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Energy/Environmental Performance Assessment in Practice - Introduction

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An important part of designing buildings can be argued to derive from the practitioner's library of experience accumulated through practice. This case-based process, however, can only be used as a guide when designers are faced with rapidly changing conditions and constraints. For example, the importance of internal gains has increased substantially as both insulation levels and levels of equipment have increased. New materials and advanced glazing systems pose new challenges. Most of these changes tend to increase the importance of interactions between systems and require a better understanding of the dynamics of energy processes occurring in buildings. Computer modelling is a technique which may be able to assist designers. The rapid growth in computing power has led to a considerable increase in availability even in small practices and therefore makes modelling very much a technique worthy of consideration.

Since the 1970s a great deal of effort has been devoted, both in the academic sector and the construction industry itself, to developing calculation methods to enable the thermal performance of buildings to be predicted. Many of even the most advanced software packages are now available on relatively low cost computers. Doubts have been expressed as to how reliable such software is, and, even more importantly, as to how this could be established so that legal liability could be established in the event of problems arising. Procedures for establishing the accuracy of these computer programs are now, for the first time, reaching a stage where independent testing can be performed reliably and consistently. Recent work has shown that this is very important - even the most developed programs have been found to contain errors.

Apart from errors in implementing algorithms, there are a great deal of methodological issues which have to be addressed by the program users. Performance Assessment Methods explaining how particular design issues should be tackled, e.g. for assessing overheating risks, need to be documented so that the many assumptions made are open to scrutiny, and so that QA checks can be made. It is also necessary to establish authoritative sets of data on e.g. climate, occupancy etc. that can be used as input to these programs. These datasets need to be tailored to the particular purpose for which the performance assessment is being conducted. Awareness of such issues has improved markedly in the last few years and the idea that a simple comparison between measurements and predictions can be taken to imply a once and for all validation of a program has become thoroughly discredited. Programs are only tools - used in the correct way, by people who have a good understanding of their limitations, and within their field of applicability, they provide a valuable part of the designers' armoury and can thus contribute to the design of better buildings. A vital part of establishing the field of applicability is the definition of the purposes for which the program will be used. The needs of the Industry must determine the tools used, not the other way round. Any further effort into improving the accuracy or the functionality of predictive tools should be based on real needs.

The Building Research Establishment has therefore sponsored investigations into the use currently made of performance prediction methods and the perceived needs of the Industry. This is regarded as an essential step at this stage in the development of modelling. It is particularly necessary in view of the connection of modelling with target setting and regulation. This BEPAC event allows the organisations who carried out the work for BRE (and ETSU) to summarise the studies performed (questionnaires, surveys, interviews, analysis) and the main conclusions. In addition, a number of individual case studies will be presented to illustrate the way in which performance prediction tools are used in practice.

Building design based largely on
EXPERIENCE

Additional tools needed when conditions & constraints change :

increasing importance of internal gains
new materials
advanced glazing systems, ...

Increasing importance of **interactions between systems** require better understanding of **DYNAMICS** of energy processes

Computer MODELLING may be able to help

Increasing availability of powerful computers makes modelling worth considering

- Since the 1970s significant work done on development of calculation methods for prediction of thermal performance of buildings

- Procedures for establishing accuracy of programs only now at stage where independent testing can be performed reliably and consistently

- Recent work has shown that even the most developed programs contain errors

Accuracy ??

Errors arise in implementing algorithms,
but also ...

from methodological issues which have to be addressed by the program users

'Performance Assessment Methods' (**PAM**s) describe how particular applications should be tackled:
e.g.

- for assessing **overheating** risks & establishing need for **Air Conditioning**
- for carrying out a **Home Energy Rating**
- for **sizing** a heating system, ...

Effect of USER of computer program

bre

The PAMs need to be thoroughly documented so that:

(a) the many assumptions made are open to scrutiny, and
(b) so that **QA** checks can be made

Documentation

PAMs are program specific:

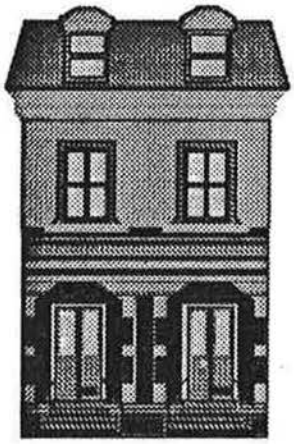
PAM = PROGRAM + INPUT DATA + OUTPUT DATA & INTERPRETATION

A PAM must:

specify the rules for selecting appropriate input data

Input data include **occupancy-related** & **climate** data, and also

the result of
approximating the building design
to the program's internal representation



A single comparison between measurements and predictions is **not** a once and for all validation of a program

BRE work has contributed largely to an improvement in awareness of such issues

BRE has been active in:

- developing tools to assist in consistent **documentation of model assumptions**
- developing and testing **validation procedures**
- establishing appropriate **reference data sets**, published through **BEPAC**
- establishing **Industry needs**

Programs are only tools -

used in the correct way,
by people who have a good understanding of their limitations,
and within their field of applicability

they provide a valuable part of the designers' armoury and can contribute to the design of better buildings

Definition of the **purposes** for which the program will be used is **vital**

Needs of the Industry must determine the tools used

Any **further effort** into improving the accuracy or the functionality of predictive tools **should be based on real needs**

- ***What for?***
- ***Accuracy needed?***
- ***Used at what stage in design?***
- ***What data would be available?***

...

Building Research Establishment sponsored investigations into:

the use currently made of performance prediction methods, and
the perceived needs of the Industry

This is an essential step at this stage in the development of modelling, particularly for **target setting and regulation**

Construction Industry Computing Assoc.
and
Eclipse Research Consultants

carried out investigations for **BRE** and **ETSU**

The following presentations will describe this work and the main conclusions

Individual case studies illustrate how performance prediction tools are used in practice

A Building Environmental and Energy Design Survey

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Director of CICA Services Limited

In Spring 1990, under a commission from the Building Research Establishment and the Energy Technology Support Unit, the Construction Industry Computing Association surveyed vendors of thermal modelling software, users of such software, and a selection of building designers.

The prime objectives of the vendors survey was to gather information on available programs, the number of firms using them, and their vendors' opinions on factors believed to inhibit or promote the wider usage of such programs.

The surveys of known program users and representative contruction industry groups were undertaken to gather information indicating the levels of building environment and energy calculation with and without the use of computers and to assess which factors inhibit building environment and energy calculation most strongly.

In Spring 1991, under a second phase, CICA in conjunction with Eclipse Research Consultants, carried out a series of structured interviews with respondents to the postal surveys in order to explore their reasons for using and not using calculation and computing methods to predict energy and environmental effects, and to gain further understanding of when and how designers consider energy matters.

This paper describes the work undertaken and presents some of the findings of these studies.

Program Vendors Survey

16 vendors of environmental and energy analysis software were surveyed, 8 responded with details of the programs they offer, the assessments supported by different programs and the methods employed, together with the numbers of users of their software falling in different categories. This information, together with information on the primary and secondary activities of the vendor firms, their staffing, turnover, development plans, and comment on factors that affect the use of assessment programs and might encourage greater usage are summarised in the survey report.

In general, building services consultants and environmental/energy consultants were the heaviest users of the programs represented, although ENERGY/1, Richard Twinch Design's basic building regulation conformance checking and condensation risk analysis program, was used mainly by architects.

Some vendors claimed significant number of users. HEVASTAR from Hevacomp was said to have attracted a total of 1010 users since its launch in 1978; Cymap claimed 600 users of ENERGY, a program launched in 1984. However, the number of user firms claimed was modest when compared with total number of construction industry firms that one would expect to be concerned with environmental/energy design issues.

The General 'Designers' Survey and the Survey of Known Program Users

CICA conducted a general survey of 300 organisations. 60 firms in each of the 5 following categories were surveyed: architectural practices, local authorities, building services engineers, house builders, and housing associations.

CICA also surveyed 94 firms drawn from the users lists supplied by 4 vendors of computer programs for energy/environmental assessment (the Energy Advisory Service, Facet, Hevacomp, and Richard Twinch Design).

Table 3.1 depicts the survey response and the staffing profiles of the respondents.

Both surveys were essentially the same. The firms were asked about their activities, staffing, workload profiles, inhouse energy and environmental assessments, calculation methods, program usage, use of external consultants, factors inhibiting calculations, factors that might encourage calculations, their general computer usage, and planned computing purchases. The responses relating to all of the above areas are analysed in the survey report. The types of assessments firms were asked about and the general profiles of the assessment activities (with or without computers) of the different groups are shown in Table 3.8.

Table 3.1 Survey response and staffing profiles of respondents

	Designers survey					User survey							
Number of organisations responding: **Designers survey** by survey categories (60 were surveyed in each group) User survey by primary activities claimed	Architects	Local Authorities	Building services consultants	House builders/ contractors	Housing associations	Multi-professional	Architects	Local authorities	Building services eng.s	Environ. consultants	Contractors	Material producers/ suppliers	Research/teaching
No. of responses by group	10	11	11	11	17	4	9	1	10	6	1	1	2
% response by group	17	18	18	18	28	Not applicable, full details unknown in advance							
Size distribution													
1 - 9 staff	4	–	1	1	2	–	1	–	2	2		–	–
10 - 49 staff	3	1	3	4	7	–	6	1	4	4	1	–	1
50 - 99 staff	1	1	2	5	4	1	1	–	1	–		–	–
100 - 500 staff	2	6	3	–	4	–	–	–	2	–		1	1
Over 500 staff	–	1	2	1	–	3	–	–	–	–		–	–
Avg.%staff taking decisions	46	18	37	13	17	[A]	50	[A]	30	29	[A]	[A]	[A]

Notes
[A] Response too small to permit or merit averaging numbers of staff involved

3.8 General profiles of the assessment activities

	Designers survey					User survey			
Percentages of respondents undertaking different types of assessments by category **Survey group** **Assessment type**	Architects	Local Authorities	Building services consultants	House builders/ contractors	Housing associations	Multi-professional	Architects	Building services eng.s	Environ. consultants
Building regulation checking	60	81	100	40	12	100	89	90	80
Annual energy prediction	10	64	100	10	–	100	33	100	100
Plant sizing	–	91	100	10	–	100	22	100	60
Condensation risk analysis	40	91	100	20	12	100	100	90	80
Temperature/humidity levels	20	73	100	20	12	75	22	100	80
Ventilation rates	30	82	100	20	12	75	11	90	60
Natural lighting levels	20	64	100	10	5	100	22	70	60

The assessment practices and program usage by architects and building services consultants responding to both the general designers survey and the survey of known program users were analysed separately with the following findings.

Architects responding to general survey - Building regulations checking was the most common type of assessment (claimed by 6 of the 10 respondents), 4 firms claimed to undertake condensation risk analysis, 3 claimed the calculation of ventilation rates. Most strikingly, only 1 firm claimed to be using a computing program (for annual energy prediction and condensation risk analysis), but the respondent could not name the program used. None of the firms carried out iterative assessments of any type on any building types.

Architects responding to the survey of known program users - Building Regulations checking and condensation risk analysis were again the most common assessments and both were generally undertaken using computer methods. Annual energy prediction (normally by computer) and assessment of natural lighting levels (manually) were undertaken by only 1/3 of the respondents). Iterative use of energy/environmental assessments occurred to a significant extent only for condensation risk analysis calculations.

Building services consultants responding to general survey - The responses revealed a predictably large range of assessments and heavy usage of computer programs particularly for annual energy prediction, condensation risk analysis, and temperature/humidity level prediction. Heavy repeated assessment practices were associated with plant sizing and temperature/humidity level prediction, particularly on larger building types. Although the consultants had programs for most types of assessments, they did not necessarily use them to repeat assessments.

Building services consultants responding to the survey of known program - The profile of assessment and computer usage was similar to that of the designers survey group, but the 'user' group had more programs available for similar assessment categories.

Local authorities responding to the designers survey - Analyses of the data supplied by the 11 local authorities that responded to the designers survey showed that they undertook a wide range of energy/environmental assessments, in the main depending on steady state and CIBSE guide methodology. The made heavy and frequent use of computer programs, and tended to repeat assessments on larger building types, particularly educational and other public buildings.

Housebuilders/contractors responding to the general survey - With the exception of 2 housebuilding firms (one undertaking annual energy prediction and ventilation assessments, the other temperature /humidity level assessments), the levels of assessment other than Building Regulation checking can be traced to the responses from the head office of a very large multidisciplinary general contracting firm and 2 other firms that claimed Architect as a secondary activity.

Housing associations responding to the general survey With the Housing associations, the percentages that undertook assessments other than Building Regulations checking can be traced to 2 of 4 housing associations that described themselves as also being Architects or Building Surveyors. By and large this group does not undertake energy/environmental assessment with or without computers, the exceptions are those supporting inhouse design groups.

Rating of factors inhibiting energy/environmental assessments and factors that might encourage assessment

Each survey group was asked to rate the importance of a range of factors in inhibiting or promoting energy/environmental assessment calculations. The ratings are summarised below.

Architects - The factors inhibiting calculation rated most highly by the architects responding to the general designers survey were of lack of familiarity with calculation methods. These were followed by the extra time and extra cost incurred in calculation and fear of increased liability. However the response on inhibiting factors was very small.

The architects in the group of known program users again cited unfamiliarity with calculation methods and lack of time to adopt new techniques, but also rated lack of suitable software highly as an inhibiting factor. However, this group, which was more familiar with calculation aids, rated extra cost and time incurred in calculation, fear of increased liability, and client unwilling to pay design cost significantly lower than the architects responding to the general designer survey.

Both survey groups rated concern with the environment, concern over energy costs, and concern for the comfort of building occupants, and desire to avoid building failures most highly as factors liable to encourage more calculation.

The views of the architectural practices responding to the users survey are illustrated in the Table 4.2 Under VI (for Very Important) and AI (for Average Importance) are the number of firms assigning those ratings to the factors listed.

Table 4.2 Users survey — Views of Architects responding

Factors affecting assessments (9 responses)

Factors	VI	AI	Score	Bar graph
Unable to demonstrate benefits	2		0.44	
Client unconcerned w/ energy cost	1	5	0.78	
Clients' desire for quick return	1	3	0.78	
Designer unfamiliar w/ calculation	4	3	1.22	
Extra cost incurred in calculation		3	0.33	
Extra time incurred in calculation	1	3	0.56	
Client unwilling to pay design cost		5	0.56	
Fear of increased liability	2	1	0.56	
Liability for bldgs not meeting targets	1		0.22	
Lack of time to adopt new techniques	2	5	1.00	
Lack of necessary data	2	2	0.67	
Lack of suitable software	5	2	1.33	
Lack of suitable computer equipment	2		0.44	
Lack of faith in calculation methods		4	0.44	
Energy is not a significant factor		2	0.22	
Other:				

Factors that might encourage assessment (9 responses)

Factors	VI	AI	Score	Bar graph
Desire to offer better service	3	3	1.00	
Concern with the environment	4	3	1.22	
Concern over energy costs	5	3	1.44	
Comfort of building occupants	3	5	1.22	
Better education on energy matters	1	4	0.67	
The new building regulations	3	3	1.00	
Energy performance labelling of houses	2	3	0.78	
Easier to use computer programs	2	4	0.89	
Ind. endorsement of calc. methods	2	3	0.78	
Cheaper computer programs	2		0.44	
Better computer programs	3	2	0.89	
Better marketing of computer programs	2	1	0.56	
Integration with other software	3	1	0.78	
Avoidance of building failures	5	1	1.22	
Other:				
Other:				

Table 4.6 Users survey — Views of Building services consultants responding

Factors affecting assessments (9 responses)

Factors	VI	AI	Score	Bar graph
Unable to demonstrate benefits	1	1	0.33	
Client unconcerned w/ energy cost	5	1	1.22	
Clients' desire for quick return	5		1.11	
Designer unfamiliar w/ calculation	3		0.67	
Extra cost incurred in calculation	2	2	0.67	
Extra time incurred in calculation	4	1	1.00	
Client unwilling to pay design cost	6	3	1.67	
Fear of increased liability	1		0.22	
Liability for bldgs not meeting targets	3		0.67	
Lack of time to adopt new techniques	4	1	1.00	
Lack of necessary data	2	3	0.78	
Lack of suitable software	2		0.44	
Lack of suitable computer equipment	2	1	0.56	
Lack of faith in calculation methods	2	1	0.78	
Energy is not a significant factor	2	1	0.56	
Other: 'Cost of suitable software'	1		0.22	

Factors that might encourage assessment (9 responses)

Factors	VI	AI	Score	Bar graph
Desire to offer better service	7	1	1.67	
Concern with the environment	4	3	1.22	
Concern over energy costs	7	1	1.67	
Comfort of building occupants	5	1	1.22	
Better education on energy matters	4	3	1.22	
The new building regulations	5	3	1.44	
Energy performance labelling of houses	2	4	0.89	
Easier to use computer programs	5	2	1.33	
Ind. endorsement of calc. methods	2	2	0.67	
Cheaper computer programs	4	2	1.11	
Better computer programs	4	2	1.11	
Better marketing of computer programs	1		0.22	
Integration with other software	4	1	1.00	
Avoidance of building failures	2	1	0.56	
Other:				
Other:				

Table 4.7 Designers survey — Views of House builders/contractors responding

Factors affecting assessments (5 responses)

Factors	VI	AI	Score	Bar graph
Unable to demonstrate benefits		1	0.20	
Client unconcerned w/ energy cost		3	0.60	
Clients' desire for quick return		2	0.40	
Designer unfamiliar w/ calculation		2	0.40	
Extra cost incurred in calculation		2	0.40	
Extra time incurred in calculation		2	0.40	
Client unwilling to pay design cost	1	2	0.80	
Fear of increased liability	1	1	0.60	
Liability for bldgs not meeting targets	1	1	0.60	
Lack of time to adopt new techniques	1	3	1.00	
Lack of necessary data	1		0.40	
Lack of suitable software	1		0.40	
Lack of suitable computer equipment	-	-	-	
Lack of faith in calculation methods		1	0.20	
Energy is not a significant factor		3	0.60	
Other: 'Not pushed to do it by market.'		1	0.20	

Factors that might encourage assessment (11 responses)

Factors	VI	AI	Score	Bar graph
Desire to offer better service	5	3	1.18	
Concern with the environment	6	3	1.36	
Concern over energy costs	7	3	1.54	
Comfort of building occupants	5	5	1.36	
Better education on energy matters	2	5	0.82	
The new building regulations	7	1	1.36	
Energy performance labelling of houses	4	3	1.00	
Easier to use computer programs	2	1	0.45	
Ind. endorsement of calc. methods	1	2	0.36	
Cheaper computer programs	3		0.54	
Better computer programs	2	2	0.54	
Better marketing of computer programs	1	2	0.36	
Integration with other software	2	1	0.45	
Avoidance of building failures	4	1	0.82	
Other:				

Table 4.8 Designers survey — Views of Housing Associations responding

Factors affecting assessments (7 responses)

Factors	VI	AI	Score	Bar graph
Unable to demonstrate benefits		3	0.43	
Client unconcerned w/ energy cost		1	0.14	
Clients' desire for quick return		2	0.28	
Designer unfamiliar w/ calculation	2	2	0.86	
Extra cost incurred in calculation		3	0.43	
Extra time incurred in calculation		3	0.43	
Client unwilling to pay design cost	1	1	0.43	
Fear of increased liability		1	0.14	
Liability for bldgs not meeting targets		3	0.43	
Lack of time to adopt new techniques	2	3	1.00	
Lack of necessary data	2	4	1.14	
Lack of suitable software	1	3	0.71	
Lack of suitable computer equipment		1	0.14	
Lack of faith in calculation methods		1	0.14	
Energy is not a significant factor	2	1	0.71	
Other: 'More research required by firm'	1		0.28	
Other: 'B. Regs allow simple methods'	1		0.28	

Factors that might encourage assessment (16 responses)

Factors	VI	AI	Score	Bar graph
Desire to offer better service	10	3	1.44	
Concern with the environment	8	6	1.38	
Concern over energy costs	15	1	1.94	
Comfort of building occupants	13	3	181	
Better education on energy matters	6	6	1.12	
The new building regulations	8	8	1.50	
Energy performance labelling of houses	2	9	0.81	
Easier to use computer programs	4	5	0.81	
Ind. endorsement of calc. methods	4	2	0.62	
Cheaper computer programs	2	3	0.44	
Better computer programs	4	2	0.62	
Better marketing of computer programs	2	2	0.38	
Integration with other software	3	1	0.44	
Avoidance of building failures	10	1	1.38	
Other: 'Standards'	1		0.12	
Other:				
Other:				

Building services consultants - The response on inhibiting factors from the designers survey group was very small, but the most highly rated factors were client's desire for quick return on investment and clients' unwillingness to pay design costs, followed by clients' lack of concern with energy cost. These factors were also rated highest by the building services respondents to the survey of known users.

Both survey groups rated desire to offer a better service and concern over energy costs highly as factors that might encourage more calculation. Respondents to the designers survey also rated concern for the comfort of building occupants very highly, and gave a higher rating to avoidance of building failure (much higher than their counterparts in the user survey group). This is odd because there was little to distinguish between the two survey groups.

Vendors comments - Building clients' lack of concern with energy costs was rated most highly by the vendors as a factor inhibiting wider program usage and conversely an increase in concern for energy costs was deemed the factor most likely to encourage environmental/energy calculations. Other highly rated inhibiting factors included: the extra cost incurred in calculation, the extra time incurred, and the lack of time available to users to adopt new techniques.

The data for the views of the building services consultants responding to the users survey and the housebuilders/contractors and housing associations responding to the general designers survey are presented in the Tables 4.6, 4.7, and 4.8.

Summary of views - Looking across the survey responses, both the designers groups and the groups of known program users agreed on the main inhibiting factors as:

- lack of time to adopt new techniques
- client unwilling to pay design cost
- extra time involved in calculation
- client's desire for a quick return

There was also broad agreement between the two groups about the main factors which would encourage wider use:

- concern over energy costs
- comfort of building occupants
- desire to offer better service
- concern with the environment
- the new Building Regulations
- avoidance of building failures

Factors relating to the design and analysis programs themselves, such as better marketing of programs, independent endorsement of calculation methods, cheaper computer programs, and integration with other software, were not that highly rated as a means of encouraging the take up of computing aids. The implication is the computer industry can itself do little to promote energy calculation; what is needed is a change in the climate of opinion.

The case studies

Face to face interviews conducted with individuals from 13 organisations form the basis of the case studies published in the report. In addition follow-up telephoned interviews were conducted with individuals from 8 other organisations directly involved in the building projects and an environmental consultant. These interviews are also documented.

Perhaps the most important outcome of the case study interviews was that they confirmed the validity of the data collected from the postal surveys. They also document the manner in which decisions were taken which affected the energy/environmental performance of the buildings that served as the bases of the case studies.

Table 6.4.1 lists some of the key design decisions taken during the design process and tabulates the decisions against who took them. Overall there is a clear progression. As the decisions move from the site layout and orientation towards heat loss and plant sizing, the building services consultants take over from the architects.

As discussed above, the postal survey data indicated that Architects in general do not undertake a wide range of energy/environmental calculations. Those surveyed were primarily concerned with Building Regulation checks and condensation risk analysis and it appears that their use of the latter was directly linked to a concern to avoid building failures. In the main, (there are notable exceptions in the case studies), architects seem ill equipped to deal with other types of energy/environmental analysis and are dependent on building services engineers or other purveyors of design expertise to perform the calculations required, and cannot or do not always choose to expend money to avail themselves of advice.

As Eclipse Research observed in their report when summarising the results of the CICA surveys: "performance issues such as daylight levels, ventilation rates, and annual energy consumption, are not designed as the result of any form of calculation by the architects. They may be the outcome of analyses done by other supporting consultants, such as building services engineers, but as the extent of iterative joint working between architects and engineers remains largely unknown, this cannot be gauged." (Although the survey report case studies contain examples of close iterative joint working, overall, CICA would suggest this is not the norm.)

Table 6.4.1 Decision taking

Item Project	Site layout & orientaton	Building fabric	Fenestration	Heating/cooling	Ventilation	Lighting
CS 1: Doctors surgery £400,000	Architects	Architects	Architects	Architects	Architects	Architects
CS 2: Housing Scheme £2,35 0,00	Architects	Architects (Utility Co)	Architects (Client spec.)	Architects, Client QS, Utility Company	Architects	Architects
CS 3: Sheltered Housing £1,700,000	Architects	Architects (to Client's spec.)	Architects (to Client's spec)	BS engineers (to Client's spec)	BS Engineers (to Client's spec)	BS engineers (to Client's spec.)
CS 4: Business Promotion Centre 4,000 m^2	Architects	Architects BS engs & Client	Architects BS engs & Client	BS engineers Architects & Client	BS Engineer Architects & Client	BS Engineers Architects & Client
CS 5: School addition' £250,000 [200 m^2]	Architects	Architects	Architects	BS Engineers	BS Engineers	BS Engineers (Architect for esthetics)
CS 6: School addition 120 m^2	Architects	Architects	Architects	BS Engineers	Architects	BS Engineers
CS 7: Speculative office block 1,200 m^2	Architects (Developer)	Architects QS & Developer	Architects (BS Engineers)	BS Engineers Developer	BS Engineers	BS Engineers Tenant
CS 8: Speculative office block 3,600 m^2	Architects (Client & Letting Agent)	Architects, QS. Planners	Architects Letting Agent & BS Eng	BS Engineers (Letting Agent)	BS Engineers (Letting agent)	BS Engineers (Letting agent)
CS 9: Speculative office development 15,000 m^2	Architects, Eng QS, Developer	Architects, BS Eng.s QS, Developer	Architects, QS BS Engineers	BS Engineers	BS Engineers Developer	BS Eng, Architect Developer, Tenant
CS 10: Prison £75 million.	Architects (to previous design)	Architects (to previous design)	Architects (to previous design)	BS Engineers (to previous design)	BS Engineers (to previous design)	BS Engineers (to previous design)
CS 11: Superspec houses	(Standard design)	Energy consultant (Developer's Tech staff))	Energy consultant (Developer's Tech staff))	Energy consultant (Developer's BS Engs)	Energy consultant (Developer's Tech staff))	Developer Energy consultant
CS 12: Large single houses £800,000 each	Architects House developer	Architects House developer	Architects House developer	Arch.s, Subcontractor Supplier, Developer	Arch.s, Subcontractor Supplier, Developer	Arch.s, Subcontractor Developer
CS 13: Mental Health Resource Centre £380,000	Architects	Architects (Planners)	Architects (to client spec.)	BS Engineers (client temp. spec)	Architect BS Engineers	BS Engineers (to client spec.)
CS 14: Housing development £1,800,000	Architects (Planners & Highways)	Architects (to previous designs)	Architects (to previous designs)	Arch.s, Contractor Council's BS Engs (1)	Arch.s, Contractor Council's BS Engs (1)	Arch.s, Contractor Council's BS Engs (1)

[1] Some of the house types were fully designed by the Council's architects and engineers

Eclipse continued: "If the extent of iterative joint working is low (that is building decisions on form, orientation, fabric, and fenestration are taken by architects before building services engineers are involved, or even before they are commissioned, and if the iterations known to be undertaken by building services engineers do not cross the boundary to influence the prior decisions by the architect) then it would appear that the influence of any sort of calculation method, whether manual or computer-based, on building form and orientation is extremely low."

CICA concurs with this observation, the building projects illustrated in the case studies where architects adopted a pro-active approach to energy/environmental issues and worked closely with their building services engineers appear to represent best practice, permitting the engineers to contribute in the most positive fashion, and leading to thermal modelling being exploited in the earlier phases of the design process rather than merely as a means of ensuring a satisfactory performance of services to meet the heating/cooling loads of pre-established fabric designs.

However there are many factors that constrain this pattern of working, these include:

- Clients general reluctance to expend money on design fees
- Building services consultants' reluctance to engage in early unpaid 'architectural' design
- Speculative fee tendering
- Speculative design practices
- Developers preference for short term savings in capital cost over long term savings which may be reaped only by their tenants (Quantity surveyors may act to reinforce this preference)
- Inadequate attention generally to energy/environmental matters which is reflected in client briefing (or lack of briefing)

Energy/environmentally conscious design may also be inhibited by real or perceived market requirements and the inherent complexity of the design and procurement process.

As John Newton, an independent environmental consultant, who has acted on behalf of large private developers observed:

"The problem is that the whole process of building and selling developments is so complicated and there are so many people involved that it is difficult to get policy decisions transferred through to the end product."

Conclusions

The use of computers for energy and environmental analysis by designers was strongly divided by type of firm: almost all Building Services consultants and Local Authorities responding to the surveys used assessment programs and carry out most types of assessments; Architects, Housebuilders and Housing Associations generally did not.

Availability of computers in the responding firms was generally high and access to equipment did not appear to be a problem.

Although integration of analysis and design programs with CAD did not appear to be a major factor in encouraging more calculation, there was a significant interest in integration shown by the more sophisticated computer users.

Most of the inhibiting factors are associated with clients' lack of interest in energy/environmental issues and their unwillingness to pay for assessments to be undertaken. Private sector clients' choice of short term savings in capital expenditure rather than long term savings is a major problem, which can perhaps only be overcome by coercive penalties (like a carbon tax).

The example calculations were enclosed with the Designers survey questionnaire which showed that energy calculations need not be complex or time consuming. Nevertheless, the extra time incurred in learning new techniques and in carrying out calculations are perceived as major inhibiting factors by designers.

There was little general criticism of available programs or feeling that they need to be cheaper or their calculation methods endorsed. However, building services engineers commonly run test data through each new release of software. They were concerned about the cost of program validation and, increasingly, the need to fulfil Quality Assurance requirements.

Some designers, particularly architects, need to be given a greater awareness and training in the benefits and techniques of energy and environmental assessments. There is no shortage of equipment or lack of belief in the software, but rather a dearth of incentive and awareness. In general, the pro-activeness of designers in encouraging clients to tackle energy is very important and should be encouraged.

There is a need to examine current architectural training. Architects should leave their initial training with a good understanding of the principles of building services design and of good practice in energy/environmental design. The use of appropriate energy/environmental computing aids should be part of their curriculum. It will prove much more difficult to make up for any deficiencies through subsequent Continuing Professional Development training.

However, CPD courses on energy/environmental issues and calculation methods, organised by professional and academic institutions, should be surveyed, the relevance of their contents reviewed, and improved in-service training promoted.

Designers and clients must be made more aware of sources of advice and expertise on energy/environmental matters. Existing sources of good practice guidance should be evaluated and attempts made to improve the quality of the energy/environmental design information and procedures they contain.

Exemplary practice and good practice guidance on energy/environmental briefing and calculation procedures should be prepared (geared to individual types of designers) and disseminated to individual target audiences, including clients.

An initiative to improve the ease of use and ease of learning of energy/environmental assessment programs, and building services analysis and design programs generally, should be undertaken. Programs should incorporate help systems (operable at different assistance levels) that make them learning as well as productivity tools.

The Building Regulations should be reviewed in light of the fact that knowledgeable designers do not believe they encourage good design, particularly in relation to air tightness and condensation.

In the light of QA requirements, the onus of transparent (verifiable) validation of their own software releases may have to be taken up by software vendors. (Users may still have to validate software, but vendors may have to make validation much easier.)

In closing, CICA would like to thank all the individuals and firms that participated in the surveys and interviews for their contribution of time and effort.

Designers' Experiences in Using Energy and Environmental Modelling

Sebastian Macmillan
Eclipse Research Consultants

Why do some designers use energy modelling to assess the performance of their building? What are the advantages and disadvantages? How can an appropriate computer program be selected? What are the implications on fees and methods of working? What are the effects on a building and its performance? Should modelling be more widespread among engineers, and how could this be achieved?

In a study recently completed for the Building Research Establishment we were asked to look at how energy modelling was used in practice and the effects it was having on real buildings. To answer these questions we set out to identify those known to be using computer modelling. We began by a "contact survey" which we sent out to BEPAC members, to those identified through a literature search, and to our personal contacts. We asked the recipients to tell us whether they were using energy modelling and to identify four other users. We sent out 36 letters and got 19 replies. 59 contacts were identified - but only 20 of these were unknown to us. We wrote to the 20 and between them they identified only 9 new contacts. A chain letter of this kind might be expected to spread out through a population, but what we found was the opposite - a kind of spiralling in towards a relatively small circle of those who are using the most advanced performance assessment programs.

We selected 19 to interview - mostly engineers, but also energy consultants, architects, a fuel utility, local authorities, a computer bureau, and a design and build contractor. We purposely avoided engineering companies who are marketing their own programs, as well as vendors of programs (even those who provide a bureau service). Although we tried to eliminate one sort of bias, those who took part in the telephone survey and case studies are not typical or representative. This is important - we sought to understand the views of those who are using modelling at the same time excluding those who are seeking to promote one particular program.

We asked interviewees a fixed set of questions about their use of modelling in an open ended but structured telephone interview. The following picture emerged from these interviews.

Why was modelling used and what was it used for?

Steady state methods are used for whole buildings for plant sizing. Where modelling was undertaken the main reason given was the desire to reduce the perceived risks of poor performance - such as overheating from excessive solar gain and/or internal gains. Typically part only of the building would be selected (such as a south facing office, classroom or atrium) within which detailed aspects of performance would be investigated - such as air movement or peak summertime temperatures. A building had to be of a certain size, or the risks sufficiently large, to warrant dynamic modelling.

When asked about the alternatives to modelling, almost all the respondents said there were none to answer the questions they were asking about building performance.

What were the perceived benefits?

Several benefits were consistently identified. The key ones were:

- greater confidence in how the building would perform and greater understanding of building performance in general
- speed
- the potential for iterative working.

In design teams improved communication between members, arising from better presentation, was reported as leading to greater credibility. Clients benefit too - from accurate information about how their building would perform.

Impact on building design

There was a strong consensus that the use of modelling led to improved building design. This was reported as arising from iterative working in which technical options - building shape, form, and complex spaces - could be evaluated. Predictions were more accurate and sensitivity runs could help in checking how to rectify problems.

Three quarters of the interviewees reported that modelling led to a reduction in annual energy consumption and energy costs, with estimated savings varying from 10-50%. The remaining quarter were more circumspect, although no-one said modelling increased consumption.

On occasion modelling could lead to dramatic savings in the capital cost of buildings through the elimination of unnecessary plant. Savings could also arise by reducing cumulative design margins in manual calculations. However, modelling could also lead to increased initial capital costs.

However almost all the claims about energy and capital cost savings appeared to be based on intuition rather than any formally costed analyses of the energy benefits of various energy efficiency measures. Energy efficiency does not appear to be the driving force behind the use of performance assessment.

Impact on ways of working and fees

The impact on the design process and the sequence of decisions was reported as minimal. There was no consensus about the impact of modelling on design time - some said it was reduced, some said increased and some said it had no effect. The cost of using steady state programs appears to be absorbed, but additional fees are negotiated for more complex modelling.

The advantages of modelling

The most frequently identified advantages of modelling were described as:

- speed
- the ability to assess a wide range of options iteratively
- confidence in the results - for the designer and the client
- credibility in presenting information to others - both the client and other members of the design team
- programs provide sophisticated and comprehensive information.

The disadvantages

The most frequent disadvantages cited were:

- the high levels of skill and experience in both building design and modelling needed to run a model, and the time and cost implications of the learning curve
- risks associated with the *garbage in, garbage out* syndrome, including the ease of making mistakes and failure to identify irrelevant or erroneous results, partly associated with the seductive quality of the output
- the risk of analysing too many options through failure to analyse the problem in advance
- the time needed to input the building description, giving rise to concerns about productivity
- high cost of software and hardware
- lack of suitable programs.

The criteria used to select a program

There was broad agreement about the following criteria:

- productivity - a high ratio between the value of the information provided and the effort in entering the data
- simplicity and ease of use including clear input routines
- pedigree/accreditation/validation/quality control
- low cost
- good documentation including descriptions of the algorithms
- robustness and user support.

Some of the interviewees had developed their own in-house programs or spreadsheets. Many of the others had a long-standing association with the program developers.

The barriers to modelling and how to overcome them

Although our sample was biased towards those who are using modelling day to day, they are well aware of the barriers, and made a variety of suggestions of how modelling could become more widespread:

- greater incentives for energy efficiency, together with energy targeting and labelling
- better and more widespread marketing of programs to clients and consultants
- demonstrations, pilots and grants for training, and better undergraduate training in energy
- software improvements - better, simpler cheaper, easier to use and quicker programs, with improved interfaces and enhanced graphics
- independent and authoritative reviews, regular updated, of programs and their capabilities
- greater involvement of the professional institutions and changes to their fee scales to incorporate modelling as an activity.

Conclusions

The overall conclusions from the study were:

- modelling has been promoted as a means to increase the energy efficiency of buildings, but in practice its use appears to be almost exclusively concerned with internal environmental performance issues
- there appears to be no (or very limited) expectation from clients to have energy performance predicted - so there is little demand-pull for modelling
- modelling is still the preserve of a relatively limited circle of engineering (and other design) practices - whose interests are in the interaction between climate and building performance. For them, there is no alternative to computer modelling because they are asking questions (largely about climate sensitive buildings) which other designers do not ask.
- the terminology is still emerging - one engineer's "modelling" is another's "performance assessment" - implying a need for some kind of taxonomy of calculation procedures - perhaps alongside a review of the capabilities and functionalities of energy programs

There are some official incentives for using modelling. For example both CIBSE and RIBA issued energy policies to their members in 1990. The CIBSE policy calls on members to take action to reduce global warming - including considering the relative merits of alternative energy sources, advising on the best solution for energy efficient structures and systems, and promoting the use of air conditioning only where necessary. The RIBA's advice to its members included using BS 8207, designing buildings that are sensitive to climatic influences, and specifying low-energy fabric, plant and controls. BS 8207 *British Standard Code of Practice for Energy Efficiency in Buildings* itself calls for designers to adopt calculation methods for estimating energy requirements that take into account the complex interactions between the climate, the fabric, the plant and the occupants, and to compare design options in terms of the cost effectiveness of energy efficiency measures. Arguably, the analyses necessary to respond actively to these requirements demand the use of thermal modelling.

Recently BS 7750: 1992 *Specification of Environmental Management Systems* was published. It could be interpreted as promoting environmental quality at both internal and external levels. As such it seems to provide further potential incentive for thermal modelling. But it is not yet clear whether building design teams and their clients will decide to respond to it. How will its impact compare to that of BS 8207?

Performance Assessment in a Multi-Disciplinary Practice - The Design of Refuge House

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Director of BDP Energy & Environment

ABSTRACT

Over the last decade or so designers of office buildings have had to respond to the changing pattern of office-based activities and to the rising expectations of office staff, facilities managers, building owners and funding institutions. The need to keep operating costs down (particularly energy costs) is increasingly acknowledged, but investment in measures to achieve this end is often severely constrained by development economics. These technical and financial considerations have been joined more recently by a range of environmental concerns, not all of which are well understood.

Over the same period the same information technology that has so radically altered the modern office has provided designers with a range of tools to support their design work and to enable them make assessments of how well (or badly) the resulting buildings might perform in use.

This case study, drawn on the experience of the design of a new headquarters for one of the UK's major insurance companies, gives an insight into the approach to office design taken by a leading multi-disciplinary design practice. The resulting building has not only been warmly received by the owner and staff alike, it is also widely acknowledged to be a successful example of an emerging trend in office design.

INTRODUCTION

There have been a number of significant changes in the working environment of offices in recent years. These changes reflect a shift in the nature of office work that is largely due to the influence of information technology. Concern over energy use coupled with the wish to contain running costs have also encouraged design innovation. Latterly these influences have been joined by concerns for the health and well-being of office staff, and for the impact that buildings have on the wider environment.

Designers responding to these influences appreciate that the temperate climate of the UK provides opportunities for buildings to be energy efficient by being climate responsive. Buildings designed according to 'passive' design principles (as they are sometimes known) are characterised by narrower plan forms for good daylighting and to permit natural ventilation, they are sensibly oriented to avoid excessive solar gains through windows, and they have engineering systems that are no more complex than circumstances demand. The result is buildings that are more in tune with the environment.

It is a paradox, however, that these (seemingly) simple buildings require a greater understanding of building physics and environmental design principles than their (apparently) more complex counterparts. This is because designers need to assure themselves and their clients that these buildings will be able to cope with the demands that will be placed upon them on completion and into the future. It is only relatively recently that designers have had access to the design assessment tools that enable them to confidently embrace 'passive' design.

The designer's response to these issues is well illustrated by the design of Refuge House in Wilmslow, Cheshire - the new headquarters of Refuge Assurance.

Refuge Assurance plc, with 3,800 staff in 160 offices throughout the UK, is one of Britain's major life and general insurance companies. Its headquarters have, since the turn of the century, been in Manchester's Oxford Street.

By the early 1980's it had become apparent that the Oxford Street offices could no longer be economically adapted to Refuge Assurance's changing office operations, nor to the rising aspirations of their staff. Accordingly Refuge Assurance began an exhaustive appraisal of sites for a new headquarters. The Company wished to remain in the Manchester area, and investigated various sites both in the city centre and within the conurbation generally. From a short list of five possible available sites Fulshaw Hall near Wilmslow was selected and subsequently purchased. Building Design Partnership (BDP) were commissioned in 1983 for all design disciplines and Refuge Assurance moved into their new headquarters in November 1987.

CONTEXT

Recent developments in office planning reflect the influence that micro-computers and information technology generally is having on the pattern of office work. Many organisations are finding that deep-planned office space cannot meet all of their requirements; meetings are taking an increasing proportion of staff time and employees that spend long periods working at computer screens need the opportunity to gaze occasionally at a distant scene to relax their eyes. The burolandschaft offices of the 1970s are proving rather inflexible in meeting these needs and the trend in certain office sectors is to return to more narrow plan forms. These more readily allow a mix of cellular and open-plan office space and provide all staff with reasonable access to a window.

A further influence is the trend towards multiple tenancies. More than 50% of offices in the UK are now divided in this way. In anticipation of this demand office buildings are increasingly being designed with either common or potentially separate access and circulation areas. Even organisations planning to own and fully occupy their own buildings are tending to specify that their buildings should be designed to allow sub-division. This ensures a future place in the market for the building - a factor which, understandably, is of major concern to funding institutions.

Narrower plan forms have a number of positive attributes in terms of energy efficiency as they enable more effective use to be made of daylight and, where appropriate, natural ventilation. These positive attributes are to some extent counter-balanced by relatively higher heat losses in winter and higher solar gains in summer. However, the evidence suggests that, in the temperate climate of the UK, narrow-plan forms are more energy efficient than deep-plan forms.

This was the general conclusion reached in a study on the potential for passive solar energy in non-domestic buildings carried out in 1982 for ETSU by BDP Energy & Environment and the Martin Centre of Cambridge University. For offices, the potential for displacing energy used for lighting (by effective use of daylight) was found to be almost double the potential for displacing energy used for heating (by useful solar heat gain in winter). Displacement of energy used for lighting is much more valuable than savings in heating energy - due to the relatively higher cost of electricity compared to other fuels. In offices, where lighting often represents the most significant and costly use of energy, an overall 20% reduction in lighting energy due to improved daylighting was considered to be achievable.

Improved utilisation of daylight, which implies the switching of lighting in relation to daylight availability, is not the only means of reducing lighting energy demand. In recent years we have seen a reduction in illumination levels, significant improvements in the energy efficiency of lamps and a departure from general illumination toward more task related lighting. As a result, lighting loads and their attendant heat gains have reduced from the 50W/m^2 typical of the early 1970s to around 15W/m^2 in recent installations.

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If this reduction in lighting energy were the only significant influence on internal heat gains we might have seen a reduction in the demand for air-conditioned offices over the last decade. There are, however, many reasons to specify that a building should be air-conditioned, and a reduction in internal heat gains to levels that could be readily dissipated by natural ventilation is only part of the story.

Counterbalancing the reduction in lighting loads there has been an increase in heat gains from office equipment. Information technology has had a significant impact on the office equipment market. A few years ago loads of about 5W/m^2 were normally anticipated. Loads of this order corresponded to equipment such as electric typewriters, photocopiers and the occasional calculator. These were connected into socket outlets at the perimeter wall or sometimes into socket outlets on a fixed grid of trunking set into the floor screed.

In more recent years we have seen connected electrical loads rise dramatically, reaching extremes in City dealer rooms. There has, however, been a marked tendency to over-estimate the rate of heat release from office equipment. Experience indicates that actual heat release is on average only 30% of the equipment's rated maximum energy consumption. In more normal office circumstances we now anticipate the need to cope with equipment loads of about 20 to 25W/m^2, with up to 50W/m^2 occurring in certain areas.

For the future we can look forward to the continued growth of the information technology market. We can also expect to see significant advances in equipment design. Much of this design development is being driven by the desire for portability which, because it implies battery operation, means low power use and reduced heat release. It is difficult to predict how these two factors (market growth and reduced power) will balance out, but for the present the overall effect is that the increase in heat gains from office equipment has substantially eroded the reductions in heat gains from lighting that have been achieved over the last decade.

Another factor that has emerged in recent years is the level of dissatisfaction among building users at having little or no control over their environment. Indeed this is now regarded as a contributory factor to that (not well understood) condition known as sick building syndrome. In deep-plan spaces it is technically difficult and also expensive to provide individual control over what is essentially a shared environment. Individual control is more easily provided in shallow-planned and more cellular office space.

It is interesting to note that building users are far more tolerant of the wider range of conditions that occur in naturally ventilated buildings than they are of variations in what is supposed to a controlled environment. An illustration of this is that if the temperature in an air-conditioned office were to rise above 25° in peak summertime conditions it would probably result in a higher level of dissatisfaction than a temperature of 28° in a naturally ventilated office.

Many organisations are only just beginning to introduce information technology into their operations and are unaware of the future implications. These organisations, when contemplating having a new office building designed, are tempted to think that air-conditioning would not be warranted in the temperate UK climate. This may indeed be the case in the short term, particularly if the building has been designed with effective solar shading and sufficient thermal mass to suppress peak summertime temperatures. However, it would be a very short-sighted organisation these days that does not at least anticipate that air-conditioning may be needed in the longer term and plans accordingly.

PLANNING AND BUILT FORM

The floor-plan of Refuge House provides outer and inner bands of office space, linked at intervals to create enclosed courtyards. Overall, 14,400m^2 of accommodation is provided. At the lowest level is located a 1,000m^2 computer suite, adjacent to which is a staff dining room, coffee lounge and kitchens. The building's external appearance is of a series of linked pavilions, sweeping round in a gentle curve that focuses upon Fulshaw Hall. Internal circulation is provided by a mall on the middle level of the inner band of offices, facing the park. Vertical access is via stair towers at back and front. The offices are 12m wide along the bands, and 15m wide along the links, so providing the potential for good daylighting. The planning module is 1500mm, allowing practically any type of interior fit-out, including cellular offices. A raised floor with a 600mm cavity to accommodate cabling and air-handling systems extends throughout all office spaces.

FABRIC

The building has the appearance of being of traditional construction with pitched roofs of natural blue-grey slate, stone copings and cills and red brick facades. The structure is in-situ concrete columns supporting 300mm thick concrete floor slabs. There are no suspended ceilings in the office areas. Instead, the under-sides of the floor slabs are finished with a textured plaster which acts as an acoustic absorber and diffuser, to break up the direct reflections of noise within the open-plan offices. The omission of a suspended ceiling allows a generous 3m floor to ceiling height which considerably enhances the effectiveness of daylight. Exposing the under-sides of the concrete floor slabs also allows the structure to act as a thermal flywheel, absorbing internal heat gains and thereby reducing or eliminating the need for cooling.

Insulation standards are by no means exceptional - the walls met the Building Regulation requirement, which at the time of design was 0.6W/m^2/K. Windows average 40% of the wall area (as measured internally), and are of high quality. The window size was decided on after an analysis of the conflicting issues of daylighting and thermal performance. The analysis which supported the decision to opt for a 40% window area was carried out on behalf of the design team by BDP's Energy Group. Daylight calculations were done manually using BRE's split flux method to determine daylight factors, which were then used to determine perimeter light switching patterns from data on diffuse sky illuminance throughout the year. Thermal performance assessed by simulation using the ESP program with input data on lighting heat gains derived from the daylight calculations. At that time ESP was run on BDP's central HP3000 mini-mainframe and the version used could only deal with a single zone at a time.

The window units selected incorporate a manually controlled Venetian blind between panes of clear glass set in a rigid, well-sealed frame. They are of a tilt and turn design which allows controllable, draught-free natural ventilation and safe access for cleaning from inside the building.

Having settled on the window arrangement, the ESP simulation program was then used to determine what summertime temperatures would to occur in a series of representative spaces if these spaces were to be naturally ventilated. These simulations (not surprisingly) indicated that orientation was a significant factor and that the results were sensitive to assumptions about equipment heat gains. Consultations with the client established that whereas initial equipment power density might only be in the order of 5W/m^2, this was expected to rise to around 15 to 20W/m^2 in the medium term.

Taking the immediate situation, naturally ventilated offices facing south (from south-east through to south-west) were expected to peak at temperatures in the region of 28 to 30^{o}C whilst more northerly facing offices would peak at 25 to 27^{o}C. The thermal flywheel effect of the exposed under-sides of the floor structure played a part in this - reducing peak temperatures by 1 to 2degK below that which would occur with a conventional suspended ceiling. Perhaps a more telling factor was that at the higher levels of internal heat gain the temperatures in the southerly facing offices would exceed 27^{o}C for up to 300 hours per year.

ENVIRONMENTAL SYSTEMS

It was considered that not all office spaces would need cooling, at least not initially. Depending on orientation, the breakpoint, beyond which cooling might be required, seemed to be when equipment heat gains exceeded 20W/m^2. Below this level it was thought that natural ventilation would generally be sufficient.

The system chosen was a four pipe fan coil unit installation with primary air plants supplying ducted fresh air to the fan coil units. Throughout the offices the air distribution ducts, water circuits and some 400 fan coil units are located within the cavity floor.

The load calculations used to determine the size and capacity of the fan coil unit system were carried out by the design team themselves, using the SPEED program which also ran on BDP's central HP3000 mini-mainframe computer. SPEED was a precursor of the HEVACOMP suite of programs and, like HEVACOMP, largely based on well established CIBSE calculation methods. The use of a program of this type for this purpose rather than a more sophisticated simulation program such as ESP reflects BDP's quality assurance procedures which favour 'industry standard' calculation methods.

The floor void within which the fan coil units are located also forms a return air plenum for the fan coil units. Air is discharged from the fan coil units at a rate of about 6 to 8 air changes per hour via diffusers at the window cill and by circular diffusers set into the floor. At current levels of heat gain the fan coil units operate at the lowest of their speed settings, which means that there is substantial spare capacity available to cope with future increases. The primary air plants have been set initially to provide approximately one air-change per hour of fresh air (10 litres/s per person) but can be adjusted to increase this to a maximum of two air-changes per hour (20 litres/s per person) if wanted.

All fan coil units are fitted with individual control valves on the heating and chilled water connections which operate in response to local thermostats. The fan coil units can also be controlled from the computer based building management system. The building manager from his own office is thereby able to adjust temperature control settings and prevent chilled water valves from opening in areas that he considers can be adequately cooled by natural ventilation.

The system allows a flexible, three mode arrangement for environmental control:

Winter:	Controlled mechanical ventilation with heating. The windows would normally be closed.
Mid-season:	A free-running mode with natural ventilation
Summer:	Controlled mechanical ventilation with provision of partial cooling

Two independent cooling systems serve the office spaces and the computer suite respectively. The office system comprises two 360kW screw compressor refrigeration machines each capable of meeting 50% of the anticipated maximum cooling load. Heat is rejected through a single open-circuit evaporative cooling tower. The computer suite system also uses screw compressor machines, but each of these is capable of meeting the full anticipated cooling load of 140kW. Heat rejection is via two open-circuit evaporative cooling towers each of which again is capable of 100% duty.

Both cooling systems are equipped to operate a free cooling cycle. In the office system this consists of a plate heat exchanger installed in parallel with the chiller. The arrangement, due to there being only a single cooling tower, is 'all-or-nothing' in that cooling at any given time is either provided by the chillers or by free cooling. The chilled water circuit operates at a relatively high flow temperature of 12°C to avoid condensation occurring at the fan coil units and to maximise the period of free cooling operation. However, it is the internal load patterns and the effectiveness of natural ventilation that principally determine this period. An assessment based on typical office conditions suggests that over a year 30% of what would otherwise be cooling load is dissipated by natural ventilation, approximately 40% is matched by free cooling capacity, leaving only about 30% to dealt with by the chillers.

The free cooling arrangement for the computer suite differs from that for the offices in that a plate heat exchanger is connected into one of the two cooling tower circuits and upstream of the chillers in the chilled water circuit. Advantage is taken of there being a standby cooling tower to allow a "free cooling" contribution to be made whenever the outside wet-bulb temperature is low enough. The computer suite chilled water circuit at full load operates at 10°C flow 15°C return. The standby cooling tower can therefore start to make a contribution to the cooling duty whenever it can provide water cooled down to 14°C (leaving a 1degK margin for system heat gains). This can be achieved when the outside air wet-bulb temperature is less than 12°C. The proportion of the load that can be matched by "free cooling" increases at lower wet-bulb temperatures such that the full cooling load can be met at around 6°Cwb. Over the year approximately 65% of the cooling requirements of the computer suite are met by "free cooling", leaving only 35% to be dealt with by the chillers.

Lighting to the office spaces is provided by 250W metal halide uplighters. These are column mounted in most instances and are designed to provide an average 400lux on the working plane. This is achieved at a power density of about 18W/m^2.

Uplighting is ideally suited to offices in which many staff work at computer screens for lengthy periods. Troublesome reflections in the screens are avoided, whilst the ceiling luminance is high enough to offset the gloomy appearance which so often results when ceiling mounted low-glare light fittings are used. The three metre floor to ceiling height makes the most of the uplighting. Ceiling luminance is by no means uniform and is none the worse for that. The textured plaster finish serves a purpose in diffusing the fringing effect that sometimes occurs with uplighters due to imperfect reflector optics.

A design illumination level of 400lux, together with window areas of 40% of the facade, should enable good use to be made of daylight. Unfortunately, current technology does not provide an effective means of dimming metal halide lamps in relation to daylight availability, and the run-up time of these lamps does not encourage casual switching. A lighting control system has been incorporated by which coded signals can be transmitted to each individual uplighter. The system can be programmed to switch off all perimeter uplighters at lunch time so that, on return from lunch, staff are caused to judge whether they wish to switch their local uplighter back on or whether daylight is sufficient.

ENERGY PERFORMANCE

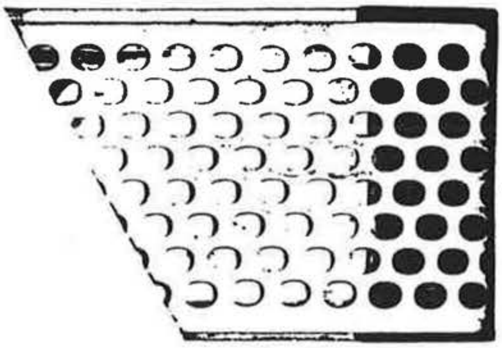
Before the building was occupied a detailed assessment was made of the buildings likely energy performance and annual fuel costs. Due to the 'mixed-mode' ventilation arrangement and the added complexity of the 'free' cooling cycle incorporated into the condenser cooling circuits, it was not practical to model the annual energy performance of the building with the ESP simulation program. Nor is it likely that any other general purpose simulation model available at that time could have adequately represented the design.

Instead, a SuperCalc spreadsheet of heroic proportions was created which attempted to describe the building and its engineering systems. This spreadsheet incorporated data from the SPEED design calculations, algorithms describing the performance of the cooling towers in relation to dry bulb and wet bulb temperatures, and climate data from Manchester Airport. Lighting and fan motor energy were simply described in terms of absorbed power over the expected period of use. Gas and electricity for catering was based on typical figures of kWh per meal.

The building has now been in use for five years and feedback has been obtained on how well actual performance compares to the prediction. As might be expected there are significant differences. Some of these differences can be ascribed to shortcomings in the model and in the assumptions made about building use (e.g. anticipated occupancy periods not corresponding to actuality). Other differences are perhaps due to over-optimistic assumptions on user factors such as window opening and light switching behaviour. Certainly, during the first year of building operation, it was evident that it took time for the client's building management team to learn how to get the best out of their new building.

incorporate the degree of energy monito. investigation of where the differences between ightforward.

Surveyors Davis, Langdon & Everest, was at that time cient offices for BRECSU. Refuge House was included in assessment of how the total measured energy consumption nabled the following comparison of predicted and actual energy



	Annual Energy Use (MWh)	
	Predicted	**Actual or Assessed**
	1,719	1,223
	107	150
	229	132
	2,055	**1,505 (metered)**
	402	631
	101	500
	365	200
	91	99
	95	99
pment	438	780
omputer	-	91
Electricity	**1,492**	**2,400 (metered)**
otal Delivered Energy	**3,547**	**3,905**

commenting further it must again be emphasised that, although the total gas and electricity consumption es are metered values, the distribution is an assessment.

is interesting to note that whereas the balance between gas and electricity usage seems to be very different, the actual total delivered energy is only 10% higher than predicted. This may in large part be due to higher lighting heat gains reducing the heating demand. It does appear that lighting is in use for longer periods than were anticipated, due perhaps to a combination of flexible working hours, a high incidence of overtime working and ineffective switching in relation to daylight availability.

The other major difference between predicted and assessed performance is in relation to the computer load. The assessment implies that computer heat gains had been under-estimated or that the diversity factor for the amount of computer equipment in simultaneous use is higher than was expected. No problems have arisen in maintaining conditions in the computer suite, which implies that the error is principally in the diversity assumption. Irrespective of this, it does not seem that fully effective use was being made of the free cooling arrangement.

It is worth setting the performance of this building into the context of other noteworthy energy efficient office buildings in the UK. To do this fairly the energy used in relation to central computer operations need to be separately accounted for. As a factor, the presence of a central computer has a significant bearing on overall electrical energy use and this varies considerably from one building to the next in this small sample of buildings.

The figures given overleaf are annual total delivered energy per square metre of gross floors area with and without computer power and the associated cooling loads.

Building	**Annual Energy Use (MWh/m^2)** **(with computer load)**	**(without)**
BRE Low Energy Office	135.6	135.6
Hereford & Worcester HQ	170.2	153.2
NFU Mutual & Avon HQ	263.5	166.3
Refuge House	**241.8**	**171.8**
South Staffs Water Co.	180.5	180.5

Sad to relate, shortly after these measurements were made of the energy performance at Refuge House, more computing equipment was installed and what was spare condenser cooling capacity was called into duty. This effectively terminated the operation of the free cooling cycle for the Computer Suite and has resulted in a significant increase in electrical energy used for cooling.

CONCLUDING REMARKS

Refuge Assurance in their new HQ have a building which respects and gains considerably from its rural surroundings. The building has been designed to be highly flexible to the demands that the future will bring, and yet (or perhaps as a result) is able to offer an energy performance that compares favourably to any other noteworthy office building completed in the UK in recent years.

Computer-based design calculations and simulations played a significant part in the design development, and an assessment of annual energy performance (although rather crude by today's standards) has enabled the actual energy performance of the building to be more incisively appraised than would otherwise have been the case.

ACKNOWLEDGEMENTS

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The Use of Dynamic Simulation in Building Design

Terry Wyatt
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Today, even as before, a design for a building can be made using only the empirical, rule-of-thumb methods customarily employed. But the buildings will be no better than before. Imagine such a circumstance in any other industry; canvas and wire biplanes, model 'T' Ford cars affordable by few, slide-rules and adding machines. Buildings for the future must be greatly improved and not simply be, the outcome of an investment exercise, built like the one before.

Designers must recognise that buildings are not static objects just to be looked at but are dynamic cogs in the mechanism of commerce. Machines whose efficiency directly relates to the performance and productivity engendered in the people in occupancy. Buildings must also be far more adaptable in order to meet users day-by-day changing needs of new projects, new equipment, and new organisation structures. And they must be more affordable to more businesses so that they vacate their present inefficient premises.

Designs for these buildings will not come from rules-of-thumb. They will come from inspired and innovative thinking enabled through the use of tools which allow the rapid and reliable testing of ideas. Design involves cyclical iterations to bring the multitude of elemental effects together into harmony, like an orchestral symphony - or - at a simple level, as an engineer, my input into the design of a building will receive much more of the Architect's attention if it is visual and made in time to keep pace with the other elements with which he is juggling.

Rapid, reliable testing of ideas and a visual output is the reason to adopt dynamic modelling for building design. Two distinct types of dynamic modelling are in regular use. The first is thermal modelling of the building for the particular site climate and with its systems in simulated operation. The second is the modelling of the features of the indoor climate as they will physically affect an occupant (or a machine).

The first is at an advanced stage of development and sufficiently reliable and rapid to be very effectively employed. The second is in two parts, one part concerned with light and the other with heat and air movement (and sound). This second is universally derived from a low R_e number $K\ \varepsilon$ model and often referred to as CFD (Computational Fluid Dynamics). This second type of modelling is undergoing massive development world wide. It is a favourite subject for academics, yet it is already of considerable practical use with great visual appeal.

Dynamic modelling of lighting will probably be the first candidate for use of "virtual reality" in design, since lighting acts directly on the visual senses. To date lighting simulation is underdeveloped and not easily improved as the visual outputs need to be, what the eye sees, and, better than a photograph. CFD suffers from the need of massive number crunching speeds, 400MIPS would be useful. Otherwise there is too great a restriction on grid spacing node points, or resolution takes a day, far too long for testing ideas and what-ifs. Another development urgently needed is for boundary layer information such that, for example, a person could be inserted in the model as an icon enabling parallel processing of the effects occurring in their "10mm" boundary layer.

Two examples of the use of dynamic simulation for building design are presented:

The first example is the recently completed building for SW Water at Plymouth. Here the objective behind the dynamic modelling was to minimise the amount of compromise asked of the Architect on his prize winning inspiration. Offering instead a range of options which would enable the building to be an efficient workplace, at minimum energy use and affordable capital expenditure.

Solar control was studied extensively through modelling. Daylighting and luminaires were roughly modelled in monochrome. The peaking nature of the thermal loads for heating and particularly cooling were simulated leading to flattening through use of thermal storage. Finally the building is remarkably like the visual outputs of the modelling and its performance will now be monitored to check the heat, light and sound simulations.

The second example is currently in course of design. Again we, the engineers, were involved only after the Architect and Developer had an "approved" design for the site in Cardiff. The design did not proceed until the point where a future tenant arrived, with some definite user requirements. Again dynamic modelling is used to identify options and study effects on internal climate, energy use, adaptability of the building and cost benefit balances. In particular this building is destined to be one of those setting new standards for workplace efficiency and energy use. Employing "natural indoor climate control" with features such as solar control, daylighting with luminance control of lighting, displacement ventilation for quality of indoor air. Heat recovery and thermal storage of heat and of cooling for dehumidification. Static cooling with natural cooling source and locally controlled static heating. Together with layouts enabling ready adaptability for different uses of the spaces in the building.

The next progression, in the use of Dynamic Simulation for building design, is into PAMS & POSYS (Performance Assessment MethodS & Post Occupancy SurveYS), to begin to close the loop between design modelling simulation and monitored performance feed back of data into the modelling programmes.

Modelling of Natural Ventilation: Practical Aspects

Sinisa Stankovic
J Roger Preston & Partners

1. INTRODUCTION

How can something so basic as fresh air become so fashionable?

Designers of contemporary buildings, architects and engineers alike are facing the challenge of re-introduction of a very well known concept in building design: **Natural Ventilation**.

Although common in residential buildings, natural ventilation was largely abandoned for prestigious commercial developments in seventies and eighties in favour of air conditioning, mainly due to a wide introduction of electronic office equipment. Today we witness the return of naturally ventilated buildings. The only difference is: 20 years ago they were normal buildings; today they are 'Green Buildings'. There is however another difference: the external urban environment is more hostile now and internal gains are higher. Green Buildings invariably either partly or completely, rely on natural ventilation for the provision of fresh air. This normally goes with the treatment of problems at source, philosophy which may include dealing with surplus heat, noise and pollution.

This presentation concentrates on issues that introduction of natural ventilation imposes on building and services modelling. One of the most unlikely applications of natural ventilation is discussed: major high-rise, city-centre office development. This is deemed to be a particularly good example since the designer has to cope with a wider range of problems than in many other cases.

Another important fact is that the study was undertaken in the real commercial environment which has inherent limitations as well as advantages and can therefore expose various design and modelling difficulties.

Some of the encountered problems have been successfully resolved using commercial modelling software; there is, however, a number of important issues which are, in author's view, inappropriately addressed by the currently available modelling tools.

In the urban climate of continental Europe, we found that natural ventilation and night time cooling alone cannot limit the internal temperatures sufficiently to eliminate mechanical cooling altogether.

The prime reasons for this finding are internal heat generation and constructional constraints imposed by the Project Brief: raised floor, suspended ceilings and internal partitions.

The number of days where temperature would exceed a pre-set comfort limit was judged by the Design Team to be too high and potential productivity loss unacceptable.

Natural ventilation can, however, substantially reduce the cooling energy consumption: by about 65%. We established this very early in the design process using various modelling techniques. The environmental control strategy that evolved proved robust enough to survive design changes throughout the conceptual stage of the Project. The result is essentially a hybrid building, normally naturally ventilated, but with full mechanical back-up used when necessary. Mechanical systems comprise chilled ceiling, fresh air and perimeter heating.

2. KEY FACTORS

In the process of assessing the general viability of natural ventilation in each case, several parameters must be considered and analysed. They are outlined overleaf.

2.1 Local Climate

Climatic analysis is a starting point to determine the **Expected External Availability (EEA)** of natural ventilation. For high rise office buildings this may include:

a) **LOCAL WIND CONDITIONS** with direction, mean and gust velocities, turbulence intensity, etc. Several corrections to meteorological data need to be made, depending on the measurement site and building site. Availability and reliability of data is sometimes a problem. Local influences require either external flow CFD analysis or wind tunnel test.

b) **AMBIENT TEMPERATURES** including dry bulb and wet bulb. Statistical analysis of a relevant period from recent history is a valuable source of reference information. Depending on source, micro-climatic corrections may be considered.

c) **PRECIPITATION** including rain, snow, etc. This may reduce external availability of natural ventilation depending on the wind, type of openings and cladding in general.

d) **COINCIDENTAL** analysis of the permissible ranges for the factors under a), b) and c). This may finally lead to area weighted average of EEA, i.e. percentage of time when external conditions are suitable for natural ventilation.

e) **SOLAR RADIATION** influences mainly **Expected Internal Utilisation (EIU)** of natural ventilation. This depends on many factors, mainly cladding and orientation. For certain facade types (e.g. 'Klima facade'), this factor should be subject of coincidental analysis with external temperatures. Solar radiation may also affect behavioural patterns of occupants in terms of willingness of people to use the windows for natural ventilation.

EIU is the frequency of possible usage of natural ventilation; it takes into account internal factors. EIU is lower or equal to EEA.

f) **OTHER FACTORS** include noise, pollution and surrounding structures.

2.2 Building Height and Orientation

These factors affect wind velocities and solar radiation. In the case of high rise building they may also affect ambient temperatures, noise and pollution levels, stack effect, etc.

2.3 Cladding System and Type of Openings

Main dilemmas facing the designer/modeller in connection with natural ventilation are the choice of facade, direct or indirect ventilation, type of openings, etc. As a common practice, 30-40 criteria for each cladding system may be considered in the evaluation process.

2.4 Type of Ventilation and Partitioning

If the building is shallow plan and not partitioned in cellular offices, cross ventilation may be practicable. If not, single sided ventilation must be relied on. The latter is however far less effective and more difficult to simulate using existing modelling tools.

2.5 Internal Heat Gains

These can seriously restrict the EIU of natural ventilation if too high. They should also be considered in conjunction with climatic factors and adopted comfort criteria. Heat extraction at source may sometimes be considered.

2.6 Comfort Criteria

Comfort criteria for naturally ventilated buildings are frequently relaxed compared to air conditioned buildings. The amount of energy savings is critically dependent on these criteria. Together with internal gains, comfort criteria are the two most influential parameters in assessing EIU.

2.7 Building Thermal Mass and Night Time Free Cooling

These are two very important factors in maximising the beneficial use of natural ventilation in terms of improving the comfort conditions and saving energy in office buildings.

2.8 HVAC System and Controls

HVAC system (if any) and its control strategy may significantly influence the EIU of natural ventilation. BMS and controls may affect the use of windows and night time free cooling.

2.9 Costs

Typically cladding system that enables natural ventilation is more expensive than the fully sealed cladding; BMS can be more complex and expensive in case of hybrid operation (buildings with HVAC systems and natural ventilation). These costs can be offset by lower energy costs and sometimes lower HVAC investment costs.

2.10 Non-Tangible and Subjective Factors

Here we can include factors like psychological benefit of the pleasant working environment, positive image of 'going green', political factors, reducing the risk of 'sick building syndrome', higher tolerance of occupants towards comfort conditions and higher overall satisfaction with working environment leading to higher productivity (this can be very tangible but difficult to quantify).

3. VIABILITY ASSESSMENT

In the process of viability assessment, natural ventilation is modelled taking into account factors 2.1 -2.8 and commercially judged against comfort levels, running and investment costs, as well as other influences, e.g. those mentioned in 2.10.

3.1 Modelling Considerations

Achieved comfort levels are usually analysed using two types of programs: dynamic thermal modelling and CFD. Problems associated with this type of modelling include:

- complex control algorithms to model occupant behavioural patterns taking into account amount of sunshine, temperatures, etc.

- accurate modelling of single sided ventilation taking into account buoyancy, turbulence, leakage and type of opening;

- generation of accurate wind pressure coefficients with/without large openings;

- calibration of CFD models and generation of accurate boundary conditions, especially at very high air change rates;

- interaction of thermal modelling and CFD programs, etc.

3.2 Costs

Running costs are normally assessed on the basis of EIU of natural ventilation, which varies from zone to zone. Depending on control strategy and circuits, savings are usually most significant in cooling energy and fan and pump running costs. In assessing the merits of each individual case, local utility choice and costs may prove critical.

Investment costs normally include trade-off between higher cladding costs and lower cooling equipment costs (e.g. chillers, cooling towers).

In both cases the reference case is a fully sealed building.

4. CASE STUDY CONCLUSIONS

For the high-rise city centre office building in continental Europe (Germany), it was found that natural ventilation is a viable concept with EEA of about 77% and EIU of about 60% (area weighted average). This means that natural ventilation can be beneficially used for about 60% of occupied time. For the remaining 40% of time mechanical system is used.

Energy savings compared to traditional building were about 65% in cooling and fan running costs; 50% overall since some heating costs were marginally higher.

The simple payback period using the adopted energy option (in this case steam-driven absorption chillers) was in the range of 5-8 years.

When supported by other factors (e.g. those mentioned in 2.10), this payback may be acceptable even for the owner-occupier of high commercial awareness.

These findings are encouraging but impossible to generalise due to a high number and high complexity of inter-related parameters. Each individual case must be assessed on its own terms.

It is the author's opinion that viability as well as environmental and cost implications of natural ventilation in the buildings of this kind cannot be successfully assessed without the use of state-of-the-art computer modelling techniques.

Notwithstanding this, the current state of modelling software on the market necessitates the use of complementing physical modelling techniques; combination of the two also helps quality assurance and risk minimisation.

The new area of modelling emerged as a challenge for researchers and software developers: **modelling of occupants' behaviour in relation to their environment** under various internal and external stimuli.

Dynamic Simulation - the Challenge and the Opportunity - The Research Machines Plc Building, Milton Park, Abingdon

Michael Carver
The Steensen Varming Mulcahy Partnership

INTRODUCTION

This building constructed by Landsdown Estates Group Limited, part of MEPC for Research Machines, comprises two storeys of non-air conditioned offices of about 1000m² on the front of 4000m² of double height (9m) production space.

The offices incorporate the main entrance and form the principal south facing facade and have been designed to achieve low summertime temperatures without the need for mechanical cooling. Key features include:

- a colonnade to the offices providing solar control to the ground floor offices;
- external sun breakers protecting the first floor windows;
- heat reflecting glass with a light tint;
- low energy, high frequency lighting; and
- good window design to encourage natural and cross flow ventilation, between the external facades and an internal courtyard introduced for the purpose.

THERMAL MODELLING AS PART OF THE DESIGN PROCESS

SVM decided to use modelling as part of the design development process for a number of key reasons:

1. It continued on from a sequence of detailed design studies for buildings at Milton Park and principally a large heavy-weight corporate HQ building where the effectiveness of a number of passive measures was assessed using thermal modelling.

2. There was a keenness on the part of the developer client and their potential tenant to get the most efficient use of the building and to balance operating costs with capital costs.

3. SVM had previously been involved in a number of projects and studies where integration of engineering and building fabric performance were key issues in relation to environmental control. This project was seen as an opportunity to evaluate the potential of various 'green' technologies in a very common building form with minimum impact on the developer's budget but maximum impact on the overall internal conditions and operational costs.

RESOLUTION OF DESIGN ISSUES

The main stages where thermal modelling was used, and the particular issues it was used to investigate, are outlined below:

South Facing Offices

Thermal modelling was used at the earliest stages to optimise building performance with a view to having offices that did not require air conditioning and to assist in resolving a conflict between the need for large areas of glass for aesthetic and daylighting reasons and the building user who was concerned that the amount of the glazing would contribute to excessive local internal gain. It was used to establish areas of glass and shading, and how the glazing related to heat gain. Sketch solutions derived intuitively were tested using thermal modelling techniques to balance one solution against another in numerical terms.

Monitoring undertaken as part of BRE's minimum use of air conditioning study during the summer of 1991 indicated that internal temperatures were lower than predicted.

Heat Gains in the Production Area

The next stage was modelling the production portion of the building which is a lightweight structure with considerable solar gains on the roof. The analysis identified the proportions of heat gain at low level where thermal capacity of the floor slab acted as a moderator, and at upper level where lighting and solar gains were significant. Careful use of the natural thermal gradient here minimised the gains seen by the central plant.

Chiller Capacity

Thermal modelling was very valuable in evaluating the likely internal conditions if only a proportion of the design chiller capacity was utilised. The building user was therefore able to make a capital expenditure decision using information relating to how many hours in the year the internal temperature exceeded 24°C if only one chiller (60% design capacity) was installed.

Infiltration rate sensitivities in Production

With a shed volume of approximately 36,000m^3 the heating and cooling plant sizes were very sensitive to variations in infiltration rates. After completion of the external envelope BSRIA were commissioned to measure air leakage characteristics of the completed structure.

BSRIA predicted the variation in air change rate with wind speed for the building together with the frequency of wind velocities that occur for the geographical area in question.

Our initial studies had assumed a fairly tight structure and, as is commonly the case with light-weight shed structures with a 2m high masonry wall at the perimeter, air filtration was found to be higher than expected. Re-running of the thermal model very quickly established that low cost remedial measures to improve air tightness were more cost effective in both capital and running cost terms than increasing heating capacity.

CONCLUSION

Thermal modelling was found to be very useful in evaluating the performance of initial intuitive design and then throughout the detail design process to evaluate in numerical terms alternative solutions. Whilst it would have been possible to achieve similar results using steady state traditional calculation methods, thermal modelling gave us the courage of our convictions.

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