IMPLEMENTATION OF AN ENERGY MODEL WITHIN A MULTI-DISCIPLINARY PRACTICE

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Implementation of computer software is concerned with trials of its robustness, relevance, and efficacy in the real-world, real-time context of design practice. This paper summarises the trials carried out within the Building Design Partnership of a dynamic energy model, ESP, developed by ABACUS at the University of Strathclyde. Over an 18 month period the program was used on 6 projects to address a variety of design problems over a variety of building types. The paper reports in outline on each of the six: four concerned with the need for a definite answer to a specific question, eg. "will it overheat in summer"; two concerned to provide, on the one hand for the client, on the other hand for the design practice, paradigms for energy conscious design of hospitals and offices. The conclusions drawn have relevance to the takeup of CAD generally.

## 1. IMPLEMENTATION IN PRACTICE - A CRUCIAL CAD ISSUE

CAD software, however powerful, accurate and elegant will remain unused by designe unless it can be shown also to be robust, relevant and efficacious in the real-wor real-time context of practice. This paper describes a study of the implementation of the ESP energy model within a multi-disciplinary building design practice, carr out jointly by the originators of the software - ABACUS, of the University of Strathclyde and the practice - Building Design Partnership (BDP).

Implementation can be placed in the sequence of stages from research to exploitati as follows:

- i) research into needs, methods, algorithms, model structure etc.
- ii) development of a pilot version of the model in the form of an application program which embodies the research findings
- iii) validation of the computer model against the actual performance of existing buildings and against current manual methods
- iv) implementation trials to test the robustness, relevance and efficacy of the software in the real-world, real-time context of design practice
- v) improvement of the software and documentation with respect to commercial standards
- vi) commercial exploitation.

## 2. THE STUDY.

In terms of the sequence identified above, the software known as ESP (Environmenta Systems Performance) was an ideal candidate for an implementation study. Research had already been done, as part of a doctoral thesis, on the most relevant theoreti basis for a dynamic model of energy flow in buildings (which turned out to be a finite difference model) and on the most efficient computational technique availabl to operate the model (which turned out to be implicit enumeration) [1]. Followin from the research, development of a pilot version of a computer program had been carried out with SRC funding: the program ESP[2] allowed design team members to predict interactively the environmental control and energy implications of alternative decisions on building form and fabric and of alternative decisions on plant operating regimes. With funding from the SDD, a validation of the program had been carried out by comparing the actual energy behaviour of three New Town houses with the energy behaviour predicted by the computer program [3]. The stage was thus set for an implementation study.

At the outset of the study, a detailed plan of work, spanning 18 months, was drawn up and agreed by the participating agencies. This document set objectives, both general and specific, proposed a phasing and methodology for the study, identified candidate design schemes and recommended roles and responsibilities for the study team.

Certain difficulties in carrying out the study were envisaged from the outset. These included:

i) the degree of control normally associated with research experimentation would be absent; the live design projects would require to proceed at their own pace whatever the effect on the study;

ii) vehicles for the study would have to be taken as and when they arose; as a guarantee against delay in, or abortion of, a programme of design work, more vehicles would be started than could be fully observed and reported.

A more benign source of difficulty was to be found in the dynamics of the relationship between BDP staff and the applications software. In the course of the study increasing opportunity was found for 'real' (as opposed to 'experimental') use of ESP. Initially it was envisaged that these uses would be outside the scope of the study; subsequently it was decided that all information on the use of ESP should be recorded and included in the study reportage. In the event, the increasing commitment by BDP to the use of ESP had the effect of stretching the ESP Implementation Study team beyond the point where reportage on all applications was as full as was envisaged as being appropriate. In the course of the Implementation Study BDP won a commission from DHSS to contribute to a Low Energy Hospital Study; as a consequence, the membership of BDP's Special Study Group grew from 1 to 5 people and ESP was pressed into the front line of the investigation.

It is relevant to note that shortly after the study started, and in response to its increasing use, a version of ESP was implemented on the BDP Hewlett Packard 3000; access to this version and to the original version on the SRC Dec System 10 in Edinburgh was via not one (as envisaged), but two Tektronix 4000 series graphics terminals.

## 3. THE CASE MATERIAL

Over the 18 month period of the Implementation Study, ESP was used substantively in six projects. Providentially, these six projects covered a range of building types and a range in scale of design problems - from "will there be summertime overheating in this space" to "what building construction will minimise energy consumption?". The following sub-sections summarise the six projects: four concerned with specific but important issues arising in the course of the design of a particular building, the other two aiming, more abmitiously, to produce general paradigms for the energy conscious design of hospital and office design.

### 3.1 Feasibility Study and Development Scheme for an Urban Site

BDP was asked to carry out a feasibility study and produce a development scheme for the comprehensive redevelopment of a narrow but important urban site; the redevelopment had to include two office blocks, each of 100,000 sq.ft., to be let by the client.

The narrowness of the site suggested a narrow floor plan in each office block, one rising to six storeys, the other to eight storeys. The proposal that one of the blocks should be air conditioned, the other not, suggested to the architect an investigation of a broad range of construction types under 'artificial', 'ambient' and 'assisted' environmental control.

In the event, a two-stage analysis using ESP was carried out in the context of the non-air conditioned building. In the first stage, office modules on the SW and NE orientations were simulated, respectively, under summer and winter conditions; within a fixed external envelope with 35% glazing, ESP was used to explore the implications of achieving shading on the SW facade, increasing the thermal mass of internal partitioning, altering the rate of mechanical ventilation and double-glazing the NE facade. In the second stage, more explicit proposals were generated for the pattern of external glazing, the internal sub-division of space, etc; and a similar series of investigations, using ESP, carried out.

Four important conclusions emerged from the project:

i) given the potential of the computer program to facilitate an explicit comparative evaluation of a wide range of constructional alternatives, the architect was frustrated by the lack of time available in the project to carry out such a fundamental evaluation. As a consequence he persuaded the design practice to let him undertake, subsequently, an R&D project on this theme. This is reported in sub-section 3.6.

ii) whereas a heavy weight construction for the internal partitioning emerged from the first stage of the analysis as more effective in controlling summertime temperatures, the architect, having checked in the second stage that the penalties were not severe, settled for the lightweight construction which for a range of other reasons, he had favoured from the outset and which he believed the client would favour.

iii) the project and the two-stage ESP analysis, highlighted the important interaction between lighting and thermal performance; as a consequence, BDP acquired the computer program NATLIT [4] for use in conjunction with ESP.

iv) also highlighted was the importance of selecting at the outset, the climate against which alternative design proposals should be tested.

## 3.2 Computer Suite for a Nationalised Industry

The design of a building to house a computer and ancillary activities for a nationalised industry was already well advanced when then the opportunity arose to use ESP. The air conditioned building, of approximately 6000 $m^2$, was to be built on four floors, each 30m wide by 50m long; office accommodation would be housed on the perimeter with rooms of more occasional occupancy in the core.

The stimulus for use of ESP came from the decision to alter the building envelope from a lightweight metal cladding system to brickwork, with an associated increase in glazing from 25% to 40% differentially arranged on the four floors. The effect of these changes on the variable air volume (VAV) distribution ductwork and on the central air-handling plant needed, as a matter of urgency, to be determined.

The ESP analysis was applied to spatial modules sited on all four corners of the building and halfway along each facade. For each module on each floor the peak load across its VAV terminals was computed and the accumulative effect on the central plant estimated. In relation to the climate data used the peak load on all space modules was seen to occur on the 17th July - a day of high air temperature and not, as had been previously assumed, within the month of September. The ability of ESP to model the dynamics of thermal behaviour hour by hour showed clearly that the peak load occurred in different space modules at different times throughout the critical day; as a consequence, although individual VAV terminal duties had to be increased, no significant increase in load would be experienced by the central plant.

As in the foregoing project the importance of testing the building against an appropriately 'severe' climate was highlighted. Additionally the engineer using the program was conscious of the importance of clearly labelling and storing data files for anticipated use during the subsequent stage of commissioning the building.

## 3.3 Extension to a University Library

BDP were commissioned as consulting engineers for the first phase of an extension to a University library, comprising a reading room with a floor of bookstacks above. The construction proposed by the architect was dense reinforced concrete with double skin patent glazing angled back from cill to ceiling.

Concern for the environmental conditions focused on the maximum occupancy period of the reading room (~May, with an estimated 350 readers) and on the mid-summer period (~June to August, with an estimated 100 readers); the architect also wished an appraisal of the scheme under winter heating conditions.

Climate files relevant to the study periods were created by modifying the climate in accordance with the diurnal range known to prevail at the location of the site. The May analysis revealed a 24 hour heat input requirement under the proposed 10 airchanges/hour ventilation regime; as a result of the analysis the proposed air change rate in the Spring was reduced to a level just sufficient to combat odours and meet ventilation requirements. With 10 air changes/hour in August, the maximum temperature was predicted to be 24°C. Given the slightly lower resultant temperature and the possibility of the 100 readers disposing themselves away from the external wall, this was considered to be acceptable. A January analysis of heat flow through the double-glazed envelope revealed acceptable comfort conditions.

## 3.4 Workshops, Stores and Offices for a Broadcasting Company

As engineering consultants, BDP was concerned about the possibility of unacceptably high temperatures in spaces on the SE facade of a building to house workshops, stores and offices for a broadcasting compnay. The proposal was for double glazing in brickwork and earlier estimations had indicated high summertime temperatures even allowing for the use of internal blinds and reflective glass. Just prior to the application of ESP a re-investigation had been carried out which seemed to indicate that whereas the introduction of external shading devices would be efficacious, a reduced area of glazing would give rise, seemingly paradoxically, to higher internal temperatures.

ESP's ability to model the pattern of thermal behaviour throughout the day and display it graphically confirmed and explained the higher temperatures. Heat build-up during the day was stored in the building mass and released from the building at night; a reduced glazed area reduced the opportunity for convective and radiative heat loss during the night hours with correspondingly higher temperatures on the following day.

As part of the ESP analysis checks were run on the incidence of solar radiation on internal surfaces and on the efficacy of the external shading devices. The outcome of this more refined analysis indicated a much lower internal temperature than had previously been feared with peak internal temperature slightly lower than the peak external temperature (28.8°C) on the day assumed to be critical, indicating a very good resultant temperature profile.

It is worth noting that when the analysis was repeated under what was assumed to be less critical climatic conditions (ie. a day on which the external peak temperature was 26.7°C as opposed to 28.8°C) the predicted internal temperature was higher!

This outcome was readily explained by the climatic analysis facility in ESP which showed particularly high diffuse radiation figures on the 26.7°C day, against whic the external shading is less than wholly efficacious.

## 3.5 Low Energy Hospital Study

Shortly after the Implementation Study was started, the DHSS commissioned an energ study of their Nucleus Hospital, with BDP retained as project leaders, quantity surveying consultants and engineering consultants. The study was envisaged as having three phases:

1. establishment of the base energy used in what would be known as a 'neutral nucleus' hospital under defined operating parameters

2. detailed examination of all design factors which have a significant bearir on energy usage, and

3. reportage

The intention in this sub-section is not to anticipate the wide-ranging conclusior of the Low Energy Hospital Study but simply to indicate the use of ESP in the gene ation of interim conclusions, particularly with respect ot window design in ward units.

From the outset BDP decided to adopt a 'theoretical' as opposed to a 'monitoring' approach, ie. the computer-based simulation of a wide variety of design variants which could be compared with the base line of 'neutral nucleus'. Unless it is son how constrained, such a parametric investigation can assume enormous proportions; for the ward window design part of the low energy study, the following constraints were imposed:

i) a six-bed ward unit would be taken as representative of ward units generally
ii) a one-week run of climate would be chosen as representative for each month c the year
iii) most importantly each state of each design variable would not be simulated i conjunction with each state of every other design variable. Rather, each variable would be dealt with progressively, with the 'best' outcome from the study of variable 'n' being the fixed basis for study of variable 'n+1'.

The search sequence and scope, then, is summarised in Table 1. The assumptions ir the third column were made in order to progress the investigation and must not be thought of as conclusions from the low energy study.

The investigation led to the conclusion that parametric studies using ESP could usefully follow this pattern provided the variables can be ordered in terms of the likely energy and cost-effectiveness but that the calculation techniques should allow for data (eg. occupant behaviour) which is probabilistic in nature, with results ranging between agreed confidence limits.

## 3.6 Low Energy Office Study

As stated in 3.1, the architect responsible for the feasibility study and development scheme incorporating two 100,000 sq.ft. speculative office blocks was impress by the potential of ESP and dissatisfied with the state of knowledge regarding the energy consequences of design choices in the context of speculative office develo ments. He therefore sought, and won, funding from BDP's 'Quality of Product' func to pursue a parametric study based on ESP [5].

The study, using as a vehicle a hypothetical 14.4m deep linear form commercial

a) estimate the relative influence on energy conservation of different external wall constructions and window treatments
b) compare the 'best-buy' solution generated by (a) with BDP and other existing schemes
c) ascertain the impact of such an approach to capital expenditure (the developer's contribution) and running costs (the tenant's contribution)

The design choices were considered to encompass the following:

i) geometry: the investigation focused on two spaces - a 3.6 x 4.2 metre office and three bays of open offices totalling 21.6m x 14.4m, the latter with two external walls.

ii) fabric: seven external wall types ranging from a slender 'cold wall' through to a traditional cavity masonry approach. All constructions were designed to have a U-value of 0.6 except one which, for reasons of stability, resulted in a U-value of 0.255.

iii) natural lighting: levels of single glazing were set at approximately 30% of wall area. NATLIT was used to check daylight factors.

iv) artificial lighting: to simulate an artificial lighting system selectively dimmable in tune with daylight fluctuations, a new program LITPROG was specified and written by BDP staff. By means of LITPROG a seasonably adjusted casual gains load attributable to lighting could be fed to the ESP program.

v) occupancy and plant regimes: lights were assumed to be on for up to eleven hours per day, from 8.00am to 7.00pm. Heating and cooling plant, if required, was assumed to operate a two hour pre-control prior to a ten hour control period starting at 9.00am. Comfort limits were taken to lie between 20°C and 24°C. Casual gains in each office cell associated with two people and one electric typewriter were assumed.

Figure 1 shows the heating and cooling demands and peak loads associated with variations of design alternatives from the selected 'standard'. The analysis indicates that:

i) changes to the fabric alone can result in a +16% or a -24% alteration to the winter heating load relative to the standard

ii) double glazing has a similar effect to that of adding a suspended ceiling, namely a 23% saving of winter energy

iii) substituting internal fabric blinds for external blinds in winter saves about 12% which is comparable to the thermal benefit of retaining full light output

iv) there is no apparent advantage in reducing still further, the U-value

v) peak cooling demands do not show an exactly negative correlation with peak heating levels loads, suggesting that a balance in the fabric/services system between winter and summer conditions may be achievable.

From the study, the architect was able to provide a base of relevant data and to conclude generally that 'if a developer seeks to offer a good level of environment it may be advantageous to the tenant in terms of running costs to do so by means of design changes to the building rather than by introducing air conditioning'. On th subject of ESP, the architect stated: "The ESP program is sophisticated; its metho exposes the inadequacy of over simplified approaches to energy modelling . Whilst adequately representing the thermal response of multi-layered elements, ESP endorse at the same time certain commonly held notions. Two such are -

i) the most significant factor in the performance of an external wall is its U-value, and

ii) treatments which limit energy use in winter tend to increase summer cooling an vice versa. By studying sensitivity analyses, however, intermediate solutions can be found "

## 4. CONCLUSIONS

The conclusions from such a necessarily unstructured study have to be based on the concensus view of those involved in it. The following points summarise the concens view.

i) Powerful models of the dynamic energy behaviour of building lead to insights in the causal relationship between design decisions and building performance which could not have been predicted intuitively; if follows, then, that this new generation of design aids have the potential to improve the quality of the built environment. It must also be noted that, in departing from intuitively "known ground", the consequences of data input error are likely to be serious

ii) A powerful model highlights the importance, generaliy, of data and of the criteria against which design alternatives are to be evaluated. A recurring issue in the implementation study was the severity of climate which the build ing should be expected to modify. The notion of climatic severity is, as can be seen from sub-section 3.4, not a simple one and this fact has stimulat further development of the module within ESP which allows analysis of histori cal climate and of a study of the concept of climatic severity related to hou ing [6].

iii) The application of a powerful model to one aspect of the design problem stimu lates the need for comparable tools for complementary aspects of the problem. The use of ESP for thermal analysis led to the acquisition of NATLIT (for prediction of natural daylight levels) and the commissioning of LITPROG (for seasonally adjusted casual gain loads attributable to lighting).

iv) A powerful model is likely to be as applicable to a parametric investigation, in an R&D environment, of causal relationships between design and performance variables as it is to 'front-line' use in the context of a particular design brief. Much remains to be decided regarding the management of parametric investigations but already the batch version of ESP and its recently added facility to provide statistical summaries of parametric relationships, aids the investigation procedures.

v) In (1) to (iv) above, reference is made to extensions to and modifications of ESP. These are a few only of the extensions and modifications implemented in response to the perceived or stated needs of the program users. This feedbac is invaluable to the program authors.

5. ACKNOWLEDGEMENTS

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