36	112.20	47%
½Y	3290	214.5	3075	1589	52%	1071	1018	33%	631	469	15%
2	220.81	163.04	57.77	0.0	0%	164.98	57.77	100%	55.84	0.0	0%
3	82.79	40.53	42.26	0.0	0%	20.71	20.71	49%	62.08	21.55	51%
4	76.20	5.08	71.12	0.0	0%	0.0	0.0	0%	76.20	71.12	100%
J	379.80	208.65	171.15	0.0	0%	185.49	78.48	46%	194.12	92.67	54%
2	215.39	120.42	94.97	0.0	0%	161.62	94.97	100%	53.77	0.0	0%
3	76.37	39.51	36.86	0.03	0%	20.71	20.71	56%	55.63	16.12	44%
4	61.38	0.24	61.14	0.11	0%	0.0	0.0	0%	61.27	61.14	100%
A	353.14	160.17	192.97	0.14	0%	182.33	115.68	60%	170.67	77.26	40%
2	200.26	65.13	135.13	0.09	0%	156.88	135.13	100%	42.99	0.0	0%
3	70.17	14.96	55.21	1.58	0%	20.04	20.04	36.5%	48.55	33.59	61%
4	58.70	0.0	58.70	9.33	16%	0.0	0.0	0%	49.36	49.36	84%
S	329.13	80.09	249.04	11.80	5%	176.92	155.17	62%	140.40	82.95	33%
2	222.95	15.07	207.88	31.49	15%	164.94	164.94	79%	26.51	11.45	6%
3	76.68	2.33	74.35	23.53	32%	20.71	20.71	28%	32.43	30.11	40%
4	96.85	0.0	96.85	65.67	68%	0.0	0.0	0%	31.18	31.18	32%
O	396.48	17.40	379.08	120.69	32%	185.65	185.65	49%	90.12	72.74	19%
2	294.67	0.0	294.67	121.54	41%	156.84	156.84	58%	16.29	16.29	6%
3	105.33	0.0	105.33	74.49	71%	20.04	20.04	19%	10.40	10.40	10%
4	156.47	0.0	156.47	138.09	88%	0.0	0.0	0%	18.39	18.39	12%
N	556.47	0.0	556.47	334.52	60%	176.88	176.88	32%	45.08	45.08	8%
2	379.38	0.0	379.38	205.28	54%	164.29	164.29	43%	9.72	9.72	3%
3	141.81	0.0	141.81	117.69	83%	20.71	20.71	15%	3.50	3.50	2%
4	193.08	0.0	193.08	178.65	93%	0.0	0.0	0%	14.43	14.43	7%
D	714.27	0.0	714.27	501.62	70%	185.00	185.00	26%	27.65	27.65	4%
½Y	2729	466.5	2263	968	45%	1092	896	37%	668	398	18%
YR	6019	681	5338	2557	48%	2163	1914	36%	1299	867	16%

APPENDIX 4, TABLE 2: Housing Configuration A: Ground Floor Intermediate Terrace Flat - Estimate of Heat Loss per Unit Heated Volume, 77.6 m^3

Month	Degree Days ABCLM	Q Net Space Htg Energy Load kWh	U sp Specific Heat Loss W/K	U vol Vol. Heat Loss W/m^3K
JAN	406.74	800.40	81.99	1.06
FEB	356.43	661.79	77.36	1.00
MAR	341.21	596.93	72.89	0.94
APR	255.90	428.27	69.73	0.90
MAY	208.38	350.60	70.10	0.90
JUN	116.13	237.31	85.14	1.10
JUL	67.68	171.15	105.21	1.36
AUG	79.28	192.97	101.41	1.31
SEP	117.36	249.04	88.42	1.14
OCT	207.08	379.08	76.27	0.98
NOV	297.98	556.47	77.81	1.00
DEC	365.29	714.27	81.47	1.05
YEAR	2819.56	5338	78.88	1.02

APPENDIX 4, TABLE 3: Housing Configuration A: Ground Floor Intermediate Terrace Flat - South Glazing Collection Efficiency, Sunporch & Bedroom

1. Predicted Annual Global Solar Irradiation on a South Facing Vertical Surface HGVS	741.22 kWh/m^2
2. Predicted Annual Useful Solar Load Z 2-4, Qsol (simulation ESPSIM, control strategies a/c, z1 upper limit 24°C, z 2-4 14-20°C)	867.00 kWh (113.30 kWh/m^2 gross collection surface)
3. Predicted Annual Gross Solar Load z 1 & 3, Qg. sol	2,161 kWh
4. Predicted Annual Useful Solar Load z 1 & 3, Q sol	1,454 kWh
5. Predicted Useful Proportion Solar Load on South Face	.673
6. Cross Area of Glazed Collecting Surface	7.65 m^2
7. Net Area of Glazed Collecting Surface	7.00 m^2
8. South Glazing Collection Efficiency = (2)/(5) x (1) x (7)	0.25 or 25%

TABLE 4.4: Housing Configuration A: Ground Floor Intermediate Terrace Flat - Solar Radiation on South Facade and Surplus Available For Rock-bed Store kWh

		J	F	M	A	M	J	J	A	S	O	N	D	YEAR
z1 & z2	Qg.sol.z1	16.31	58.10	121.31	210.03	244.31	237.12	232.35	225.18	198.37	123.24	63.81	17.96	1748
	Qs.sol.z1	-	-	12.0	75.0	87.0	90.0	100.0	113.0	69.0	23.0	-	-	569
	Qs.sol.z2	-	-	-	18.0	46.5	58.0	56.0	54.0	42.5	15.0	-	-	290
	Qs.sol. z1+z2	-	-	12.0	93.0	133.5	148.0	156.0	167.0	111.5	38.0	-	-	859
z1	Qg.sol/m^2	2.59	9.22	19.25	33.33	38.77	37.63	36.88	35.74	31.48	19.56	10.13	2.85	277
	Qsol/m^2	2.59	9.22	17.35	21.43	24.97	23.35	21.00	17.81	20.53	15.91	10.13	2.85	187
z3	Qg.sol/m^2	2.10	6.08	16.52	32.89	44.87	46.00	45.98	41.20	35.96	24.02	7.70	2.59	306
	Qsol/m^2	2.10	6.08	16.52	26.60	37.93	29.49	15.96	11.96	24.38	22.30	7.70	2.59	204
z1 & z3	Qg.sol/m^2	2.35	7.65	17.89	33.11	41.82	41.82	41.43	38.47	33.72	21.79	8.92	2.72	292
	Qsol/m^2	2.35	7.65	17.62	24.02	31.45	26.42	18.48	14.89	22.46	29.11	8.92	2.72	196
	Qsol/m^2	surplus to rock st		17.89	29.97	37.52	no demand for surplus			26.93	20.93	surplus to rock st		215
	Qsol	19.15	66.32	131.62	170.95	208.56	186.93	153.90	128.33	162.28	130.35	74.21	21.46	1454
	Qsol	surplus to rock st		143.62	245.95	285.02	no demand for surplus			219.40	153.35	surplus to rock st		1698
	% Qsol	100%	100%	91.6%	67.2%	68.4%	62.5%	52.3%	45.7%	65.7%	83.7%	100%	100%	67.3%
	% Qsol	surplus to rock st		100%	90.5%	93.5%	no demand for surplus			89%	96%	surplus to rock st		78.6%

TABLE 5.4: Housing Configuration A: Ground Floor Flat - Added Solar Load from Rock Store, kWh

	Qg.sol stair-wall collector per flat	Qg.sol stair-roof collector per flat	Qs.sol z1+z2	Qg.sol to rock st per flat	Q sol to rock st per flat 25% eff.	Q htg z2-4	Q htg z2	Q htg z2-4	Q htg z2	New HTG %	Extra SOL %
						without additional load from rock st		with additional load from rock st			
S	48.35	100.85	111.5	260.70	65.18	11.8	0.0	0.0	0.0	0%	4%
O	30.82	61.93	38.0	130.75	32.69	120.69	31.49	88.0	0.0	23%	9%
N	17.08	33.10	-	50.18	12.55	334.52	121.54	321.97	108.99	58%	2%
D	13.28	20.11	-	33.39	8.35	501.61	205.28	493.26	196.93	69%	1%
J	8.62	16.27	-	24.89	6.22	593.84	248.05	587.62	241.83	73.5%	0.5%
F	16.71	33.07	-	49.78	12.44	461.88	180.57	449.44	168.13	68%	2%
M	31.98	66.28	12.0	110.26	27.57	345.94	118.41	318.37	90.84	53%	5%
A	54.38	120.20	93.0	267.58	66.90	143.06	34.96	76.16	0.0	18%	15.5%
M	62.11	144.91	133.5	340.52	85.13	42.98	6.24	0.0	0.0	0%	12%
TOT	283	597	388	1268	317	2556	947	2335	807	44%	4%

APPENDIX 4
TABLE 6

Housing Configuration A: Ground Floor Intermediate Terrace Flat - Heat Plant Loads and Internal Temperatures in zones 1,2 & 3

	Qhtg	Heating Plant Load		No upper temperature limit			Upper temp limits: z1:24°C z2:20°C
	zone	Max kW	Mean kW	Max ti °C	Min ti °C	Mean ti °C	Mean ti °C
J	1 sunp.	-	-	20.0	3.5	9.3	9.2
	2 living	1.0	0.4	18.6	14.0	16.7	16.7
	3 bedrom	0.5	0.2	16.2	14.0	14.5	14.5
F	1	-	-	34.3	5.6	11.4	10.9
	2	0.8	0.3	18.5	14.0	16.7	16.7
	3	0.4	0.2	16.0	14.0	14.6	14.6
M	1	-	-	35.0	6.3	13.6	13.3
	2	0.7	0.2	20.5	14.0	16.9	16.9
	3	0.4	0.1	18.5	14.0	14.7	14.7
A	1	-	-	49.7	8.4	18.4	16.5
	2	0.5	0.05	27.5	14.0	18.5	17.8
	3	0.3	0.05	25.7	14.0	16.0	16.0
M	1	-	-	46.2	11.6	21.0	18.5
	2	0.2	0.01	27.8	14.5	20.2	18.6
	3	0.15	0.01	24.9	14.0	17.4	17.2
J	1	-	-	52.9	15.5	26.4	20.6
	2	-	-	34.4	18.0	25.0	19.5
	3	-	-	33.5	15.0	21.2	18.8
J	1	-	-	52.3	17.2	25.8	21.4
	2	-	-	34.6	19.3	25.1	19.8
	3	-	-	31.5	17.5	22.0	19.5
A	1	-	-	51.0	14.6	24.6	20.5
	2	-	-	31.0	17.3	23.5	19.6
	3	-	-	29.5	15.4	20.7	18.9
S	1	-	-	46.0	12.4	21.9	19.5
	2	0.1	-	27.8	15.6	21.2	19.1
	3	0.1	-	27.3	14.8	18.6	17.9
O	1	-	-	39.9	9.1	16.7	16.0
	2	0.5	0.05	24.8	14.0	18.4	17.9
	3	0.3	0.05	22.0	14.0	15.8	15.7
N	1	-	-	28.3	8.2	12.6	12.6
	2	0.7	0.2	19.4	14.0	16.9	16.9
	3	0.3	0.1	17.1	14.0	14.6	14.6
D	1	-	-	16.6	4.7	10.1	10.1
	2	0.9	0.3	18.9	14.0	16.8	16.8
	3	0.4	0.2	16.0	14.0	14.5	14.5

APPENDIX 4 TABLE 7: Housing Configuration A: Mean Daily Losses from Stairwell Collector and Rock Bed Store, September - May

Roof Collector (mean ti 40^{o}C)	U a W/m^{2}K	Surf. Area m^{2}	Δt K	Loss W
North Roof	.266	2.88	32	24.51
North Int. Wall	.289	3.60	30	31.21
Internal Floor	.274	7.20	30	59.18
E/W Gable Walls	.707	9.26	25	163.67
South Glazing	3.400	8.40	32	913.92
				1192.49 W
(1) Loss over 10 hr mean daily insolation period				11.92 kWh
South Stair Wall (mean ti 40^{o}C)				
Opaque Wall	.620	6.48	30	120.53
Double Glazing	3.400	6.48	32	705.02
				825.55 W
(2) Loss over 10 hr mean daily insolation period				8.26 kWh
Flow/Return Ducts (mean ti 35^{o}C)	.364	13.74	25	125.03 W
(3) Loss over 10 hr mean daily insolation period				1.25 kWh
Rock Store (mean t 20^{o}C)				
North Wall	.376	2.25	15	12.69
South Wall	.456	2.25	10	10.26
E/W Walls	.312	6.35	5	9.91
Floor	.460	7.14	15	49.24
Roof	.524	7.14	10	37.43
				119.58 W
(4) Loss over 24 hr storage period				2.87 kWh

Mean Daily Loss from System (1+2+3+4) = 24.30 kWh

Mean High-Day Load from Collector & Sunporches = 76.68 kWh

Therefore, Mean Daily Losses= 31.7% Mean Daily Load

TABLE 8.4: Housing Configuration A: Stairwell Collector/Rock Store System, High-day Loads and Charging Periods, 10-20K Temperature Range

Month	Mean Daily Load - ESPSIM kWh	High-day Factor ABCLM	High-day Load kWh	Sunshine Hours	Gross Hourly Load kWh	Net× Hourly Load kWh	Temp. Diff. Δt K	Energy to Charge Rock St* kWh	Time to Charge Rock St hrs
SEP	34.76	2.7	93.85	11	8.53	5.83	10 15	31.94 47.91	5.5 8.2
OCT	16.87	3.7	62.42	9.5	6.57	4.49	10 15	31.94 47.91	7.1 10.7
NOV	6.69	5.12	34.25	7.5	4.57	3.12	10 15	31.94 47.91	10.2 15.4
DEC	4.31	4.57	19.70	6	3.28	2.24	10	31.94	14.2
JAN	3.21	10.2	32.74	6.5	5.04	3.44	10 15	31.94 47.91	9.3 13.9
FEB	7.11	9.3	66.12	9.25	7.15	4.88	10 15	31.94 47.91	6.5 9.8
MAR	14.23	6.02	85.66	11.25	7.61	5.20	10 15	31.94 47.91	6.1 9.2
APR	35.68	4.03	143.79	13.75	10.46	7.14	15 20	47.91 63.88	6.7 8.9
MAY	43.94	3.45	151.59	14.25	10.64	7.27	15 20	47.91 63.88	6.6 8.8

NOTES	Density	Volume	Mass	Specific Heat	Thermal Capacity	
*Rock Bed Store ×Loss Factor = 0.683	1987 kg/m^3	6.43 m^3	12776.4 kg	0.25 wh/kgK 900 J kgK	3.194 kwh/K 11.499 MJ/K	

TABLE 9.4: Housing Configuration A: Analysis of Suitable Rock Store Volume to Collector Area Ratios in Relation to Net Monthly Mean High-day Solar Loads, Sep - May

	Net monthly mean high-day hourly solar absorption within south facing collector kWh/m^2				Time to charge rock store for various store volume: collector area ratios & differential temperatures of 10 & 15 K - hrs							
					(a) ratio .35		(b) ratio .33		(c) ratio .4		(d) ratio .3	
	(a) 42° slope: vert 1.5: 1	(b) 42° slope: vert 1: 1	(c) 42° slope	(d) vertical	Δt 10	Δt 15	Δt 10	Δt 15	Δt 10	Δt 15	Δt 10	Δt 15
S	.23	.22	.26	.18	7.6	11.3	7.5	11.2	7.7	11.5	8.3	12.5
O	.22	.215	.25	.18	7.9	11.9	7.6	11.4	8.0	12.0	8.3	12.5
N	.22	.21	.24	.18	7.9	11.9	7.8	11.7	8.3	12.4	8.3	12.5
D	.15	.155	.16	.15	11.6	17.4	10.6	15.9	12.4	18.6	10.0	15.0
J	.24	.23	.26	.20	7.3	10.9	7.1	10.7	7.7	11.5	7.5	11.25
F	.34	.33	.38	.28	5.1	7.7	5.0	7.5	5.2	7.8	5.4	8.0
M	.32	.31	.36	.26	5.4	8.2	5.3	8.0	5.5	8.3	5.8	8.7
A	.33	.31	.37	.25	5.3	7.9	5.3	8.0	5.4	8.1	6.0	9.0
M	.31	.295	.36	.23	5.6	8.4	5.6	8.3	5.5	0.3	6.5	9.8
	Thermal capacity store per m^2 collector area				.174 kWh/K		.164 kWh/K		.199 kWh/K		.149 kWh/K	

APPENDIX 4, TABLE 10: Housing Configuration C: East/West Mezzacaust Analysis

Using Solar Surplus from Sunporches and Living/Kitchen

		Monthly Surplus kWh	High-day factor	High day surplus kWh	sunshine hours hrs	gross hourly kWh	net hourly kWh	Energy to raise 7.5K kWh	Time to charge hrs
Sep	W	114.85	2.7	10.34	11.0	0.94	0.70	5.175	7.4
"	E	68.22	"	6.14	"	0.56	0.42	"	12.3
Oct	W	30.11	3.7	3.59	9.5	0.38	0.28	"	18.5
"	E	55.74	"	6.65	"	0.70	0.53	"	9.9
Nov	E	36.34	5.12	6.20	7.5	0.83	0.62	"	8.3
Dec	E	28.39	4.57	4.18	6.0	0.69	0.52	"	10.0
Jan	E	24.16	10.2	7.95	6.5	0.81	0.61	"	8.5
Feb	E	26.46	9.3	8.79	9.25	0.95	0.71	"	7.3
Mar	E	46.01	6.02	8.93	11.25	0.79	0.60	"	8.7
Apr	W	132.06	4.03	17.14	13.75	1.29	0.97	"	5.3
	E	91.20	"	12.25	"	0.89	0.67	"	7.7
May	W	235.0	3.45	26.15	14.25	1.84	1.38	"	3.8
	E	105.29	"	11.71	"	0.82	0.62	"	8.3

APPENDIX 4, TABLE 11: Housing Configuration C: Roof Collector/Rock Store Analysis

Using Modified Rock Store Volume of 3.6 m^3, 1.8 kWh/K Thermal Capacity

Unit kWh	Monthly Load	High-day Factor	High day Load	sunshine hrs	gross hourly	net hourly	Energy to raise 10&15K	Time to charge
Sep	38.70	2.7	34.84	11.0	3.17	2.12 $.15/m^2$	17.88 26.82	8.4 12.7
Oct	216.7	3.7	25.86	9.5	2.72	1.82 $.13/m^2$	17.88 26.82	9.8 14.7
Nov	109.2	5.12	18.66	7.5	2.49	1.67 $.12/m^2$	17.88 26.82	10.7 16.0
Dec	65.7	4.51	9.68	6.0	1.61	1.08 $.08/m^2$	17.88 26.82	16.6 24.8
Jan	70.7	10.2	23.22	6.5	3.57	2.39 $.17/m^2$	17.88 26.82	7.5 11.2
Feb	125.7	9.3	41.72	9.25	4.51	3.02 $.21/m^2$	17.88 26.82	5.9 8.9
Mar	255.5	6.02	49.62	11.25	4.41	2.95 $.20/m^2$	17.88 26.82	6.0 9.1
Apr	498.0	4.03	66.92	13.25	4.87	3.26 $.23/m^2$	17.88 26.82	5.5 8.2
May	641.1	3.45	71.35	14.25	5.01	3.35 $.23/m^2$	17.88 26.82	5.3 8.0

Appendix 4: ESP Energy Analysis

Typical Synoptic Output for Housing Configuration A:

January Loads in Non-solar First Floor Gable-end Flat

```
Interrogation output
for result-set  1 Period considered from day  1 of month  1 at hour  1
                                           to day 31 of month  1 at hour 24
Simulation time-step =   1/hour
Output time-step increment =   1 (results not averaged)
Energy requirement information (KWhrs)


Zone Heating Energy Cooling Energy

  1          389.62          0.00
  2          140.46          0.00
  3          248.31          0.00

All          778.39          0.00

Do you require a causal energy breakdown
for any zone ?
>Y
```

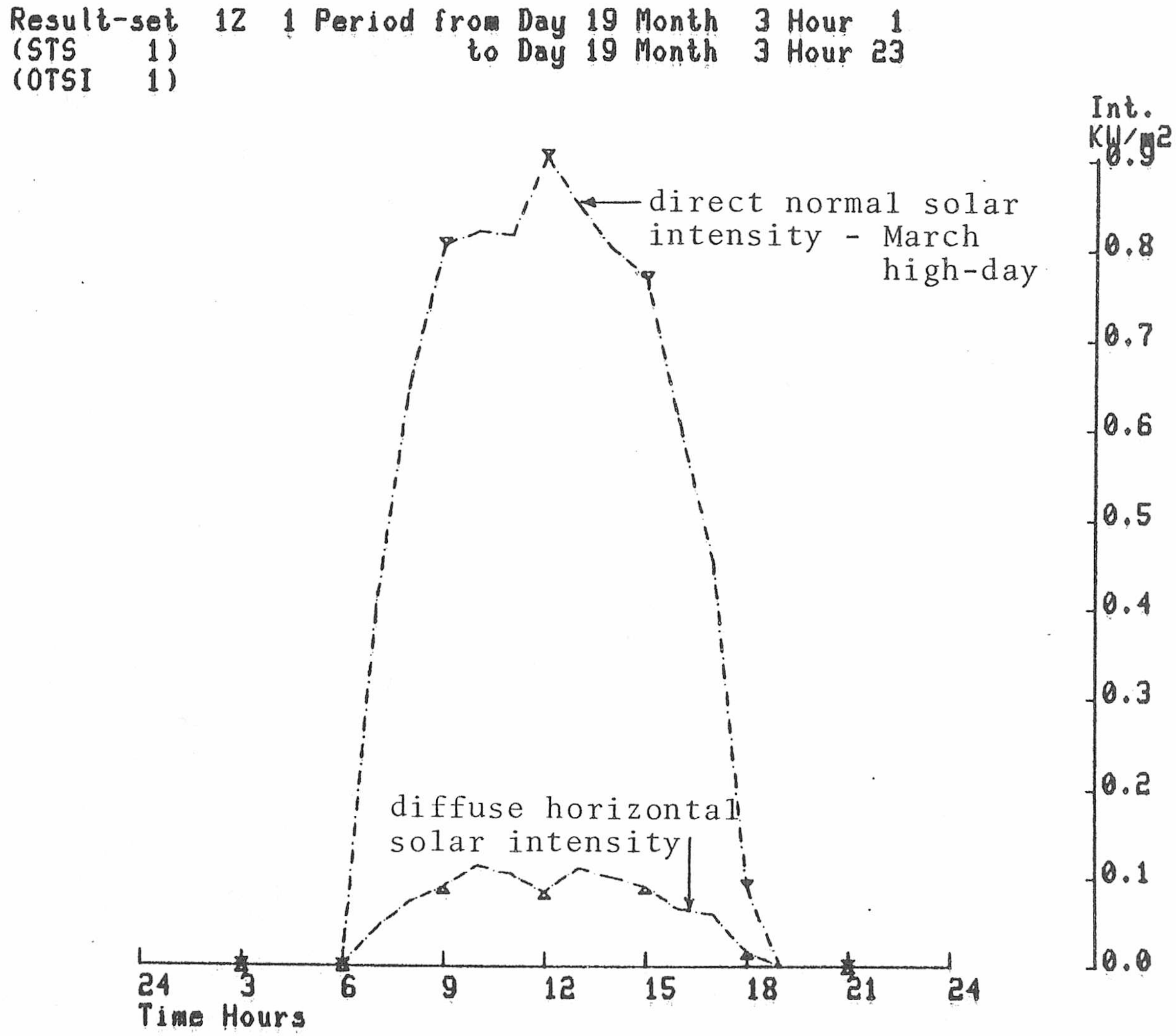
```
Interrogation output
for result-set  1 Period considered from day  1 of month  1 at hour  1
                                      to day 31 of month  1 at hour 24
Simulation time-step =    1/hour
Output time-step increment =   1 (results not averaged)

Heating capacity information (KW)

Zone Maximum value Minimum value Mean value
  1        1.335          0.000      0.524
     @ 7, 1, 9.00  @14, 1, 1.00
  2        0.462          0.000      0.189
     @ 8, 1, 6.00  @ 1, 1,12.00
  3        0.721          0.068      0.334
     @ 7, 1, 9.00  @14, 1, 2.00
All        2.318          0.147      1.046
     @ 7, 1, 9.00  @14, 1, 2.00

Do you require a causal load breakdown
for any zone ?
>N
```

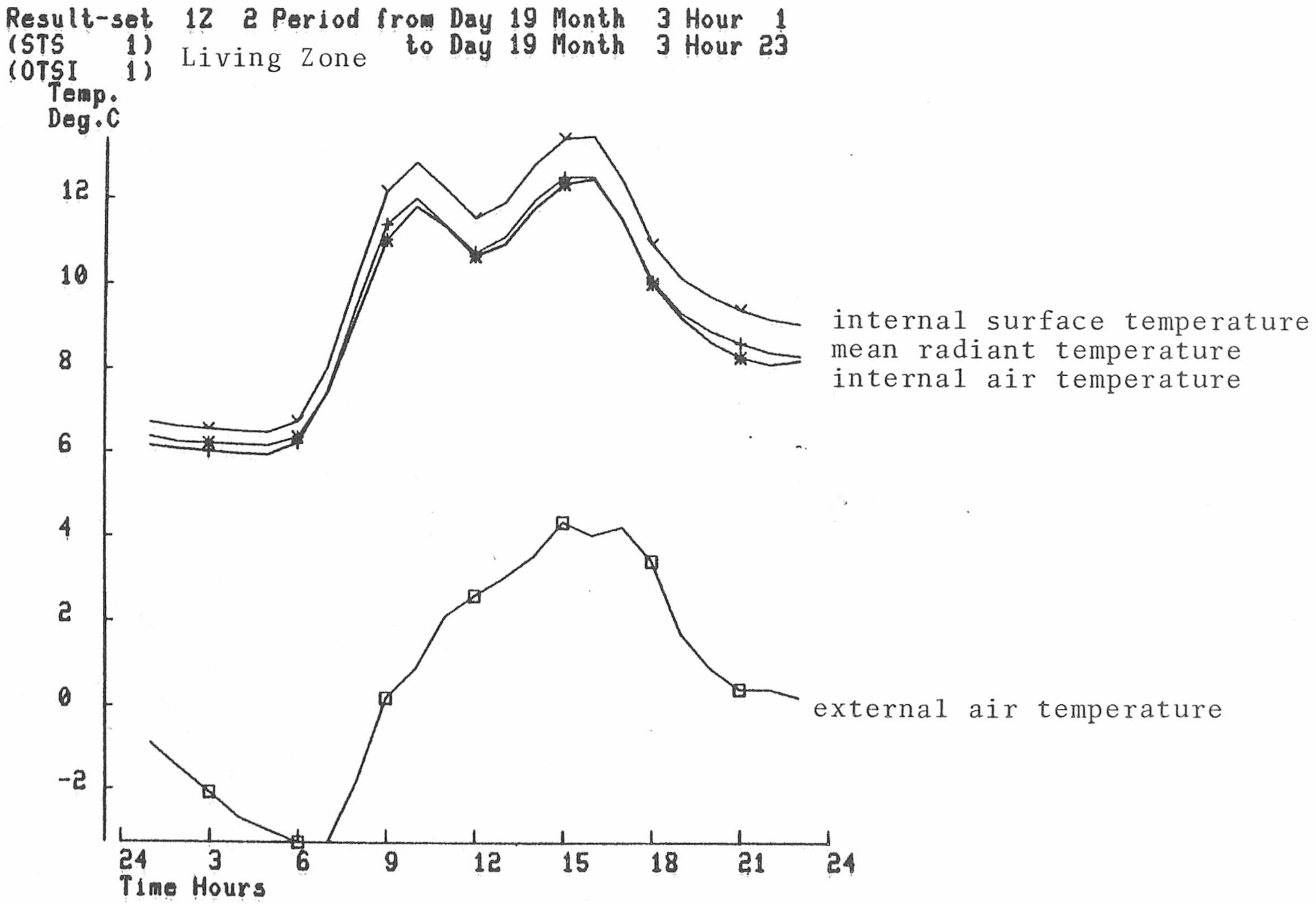
```
----------------------------------------------------------------------------

Causal energy breakdown (KWhrs) for zone 2
Period from Day  1 Month  1 Hour  1
         to Day 31 Month  1 Hour 24

Simulation time-step =   1/hour
Output time-step increment =   1 (results not averaged)


                                         Gain        Loss

Infiltration air load                    0.00      -85.67
Ventilation air load                     0.00        0.00
Window conduction: external              0.00      -41.50
Window conduction: internal              0.00        0.00
Door conduction: external                0.00        0.00
Door conduction: internal                0.00        0.00
Air point solar load                     0.42        0.00
Convective casual load                  20.71        0.00
Opaque surface convection                3.53      -38.74
Plant capacity                         140.46        0.00

Totals                                 165.12     -165.91
```

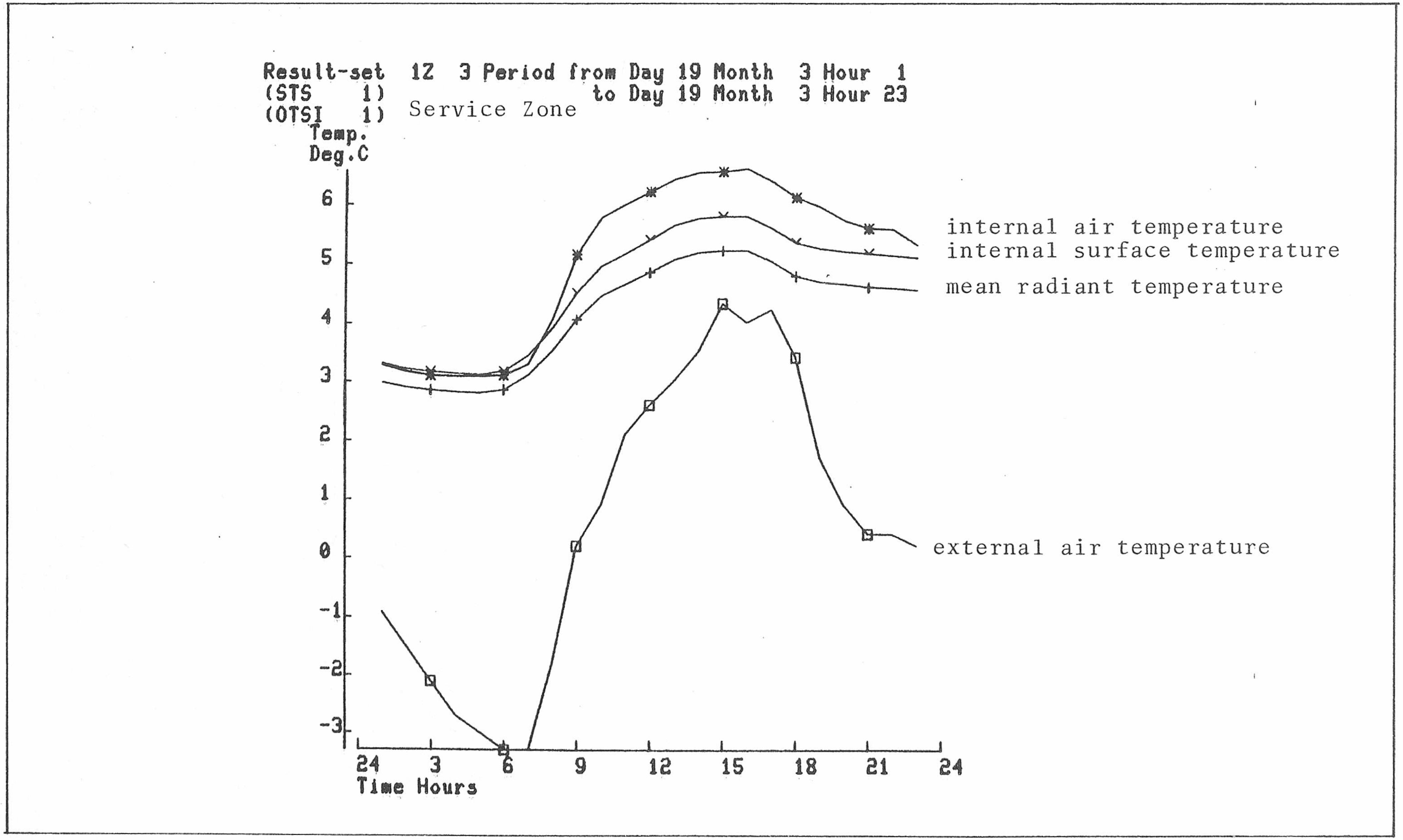
Appendix 4: ESP Energy Analysis

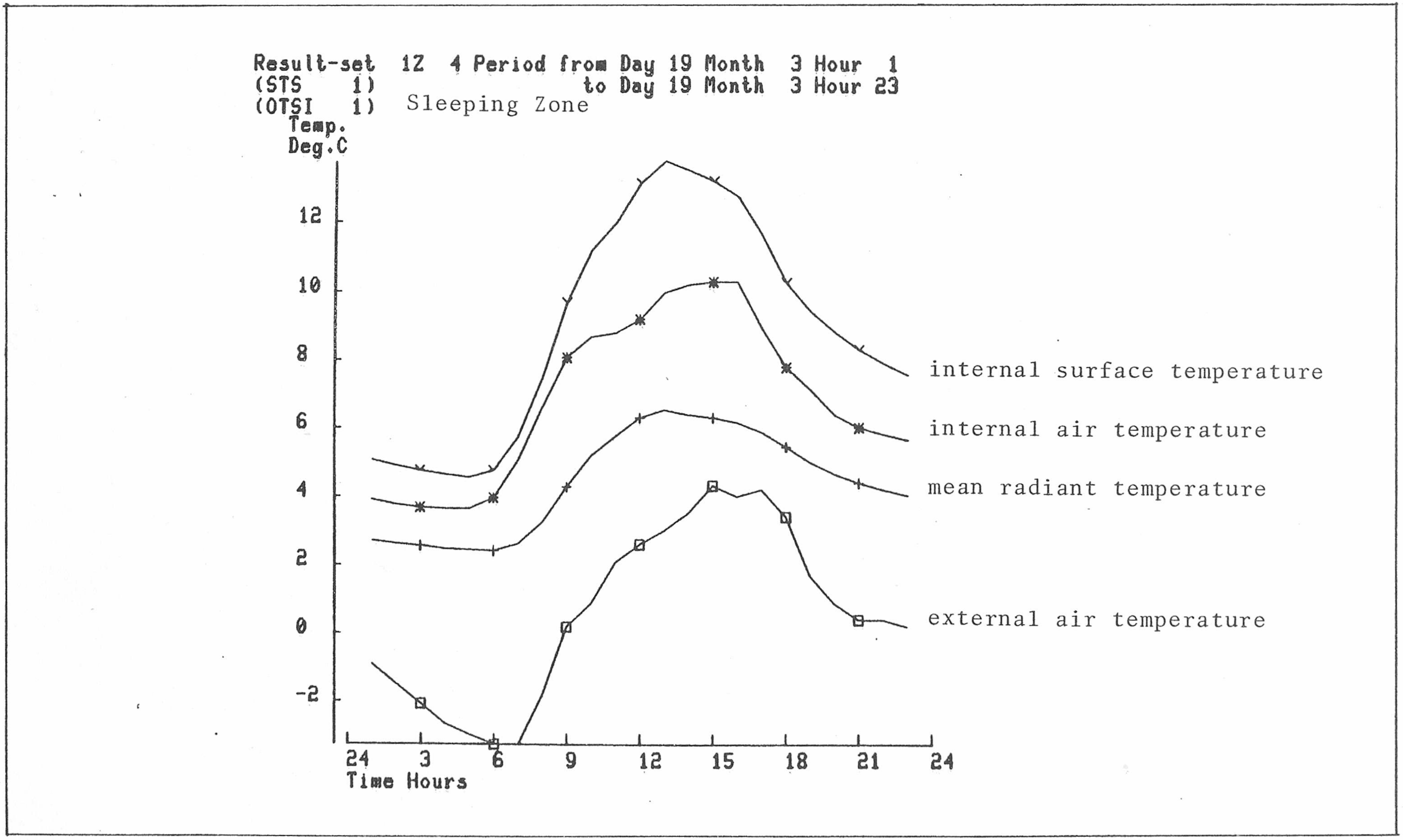
Typical Graphical Output for Housing Configuration B:

Free-floating Simulation without Heating Plant
on a March High Insolation Day


Result-set 12 1 Period from Day 19 Month 3 Hour 1
(STS 1) to Day 19 Month 3 Hour 23
(OTSI 1)
Int.
KW/m2
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
direct normal solar intensity - March high-day
diffuse horizontal solar intensity
24
3
6
9
12
15
18
21
24
Time Hours


Result-set 12 2 Period from Day 19 Month 3 Hour 1
(STS 1) to Day 19 Month 3 Hour 23
(OTSI 1) Living Zone
Temp.
Deg.C
12
10
8
6
4
2
0
-2
24
3
6
9
12
15
18
21
24
Time Hours
internal surface temperature
mean radiant temperature
internal air temperature
external air temperature

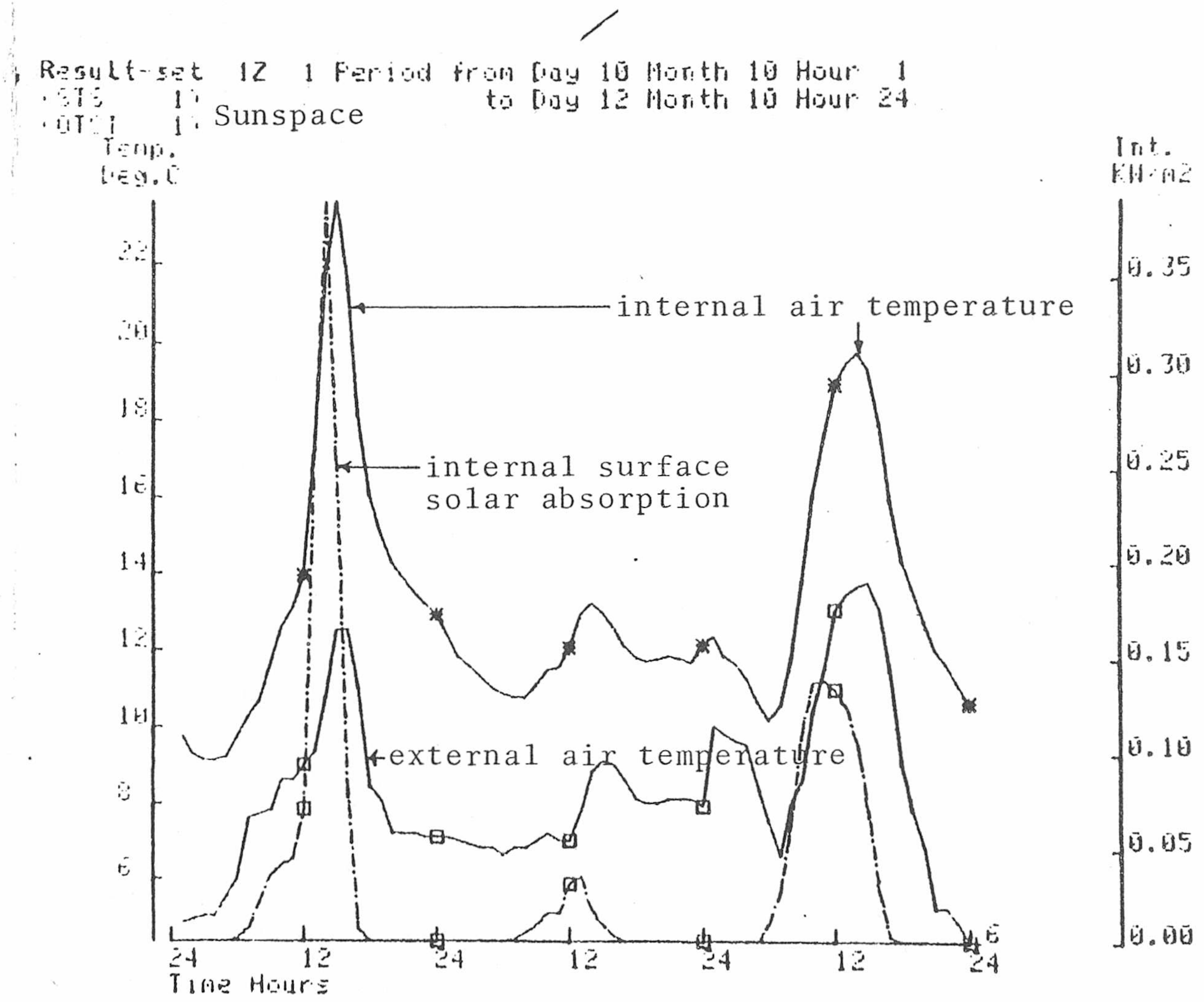

Result-set 12 3 Period from Day 19 Month 3 Hour 1
(STS 1) to Day 19 Month 3 Hour 23
(OTSI 1) Service Zone
Temp.
Deg.C
6
5
4
3
2
1
0
-1
-2
-3
24
3
6
9
12
15
18
21
24
Time Hours
internal air temperature
internal surface temperature
mean radiant temperature
external air temperature


Result-set 12 4 Period from Day 19 Month 3 Hour 1
(STS 1) to Day 19 Month 3 Hour 23
(OTSI 1) Sleeping Zone
Temp.
Deg.C
12
10
8
6
4
2
0
-2
24
3
6
9
12
15
18
21
24
Time Hours
internal surface temperature
internal air temperature
mean radiant temperature
external air temperature

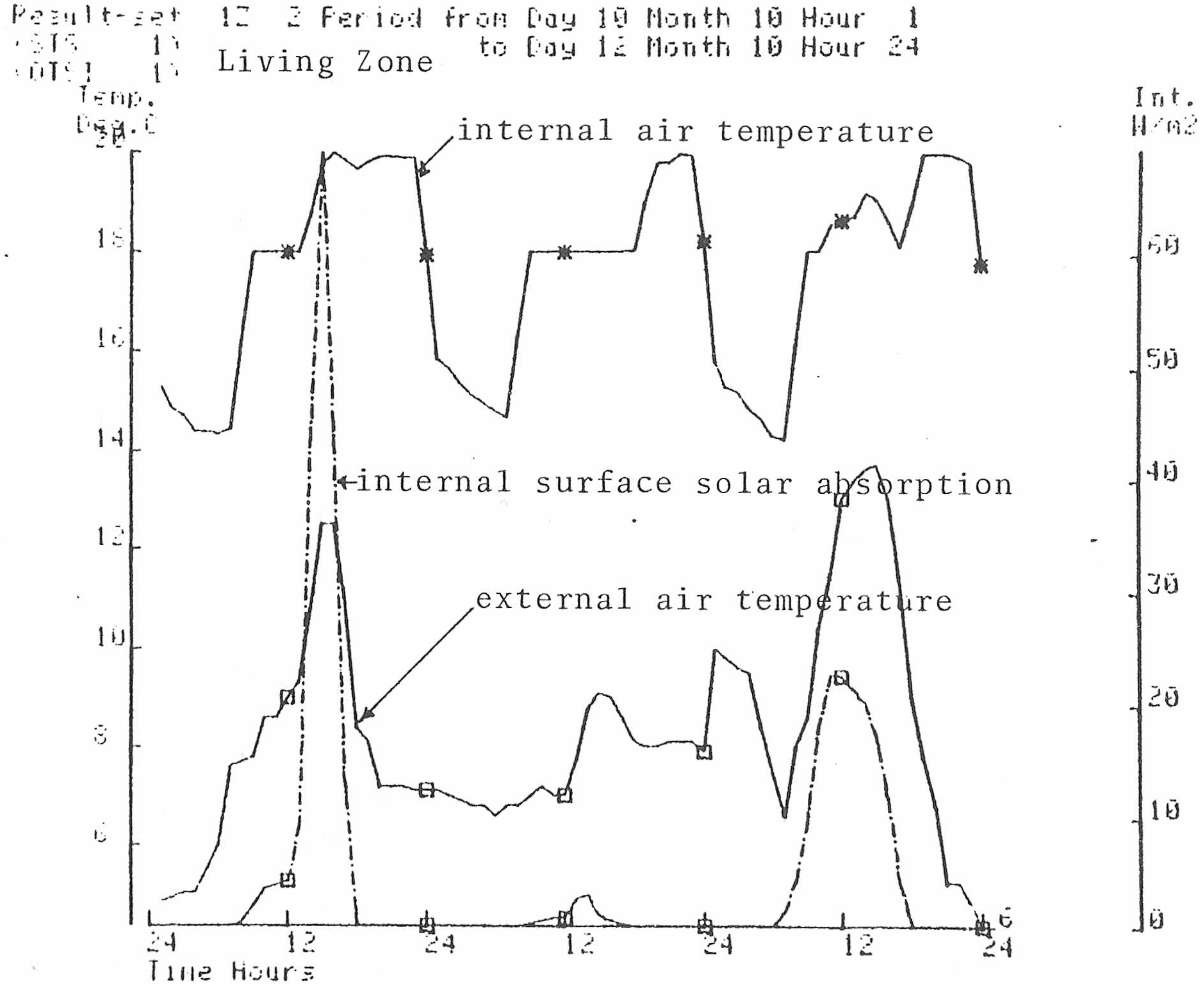
Appendix 4: ESP Energy Analysis

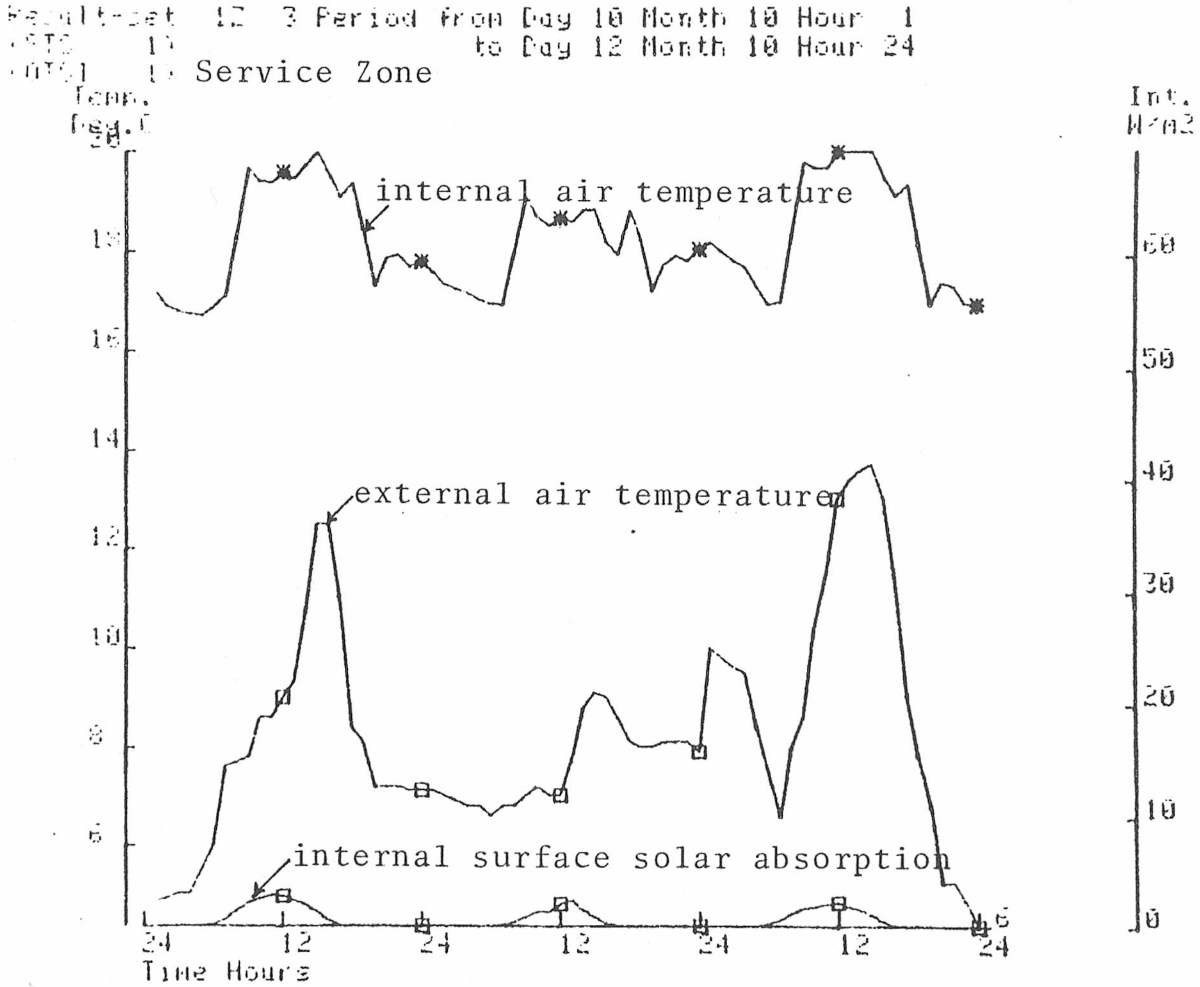
Typical Graphical Output for Housing Configuration B:

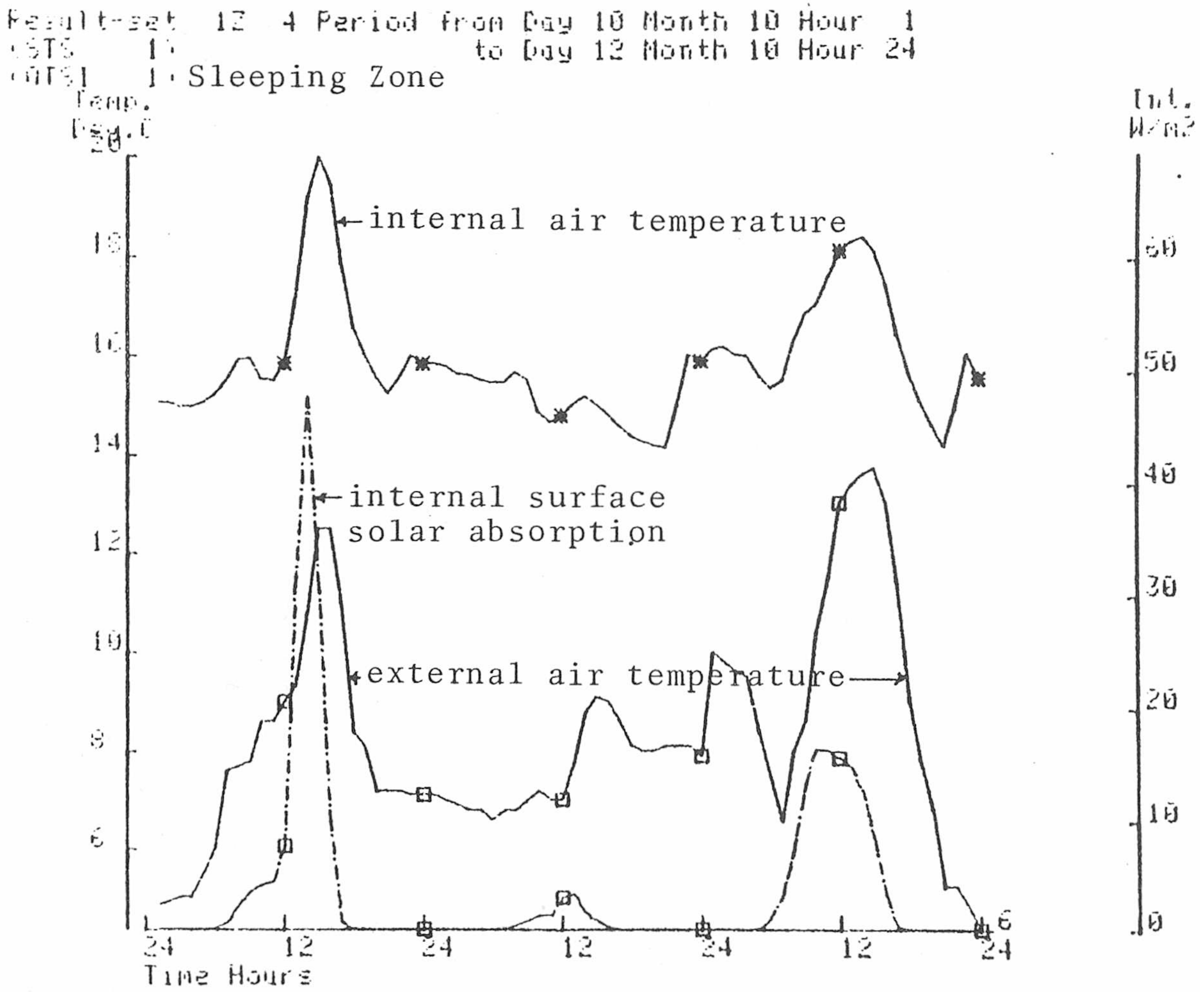
Simulation with Heating Control Strategy for Zones 2-4 on a Typical October High, Low and Medium Insolation Days

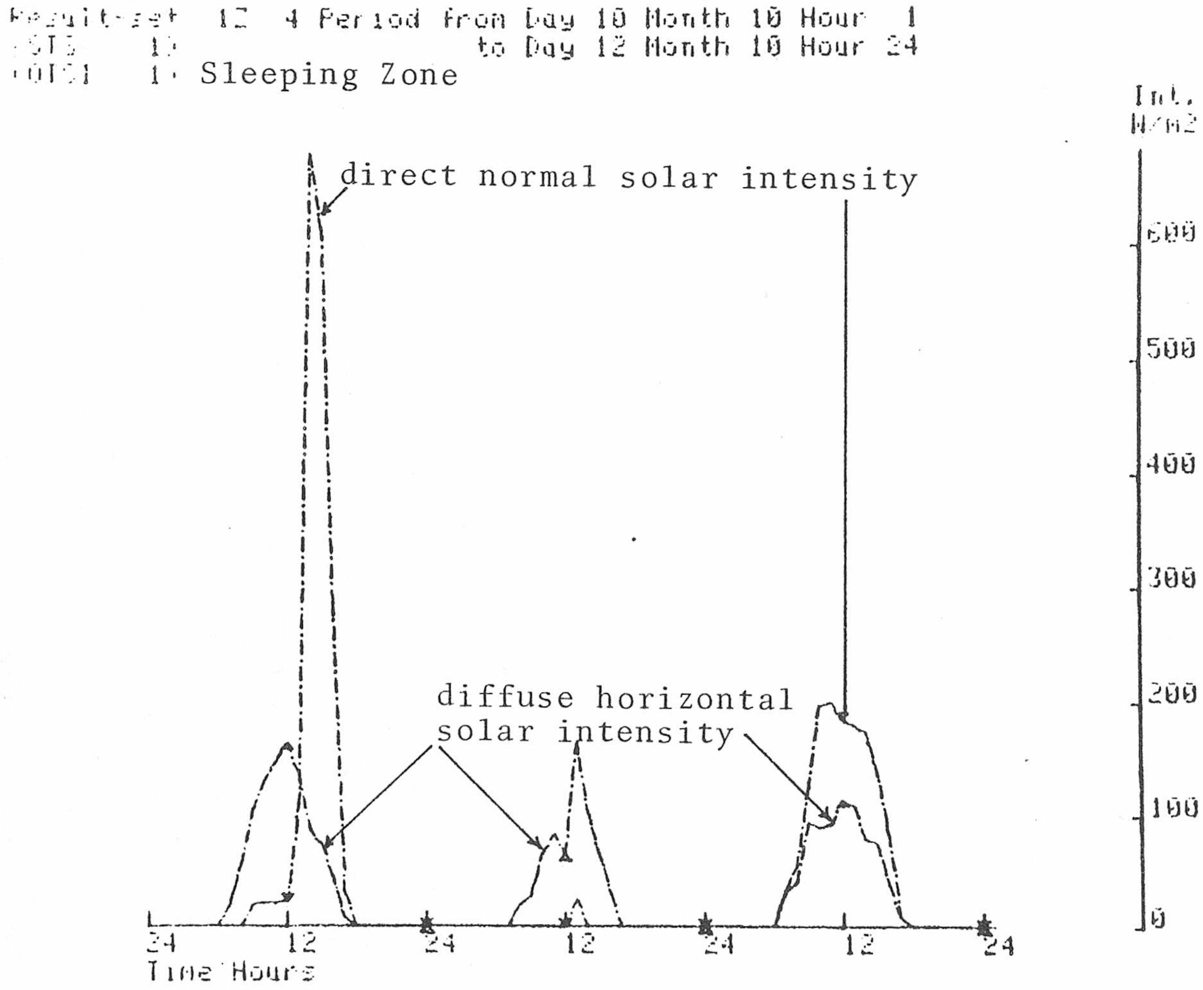


Result-set 12 1 Period from Day 10 Month 10 Hour 1
to Day 12 Month 10 Hour 24
Sunspace
Temp.
Deg.C
Int.
KW/m2
22
20
18
16
14
12
10
8
6
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
24
12
24
12
24
12
24
Time Hours
internal air temperature
internal surface solar absorption
external air temperature


Result-set 12 2 Period from Day 10 Month 10 Hour 1
to Day 12 Month 10 Hour 24
Living Zone
Temp.
Deg.C
20
18
16
14
12
10
8
6
Int.
W/m2
60
50
40
30
20
10
0
internal air temperature
internal surface solar absorption
external air temperature
24
12
24
12
24
12
24
Time Hours


Result-set 12 3 Period from Day 10 Month 10 Hour 1
to Day 12 Month 10 Hour 24
Service Zone
Temp. Deg.C
Int. W/m2
20
18
16
14
12
10
8
6
60
50
40
30
20
10
0
internal air temperature
external air temperature
internal surface solar absorption
24
12
24
12
24
12
24
Time Hours


Result-set 12 4 Period from Day 10 Month 10 Hour 1
(STS 1)
to Day 12 Month 10 Hour 24
(MTS) 1 (Sleeping Zone
Temp.
Deg.C
20
18
16
14
12
10
8
6
Int.
W/m2
60
50
40
30
20
10
0
internal air temperature
internal surface
solar absorption
external air temperature
24
12
24
12
24
12
24
6
Time Hours


Result-set 12 4 Period from Day 10 Month 10 Hour 1
to Day 12 Month 10 Hour 24
Sleeping Zone
Int.
W/m2
600
500
400
300
200
100
0
direct normal solar intensity
diffuse horizontal
solar intensity
24
12
24
12
24
12
24
Time Hours

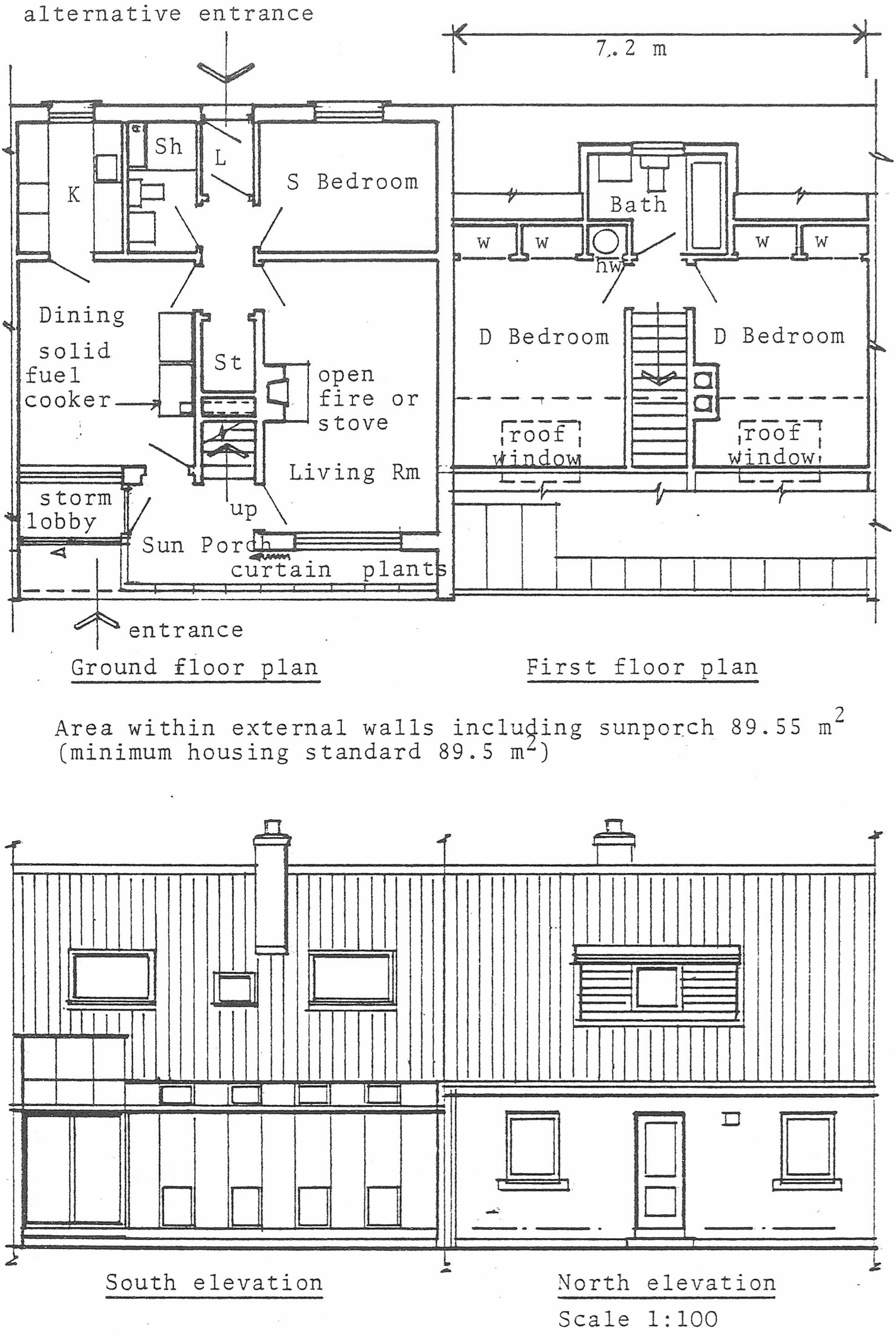
Appendix 5: A Rural Application Using Solid Fuel Auxiliary Heating

The text has established that passive solar heating design is not concerned with 'clip-on' systems, as might be said of active solar design. The whole building is involved right through the planning, design process involving both composite geometry and construction. Four representative housing models have therefore been used simply as a vehicle to test out various combinations of passive solar features, which preliminary analysis indicates are feasible. The limits which have emerged from detailed analysis of these models should not however restrict the designer in a creative sense.

Direct interest in passive solar design applications has now been expressed by two separate island local authorities in Scotland, the Western Isles Islands Council and the Shetland Islands Council. However, the particular project under construction in Stornoway, configuration 'A' in the analysis, does not make use of the indigenous natural asset in terms of fossil fuel for auxiliary heating, and common also to the Shetlands, namely peat. Therefore, it is considered appropriate to include in an appendix sketch proposals for a family house, specifically designed to optimise the balance between peat energy and solar energy, whilst in no way departing from the principles embodied in for example configuration 'B'. Solid fuel is of course still widely used in Scottish housing, particularly in more rural areas, and peat is also beginning to re-establish itself as a major domestic fuel source on the mainland. Therefore, this particular application has a relevance which extends beyond remote island authorities. But its main function in this context is not to become another 'model', rather to illustrate that passive solar design is not restricted to specific models or house-shells.

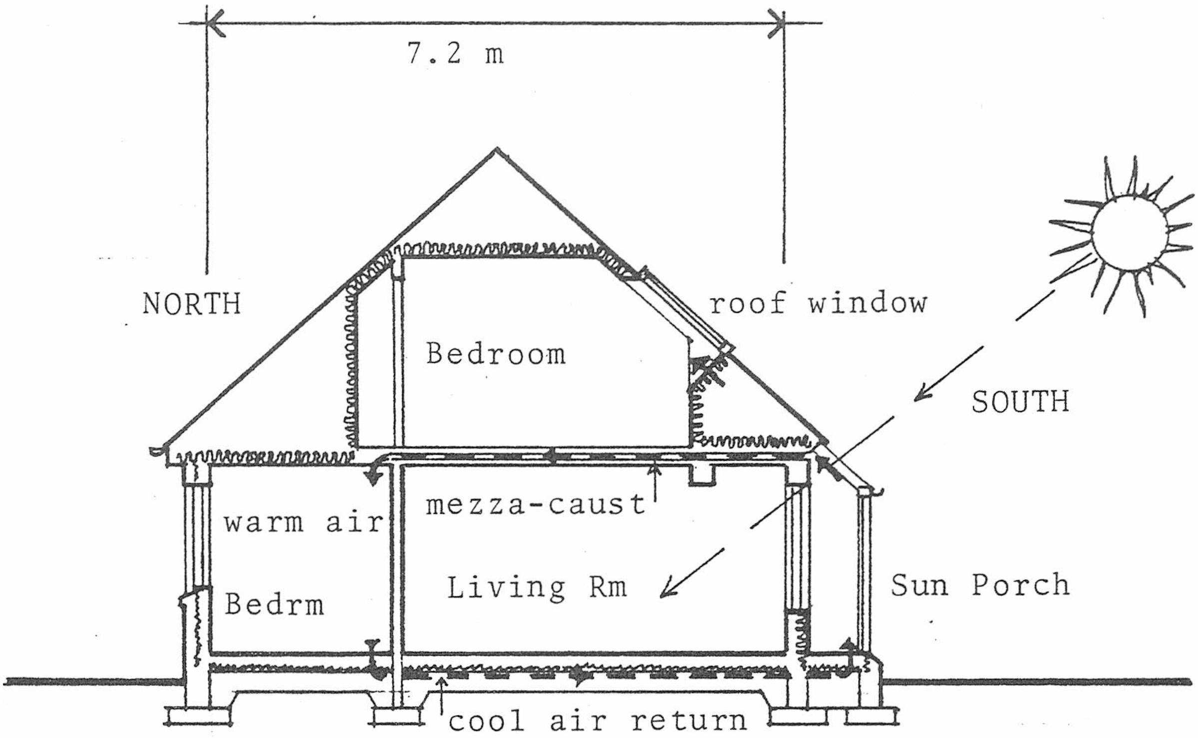
Figs (a) and (b) illustrate that the main feature of the design is, in common with configurations 'A' and 'B', a living space protected by two buffer zones, one a north facing service space, the other a south facing sun-space. In this instance the sunspace has been modulated to provide a storm lobby, an inner porch large enough for seating, and a narrow plant growing section. It is again a dual entrance plan form for site flexibility, but the north entrance could be discarded. Another refinement aimed at area of severe exposure is that there are three doors between the outside and all internal living spaces.

The ground floor living space has been divided into two sections, one a conventional sitting room, the other a family cooking and eating room, the latter having a service space adjacent rather in the manner of the old rural scullery. Each of the two main spaces is designed for a solid fuel appliance, a cooking stove in the latter and an open or closed radiant/convective emitter in the former. Both make use of the structure surrounding the central stairs as a casual gain storage element, incorporating a combined chimney stack. Since particularly the cooking appliance is most efficient if operated continuously, banked down when not in use for cooking, the auxiliary heating will tend to provide a continuous rather than an intermittent auxiliary heating regime. The thermal response conflict between solar and auxiliary heating will therefore largely disappear. Accordingly it would be reasonable to use a higher proportion of heavy linings to living spaces, which can also absorb direct solar gain. For example the floor of the family kitchen could well be finished in clay quarries. Otherwise the solar gain system will be very much as in configuration 'B', passing solar heated air from the sunspace through a mezzacaust floor between living and sleeping rooms and dumping any excess air in the rooms of the north buffer zone, which in this case include a third single study/bedroom. Although solid fuel appliances are clearly not fast response emitters, a reasonable degree of control can be achieved by 'damping' down. It is anticipated that although difficult to model with any accuracy, the solar and peat heating systems would be complimentary in providing a comfortable and enjoyable internal environment in locations normally associated with dampness and cold draughts.

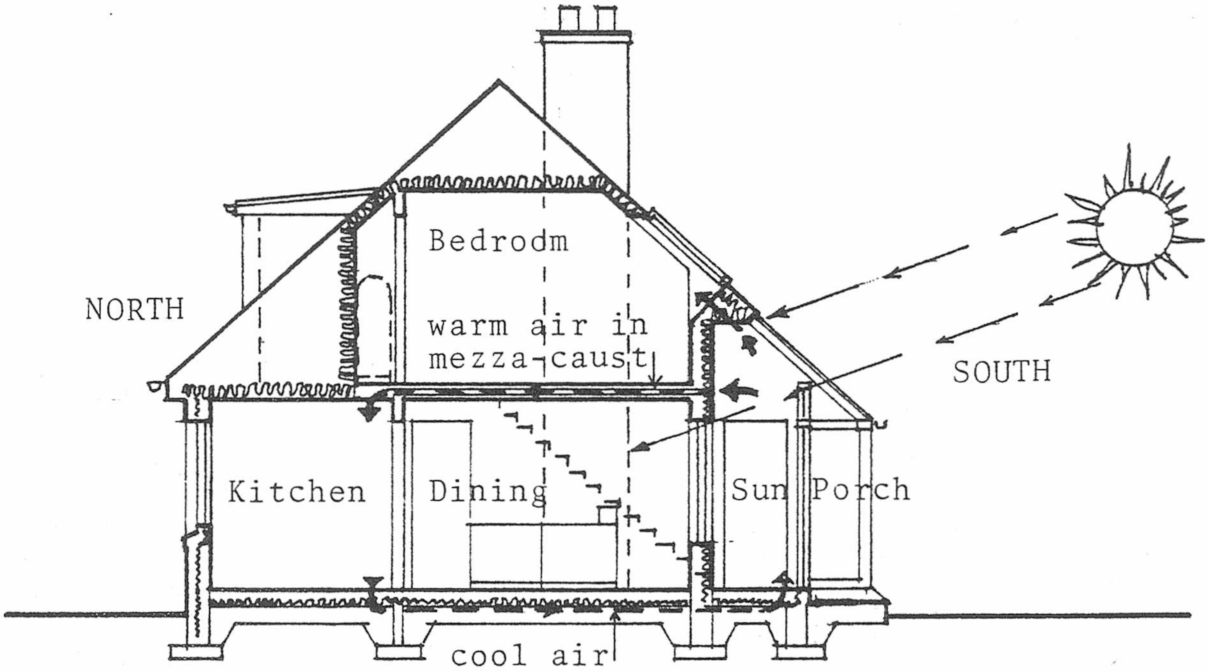


Area within external walls including sunporch 89.55 m^2
(minimum housing standard 89.5 m^2)

FIG (a) Rural Housing Configuration: 5 person wide frontage, south aspect 1½ storey terraced house.



Cross Section thro' living room   Scale 1:100



Cross Section thro' kitchen and dining

FIG (b): Rural Housing Configuration: $1\frac{1}{2}$ storey