THE ENGINEERING DIMENSION OF nD MODELLING: PERFORMANCE ASSESMENT AT CONCEPTUAL DESIGN STAGE

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SUMMARY: *Whilst naturally ventilated buildings are currently considered to be the ideal solution to low energy design there remain a large proportion of buildings for which air conditioning offers the only practical solution. The project presented in this paper is intended to provide a means to assess design options for such buildings at a very early stage in the design and in particular address the selection of the most appropriate system. The form of the interface is still developing and while it has been demonstrated to designers no third party tests have yet been carried out. This paper reports on a project that aims to show that a general description of the building can be used to generate sufficient data to drive a valid analysis using a detailed thermal model at the early sketch stage of the design process. It describes the philosophy, methodology and the interface developed to achieve this aim. The interface guides the user through the input process using a series of screens giving options for keywords used to describe the building; comprehensive default data built into the software are then attached to these keywords. The resulting data file is a building description that is the best possible interpretation of the design intent. This can then be used to assess options and guide towards a final design.*

KEYWORD: *architecture, engineering, energy, assessment, sketch stage, design process, data transfer, XML*

1. INTRODUCTION

At present, during the early design stage of a building, different options are assessed using simple tools (tables, graphs and software) that contain a large number of assumptions the very nature of which can bias choice or possibly lead to an inappropriate solution. It can be argued that the only way to provide a rational assessment of options is to use calculation methods that represent in detail the physical processes involved; this usually involves the use of dynamic thermal models. Dynamic thermal models differ from the design models in that they are capable of predicting (simulating) the performance of the building and associated systems at hourly intervals for a complete year (design models typically predict conditions for a single day under steady cyclic conditions). At present the dynamic thermal model is normally used at the detailed design stage. A further advantage of using the model at the early stage is that the same theoretical assumptions are applied throughout the design process.

Initial development of these models concentrated on the calculation engine, the interface was usually crude or non-existent, that is an ASCII data file. The lack of a user-friendly interface was not of particular concern (at this stage of development DOS would have been the common operating system) because computers were not sufficiently fast to enable the use of these models within the design process.

At this time the use of computer aided drafting systems was increasing and so in parallel with the development of the calculation engines researchers and designers saw that there would be an advantage in integrating the drawing and calculation systems (Augenbroe, 1994). As a result commercial software houses in the United Kingdom directed interface development towards means of extracting geometrical data from architectural drawings. These interfaces are closely linked to the calculation engine using a private data structure.

The situation is different in the USA where Government has funded the development of the calculation engine and interface development is carried out by a third party. To do this the data structure is in the public domain making it possible for anyone to develop an interface. Again the attraction of linking to architectural drawings has been recognized.

These developments lead to interfaces that, although easy to use, enable the engineer to describe the building in great detail. In practice the numerical model cannot take advantage of this detail. A simple example is that heat flow through walls is assumed to be one-dimensional that is the effects of corners and window reveals cannot be modeled. Consequently a simpler approach to geometry would not invalidate the use of the calculation engine. Thus provided the features responsible for the major heat flows are captured a simple representation of the building geometry can be used and that the results will provide a good indication of the performance of the building. This is particularly true for air-conditioned buildings where the energy consumption is more closely linked to the type of system chosen and the enterprise than the heat flow through the building fabric.

Many designers are of the opinion that, because not all details are known, then such tools are not suitable for application at early stages in the design. This view can be challenged because; even at the concept stage a great deal is known about the building, for example:

- Size;
- Number of floors;
- Occupancy;
- Preferred glazed areas;
- Insulation standards;
- Thermal mass;
- Required internal environmental conditions.

Not withstanding this there is still resistance to the application of simulation at an early stage in the design, typical reasons given are:

- Too time consuming to input the necessary data;
- The program is not user friendly;
- Manual methods are quite adequate;
- Programs cannot be trusted;
- Do not understand how the program works.

Arup had already recognized the need to address these issues and encourage the use of simulation throughout the life cycle of the building and so, at their own expense, joined the International Energy Agency (IEA), Building and Community Systems, Annex 30 (Bringing Simulation to Application). Arup Research and Development was the official UK Participant.

The IEA project demonstrated the value of simulation throughout the design process, the value of good quality default data and the need for software validation. However despite identifying user friendliness as an important issue in increasing the uptake of simulation throughout the construction industry, it did not make a serious attempt to address that issue. The objective of *EnergySave* is to redress this.

2. STATE OF THE ART AND RELATED WORK

There have been a number of projects that aim to provide simple interfaces to assist designers examples include: NATVENT (BRECSU, 1999); Office Design Tools (Bunn, 1999) and Building Design Advisor (Papamichael et al, 1997). The complex nature of ventilation and the very uncertain nature of the boundary conditions (wind environment, pressure coefficients, for example) justify the simple nature of the analytical models used in the first two examples. The third is a way of using a detailed thermal model to analyse design options. The main difference between this work and the BDA lies in the interface. The BDA uses a graphical tool that requires each space to be specified in some detail. It is therefore close to a conventional analysis tool and as such is not suitable for studies at the sketch stage of the design. The method by which results are presented is however one example that will be examined during the project. Members of the *EnergySave* team have visited the Laurence Berkley Laboratory in California and are therefore fully aware of the strengths and weaknesses of the BDA.

The intention of the *EnergySave* project was to make use of available software and skills. In particular, whilst a detailed thermal model is necessary for the implementation of the method there is no intention to develop that model. It is however important that the source code of that model is available to the team. The model selected is ENERGY2. This program has been developed in Arup Research and Development and has been exposed to the International Simulation Community by means of the IEA Annex 21 (a task shared project related to quality assurance and validation of thermal models).

In order to facilitate energy calculations it was necessary to develop generic system models. These are based upon those described in the CIBSE Energy Code 2, 'Energy demands for air conditioned buildings'. Arup Research and Development were involved in the drafting of this code and made significant inputs into the building description application of climatic data and testing of early versions. Although these models are very simple they capture the essential features of the systems. This means that the major inefficiencies are accounted for.

3. THE ENERGYSAVE APPROACH

The objective for the *EnergySave* interface is to capture the essential elements of a design in an unambiguous way to enable a valid energy analysis at the concept stage of a design. Of equal importance is that any data output should be in sufficient detail to enable the use of a detailed thermal model[1] for the prediction of energy consumption. This model would also be used at later stages in the design process so bringing a consistency to the analysis through out design. A second and equally important objective is to provide a mechanism to bring simulation to those who believe it to be too complex for their needs and far too difficult to use. This is done in several ways:

- The use of extensive, intelligent defaults to minimise the amount of data that are required;
- The use of a pictorial based input system to identify the main input parameters;
- The use of minimum data to describe building;
- A critical assessment of the most significant features that can affect the energy consumption of the building.

An example of the later is the way solar shading is described. In the case of passive buildings it is particularly important to ensure that the effect of any purpose built shade is accurately represented. In the case of air-conditioned buildings this is less necessary because energy consumption is far more closely related to systems and controls. *EnergySave* does not ignore external shade but on the other hand does not encourage users to be obsessed with complex representations. The form of the building is simplified, at present to a rectangle. While this is recognised to be a limitation it is also felt that the majority of buildings can be adequately represented. *EnergySave* is intended to apply to the norm. Section 4.1 demonstrates the principles described above.

A second fundamental to the system is to use what is already available, thus the main database used is a commercial product chosen because the majority of PC users will have access to it. Intermediate data transfer uses the Green Building Schema (http://www.gbxml.org/) developed to facilitate interoperability between building design models and engineering analysis tools using the Extensible Markup Language (Harold, 1999).

It is important to realise the *EnergySave* **does not** contain a calculation engine. It is intended that the XML file be described in sufficient detail to allow the use of third part 'engines'. This is direct contrast to the development of public domain engines in the USA.

4. STRUCTURE OF THE SYSTEM

Figure 1 shows the architecture of the *EnergySave* system which consist of three main layers; the input layer consisting of the *EnergySave* interface, the analysis layer containing the calculation software and the XML data input and output translators, and the output layer for the final reporting on the design options' overall

[1] A detailed thermal model is usually a simulation program capable of calculating the performance of both building and HVAC systems at hourly intervals for the period of a year. In the UK context design programs based upon the CIBSE Admittance method are not considered to be detailed thermal models.

performance.

4.1 Input Layer

The written descriptions of the building are converted into components using rules developed from discussions with designers from the industrial partners who have also provided default data based upon previous projects. These are combined with user specific data into building and system components and written to a standardised data file. The data structure produced by this process is to be specified in sufficient detail to allow any developer to use their model in conjunction with this system. One function of the interpreter is convert simple descriptions into physical layers that are suitable for use in a detailed thermal model. Examples are:

- Opaque walls. Input U value and response time – output layers in the construction and the physical properties of those layers.
- Glazing. Input shading coefficient – output layers and basic properties such as transmission and absorption at normal incidence for each.

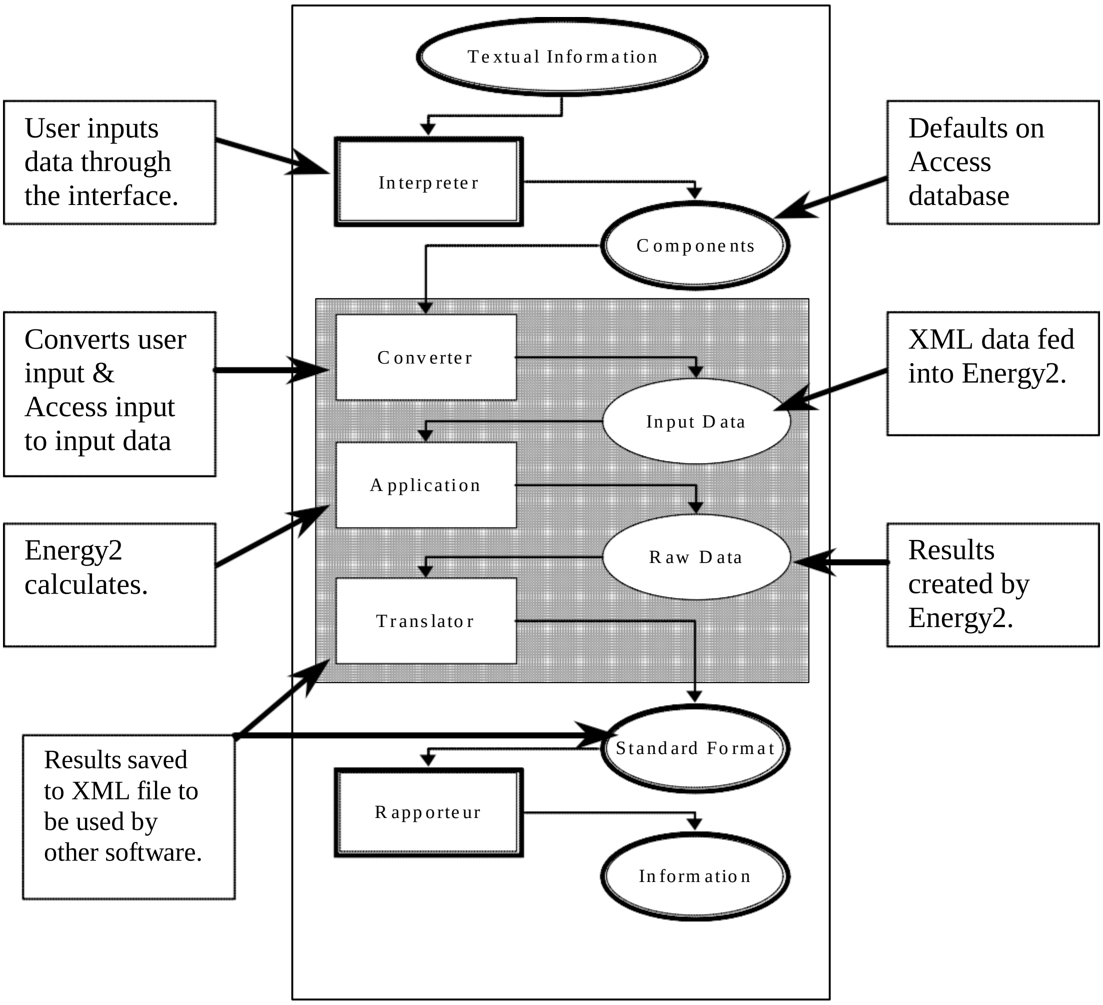

FIG. 1: The EnergySave System Architecture

The Interpreter containing the main EnergySave input interface combines the default data taken from the database with the user input data to create the XML file. It is important that a single XML file contains ALL design options investigated. This was done by specifying each as a new building on the same site.

The XML input data file contains the following:

- Location and climatic data information;
- A full geometrical description;
- Thickness and properties of the walls;
- Transmission, reflection and absorption characteristics of each element within a window.
- Shading details;
- The configuration of the HVAC plant.

Some of the interface forms used during the input are shown and explained below.

4.1.1 Project definition

In addition to capturing the standard inputs such as project description and user, the location and function of the building are defined. Location sets insulation standards via local building regulations and occupancy patterns and internal gains are set by the function. A default building is generated.

FIG. 2: Project location

4.1.2 Location

Each region on the country map contains a link to a climatic data file. Software vendors can enter their particular file names on the database. Exposure is also identified. Because this can be done in several ways, an advanced option allows an alternative definition, terrain type. This is intended to provide data for software that requires some means to describe wind shading for infiltration and ventilation calculations.

FIG. 3: Input of climatic data and site exposure

4.1.3 Building's form

A simple model of a building is created, using zones based on the façades. The user inputs the length, width, floor-to-floor height, and the number of floors. Simple solar shading is also set here, another input (not included) allows for individual window shade to be entered.

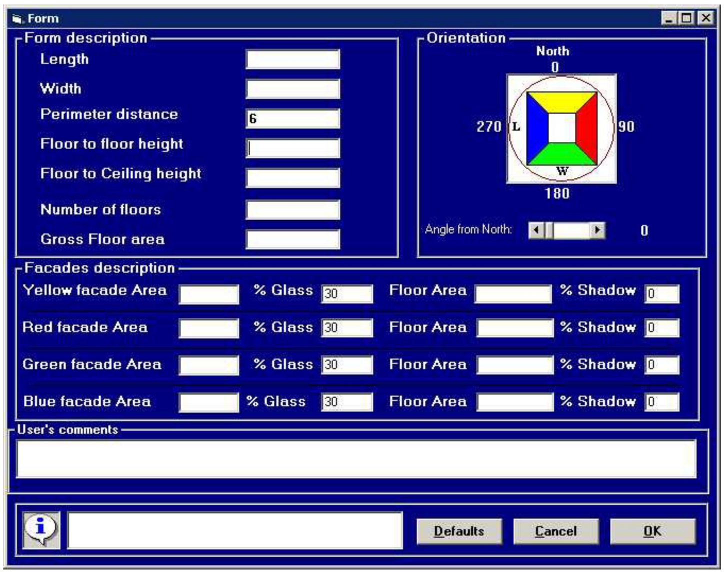

FIG. 4: Building form

4.1.4 Internal Gains

Internal loads are defined by 'level', very high to very low. The defaults corresponding to these levels are displayed and it is possible for the user to make changes.

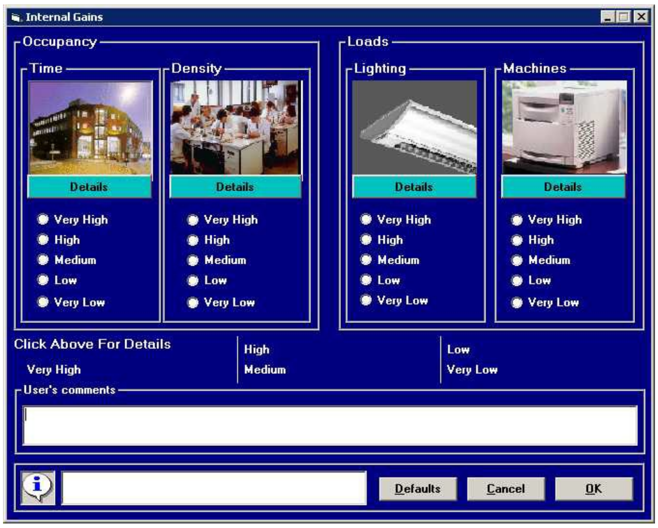

FIG. 5: Internal gains

4.1.5 External Walls

Materials used in external walls can be selected. The variations are labelled by their U-Value and thermal response time (Admittance). The user can select the closest type of wall or alternatively create a custom wall using the advanced option

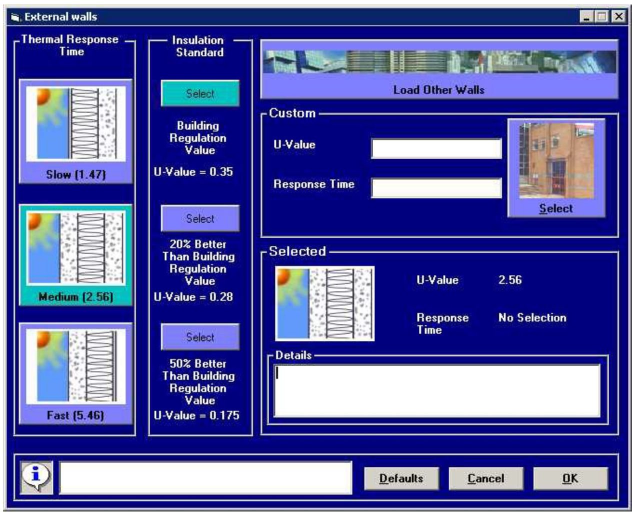

FIG. 6: External walls

4.1.6 HVAC Systems

A side view cut out section of the building is split into the core, inner perimeter and outer perimeter. Each section can be "filled" with heating and cooling systems. This is shown in the green section with the under-floor VAV system. As the user enters data, options are limited for other sections so that inappropriate combinations cannot be selected.

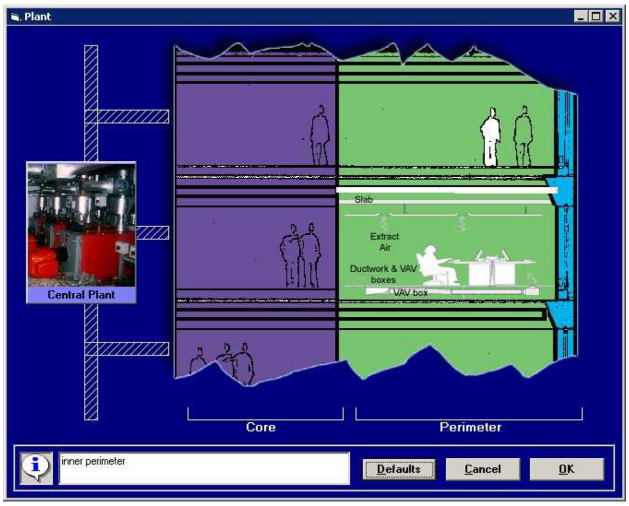

FIG. 7: HVAC systems

4.2 Analysis Layer

The main component in this layer is the analysis software that can be any appropriate thermal model chosen here to be the ENERGY2 programme. This is a dynamic thermal model intended to be used to predict the performance of building and systems installed within it. This is closely related to the local climate expressed in terms of temperature, solar radiation, wind speed etc., and internal gains from occupancy and equipment. Heat flow within the walls, floors and ceilings is calculated using and explicit finite difference method. Transmission though glazing takes due account of absorption of short wave solar radiation and the inter-reflection between the various elements tat make up the glazing system, including blinds. Space temperatures and loads are calculated by means of room heat balance that takes account of the internal distribution of radiant heat gains and the possibility of stratification arising from the application of displacement ventilation systems.

The Converter is a translator specific to the simulation model used and written to convert the data in the XML file to that required by the program. The Translator is also specific to the program used in the analysis and is used to convert the predictions (raw data) into a standard format. This format is specified in detail to allow the system to be used by other software developers. The output from the translator is written to the XML output file.

4.3 Output Layer

The nature of the output from an energy simulation requires specialist knowledge for a valid interpretation, in particular where comparisons are to be made. The **rapporteur** provides a facility to compare and interpret design options. It is hieratical in nature so the user is first offered overall energy (and CO_2 figures). It is then possible to delve deeper to looking order to develop an understanding of the performance indicated. Automatic comparison of options will be available. The rapporteur allows comparison of results for up to 4 options. The parameters covered are:

- Carbon dioxide production;
- Energy consumption in terms of electricity and gas;
- Energy consumption in terms of cost;
- A breakdown of the loads on the building (solar, infiltration etc.)
- An 'end use' breakdown – fans, boilers, chillers humidification etc.

The data are presented as both annual and monthly totals as shown in the figure below.

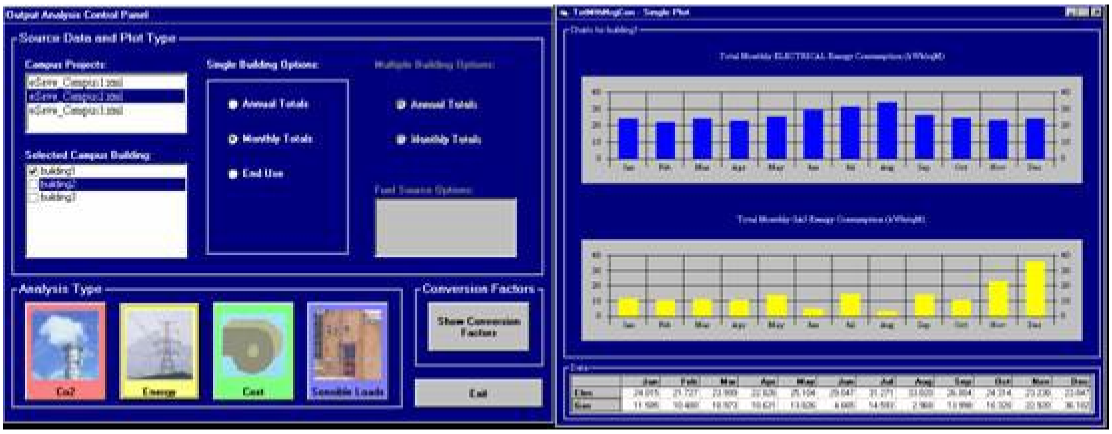

FIG. 8: Output screen

5. CONCLUSION

The *EnergySave* project aimed at facilitating the use of performance analysis models during the early conceptual design where detailed information about the building is not yet available. The system developed uses data defaulted from the general description of the building and creates enough information for a standard thermal model to be run and performance figures to be obtained. This enables designers to quickly assess different design options and make informed decisions regarding energy consumption and thermal comfort levels. The input interface in the system has been developed to make the data input process simple and independent from the detailed calculations that take place within the analysis software. This would open the use of simulation tools to professionals with limited technical knowledge and also facilitate collaborative design development between members of the design team. *EnergySave* differs from other approaches to simplified energy analysis in that simplifications are made in the way data are described to the analytical engine and not in the engine itself.

6. ACKNOWLEDGEMENT

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