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Contents

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The International Building Performance Simulation Association (IBPSA) exists to advance and promote the science of building performance simulation in order to improve the design, construction, operations and maintenance of new and existing buildings worldwide.

Volume 9 Number 1
April 1997

President's message

1997 is now well underway and it is with some optimism that we can look forward to IBPSA's 5th International Conference, Building Simulation '97, which will take place from 8-10 September in Prague, the capital of the Czech Republic. I say this for two principal reasons.

Firstly, the technical programme promises to build upon, and in some respects surpass, the achievements of our previous conferences in Vancouver ('89), Nice ('91), Adelaide ('93) and Madison ('95). Some 198 paper abstracts have been accepted by the Scientific Committee, our highest number ever. The Committee, along with a team of volunteer reviewers are currently preparing themselves for the effort-intensive review procedure which lies before them. As with our last conference, BS'97 will host a major exhibition featuring contemporary software products for building performance evaluation.

My thanks to the Organising and Scientific Committee members and reviewers for their time and effort. For further details on the conference programme, please visit the BS'97 Web site at http://www.fsid.cvut.cz/bs97.

Secondly, Prague is a beautiful city and amongst the best preserved of Europe's historical locations. I have also heard it said that the Czechs are the number one beer brewing nation in the world today. Judge for yourself by visiting http://www.radio.cz/beer/ or, better still, attend the conference and sample the real thing.

On other fronts, the regionalisation of IBPSA is proceeding to plan. The intention now is to move to a new organisational structure by which the regions can be better represented and their development better served. It is planned to hold an open discussion on this issue at the time of the conference. Please watch out for this event and attend if you would like to contribute to the further evolution of IBPSA and the simulation technologies we seek to promote and support.

I hope that you find value in this newsletter and hope to see you in Prague.

Joe Clarke, President, IBPSA

Workshops on Next-Generation Building Energy Simulation Tools

Part 2: Contrasting Developers and Users

Drury B. Crawley[1], Linda K. Lawrie[2], Frederick C. Winkelmann[3], and Curtis O. Pedersen, Richard J. Liesen and Dan E. Fisher[4]

INTRODUCTION

In early 1996, the U.S. Departments of Energy and Defense (DOE and DOD) began developing a new building energy simulation tool that builds on their existing programs—DOE-2 (Winkelmann et al. 1993) developed by Lawrence Berkeley National Laboratory (LBNL) and BLAST (BLAST Support Office 1992) developed by U.S. Army Construction Engineering Research Laboratories (CERL) and University of Illinois (UI). The new program—EnergyBase—is expected to become available in 1998. As EnergyBase begins testing, the EnergyBase team will begin planning for next-generation building simulation tools that go substantially beyond the capabilities of simulation programs available today.

DOE and DOD sponsored workshops in August 1995 and June 1996 on next-generation building energy simulation tools to provide input to planning for future building energy simulation tools. The results of the first workshop were described in the previous issue of *ibpsa*NEWS (Crawley et al. 1996). During both workshops, participants generated and ranked applications, capabilities, methods and structures, and interface concepts for next-generation simulation environments. Energy simulation developers and expert users were invited to the first workshop (developers workshop). Energy simulation users and other professionals attended the second workshop (users workshop), held in Washington, D.C. This article describes the results of the two workshops, including methods used and contrasts the differences between the developers' and users' recommendations.

STRUCTURE OF THE WORKSHOPS

The goal of both workshops was to generate and prioritize ideas for next-generation simulation environments where the scope was simulation of building life-cycle processes that influence energy performance and environmental sustainability. The developers workshop focused on applications, capabilities, and methods and structures; the users workshop focused on applications, capabilities, and user interfaces. Participants were reminded that the workshops were not a forum to discuss pros and cons of any existing tool, nor to decide who might perform any development work for any potential U.S. next-generation simulation tools.

Each workshop was organized in three breakout sessions: Applications, Capabilities, and Methods and Structures for the developers workshop; Applications, Capabilities, and User Interfaces for the users workshop. We divided the participants into groups facilitated by a team member from the EnergyBase team. The facilitators used a five-step process for each of the breakout sessions: brainwriting, grouping and eliminating duplicate ideas, brainstorming, prioritizing and pareto voting, and summarizing.

At the beginning of each breakout session the facilitators described the general subject of the session. Then, the groups began brainwriting in which each workshop participant writes down one idea on a note card and passes that card to their right. As cards are passed, each person reviews the idea and continues to generate their own new ideas. Brainwriting encourages idea generating through individual creativity and brainpower. After 10-15 minutes the groups organized the cards/ideas into general groups and eliminated duplicate ideas. To make sure no important ideas were missed, the groups then spent 10-15 minutes brainstorming—working as a group to generate new ideas. After brainstorming, each group counted the number of cards/ideas and multiplied by 0.2. This was the number of votes each participant had when selecting their top 20% of the ideas (pareto voting). Votes (using dots) were applied to the cards once all participants in a group had selected their top 20%. The groups then rank-ordered the cards from highest priority (most votes) to lowest priorities (fewest votes). Voting provided a relative ordering of the ideas within each group—all of the ideas generated would be useful to the group. Last, each facilitator prepared a summary that they presented to the entire workshop at the end of each breakout session.

RESULTS OF THE WORKSHOPS

The following figures present summary grouping of the concepts and ideas generated in the two workshops. In total, the developers workshop generated 225 ideas for the Applications breakout session, 242 ideas for the Capabilities breakout session, and 201 ideas for the Methods and Structures breakout session. The users workshop (with more participants) generated 247 ideas for the Applications breakout session, 301 ideas for the Capabilities breakout session, and 213 ideas for the User Interface breakout session.

Figure 1 compares the application priorities of users and developers. The raw votes of software developers and users were normalized and plotted in the figure. The developers workshop included researchers in the field of building simulation and energy analysis. Predictably, users disagreed

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with developers on the importance of research. The significance placed on design by the user community was also not surprising. But although the expected bias of the two groups is discernible, there is remarkable agreement on program application priorities. This indicates that, for the most part, researchers and developers are cognizant of the needs of the user community.

The same trend can be seen in Figure 2, which compares the capability priorities of users and developers. For the most part, developers seem to be aware of user concerns. The most serious disconnect occurs on the issue of input and output capabilities. This category, which developers and researchers considered fairly insignificant, was clearly a high priority for users.

Figure 3 shows interface priorities for the users workshop. Interoperability among programs was considered the most important. Figure 4 provides similar information on methods and structures from the developers workshop. Here, pre- and post-processing methods had highest priority.

Tables 1 through 4 accompany each figure to provide more detail. The tables show the votes for topics within each category from the user and developer workshops. Tables 3 and 4 (as with Figures 3 and 4) show information only for the users and developers workshops respectively. Note that the topics are often quite different between the two workshops.

SUMMARY

Surprisingly, not many new or unusual ideas were brought up—even with a group of international building energy simulation developers and users. The hundreds of ideas generated during both workshops showed instead that the field of building energy simulation still has many fundamental problems that need to be addressed. The developers will not stretch the boundaries and capabilities of simulation (even in their own minds) until more basic simulation issues are resolved. The concepts developed in the users workshop showed that users also feel that simulation still has a long way to go to meet their needs. The authors hope that the workshops will start the building simulation field talking about the future, instead of focusing on where it is today. The complete list of ideas generated during the workshops is available from the authors.

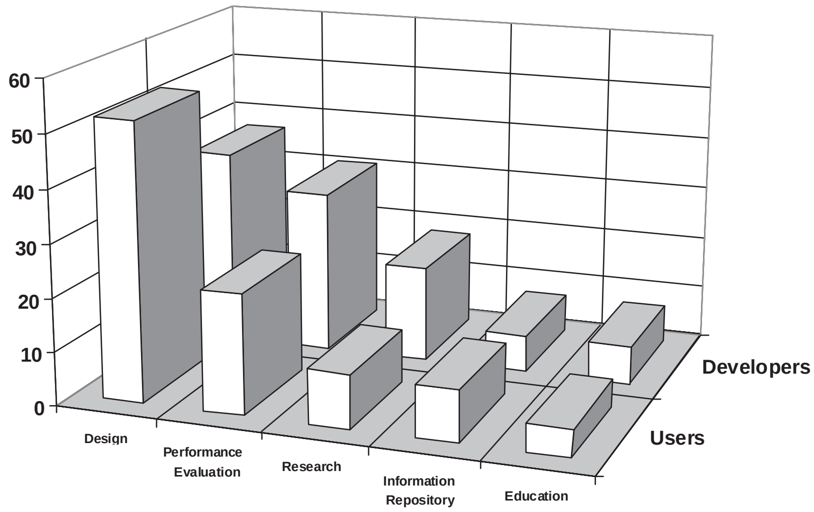

Figure and Table 1 Program Applications: Priorities of Developers and Users

Design

Developers	Votes	Users	Votes
Collaborative, integrated, facilitated building design	39	Envelope design	37
Building code compliance—energy and environmental impact	18	Early analysis of design alternatives	25
System selection and equipment sizing wizards	16	Environmental impact and sustainability	24
Lighting/daylighting (selection of products, performance assessment)	7	Economic and cost analysis	15
Aid in selecting retrofit strategies	7	System design	14
		Occupant comfort and safety	11
		Retrofit design	3

Performance Evaluation

Developers	Votes	Users	Votes
Comfort evaluation	21	Performance contracting	16
Economic, life cycle, and cost-benefit analysis	14	Code development and compliance	11
Optimal operation and control	14	Performance data acquisition and analysis	8
Control strategies/ optimization/supervisory	13	Commissioning	7
Indoor air quality	12	Comfort- and energy-based controls	7
		Fault detection and diagnostics	7

Research

Developers	Votes	Users	Votes
Policy formation code development	9	Emerging technologies and new processes	11
Solution of inverse problem to calibrate model for existing building	6	Occupant health and productivity	8
Basic research	5	Environmental impact	6
Sensitivity and error analysis	5		
Provide basis for simplified tools	4		

Information Repository

Developers	Votes	Users	Votes
Electronic owner's manual (building life cycle)	9	Performance databases and libraries	12
Feed intelligent database for future designs	5	Design databases and libraries	8
Need for structural libraries of models, object-oriented programming	3	Expert systems	4
No gap between description and behavior; i.e. performance data immediate after object selection	2		
Use of historical data files, previous work/buildings	2		

Education

Developers	Votes	Users	Votes
Student and practitioner education	23	Student education	13
Make it fun	2		

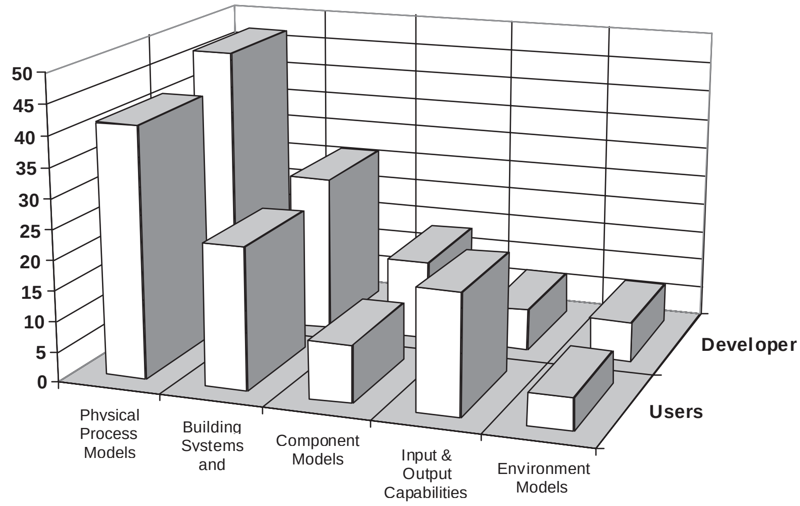

Figure and Table 2 Program Capability: Priorities of Developers and Users

Physical Process Models

Developers	Votes	Users	Votes
Air flow modeling	25	Envelope/environment interaction	47
Moisture absorption/desorption in building materials	17	Heat transfer models	37
1-, 2-, and 3-D transient conduction	15	Air infiltration and movement within spaces	22
Daylighting	14	Realistic simulation time steps	7
Full generality 3-dimension shading, lighting, and solar geometry	14	Moisture	7
		Indoor air quality	5

Building Systems and Controls

Developers	Votes	Users	Votes
Flexible system and plant modeling	18	Integrated systems with modular component models	21
First principles system and plant models	14	Realistic building and HVAC simulation	18
Imperfect mixing of zone air	13	Process (e.g. moisture, daylighting) and component controls	12
Zones, systems, plants coupling	8	Performance, compliance and validation	10
Passive and active solar	6	Multiple building systems	7
		Human interaction models	3

Input and Output Capabilities

Developers	Votes	Users	Votes
Variable time step	5	Flexible inputs and outputs	26
Uncertainty analysis	4	Life-cycle and real time cost analysis	11
Economic Analysis	3	Expert systems	7
Costs based on utility rate schedules modular interchangeable features	2	Optimization	7
Shell to facilitate the combining of components into a system	2	Access library and database information	4
		Design support	3
		Multi-platform, parallel processing	2

Component Models

Developers	Votes	Users	Votes
Advanced fenestration	11	Air delivery system component models	10
Energy storage in buildings including phase change	8	Central plant equipment models	10
Advanced lighting system modeling	4	Building envelope component models	7
Dynamic coil models	3	Multilevel component models	2
Duct losses	3		

Environment Models

Developers	Votes	Users	Votes
Occupant comfort	9	Pollution models and environmental impact	6
Typical, extreme and site-specific weather	5	Daylighting	6
Wind pressure distribution	4	Micro and macro weather data	4
Modeling of terrain and surrounding obstructions	2		
Long-term climates with special peak conditions and micro-climates	1		

Continued on page 4

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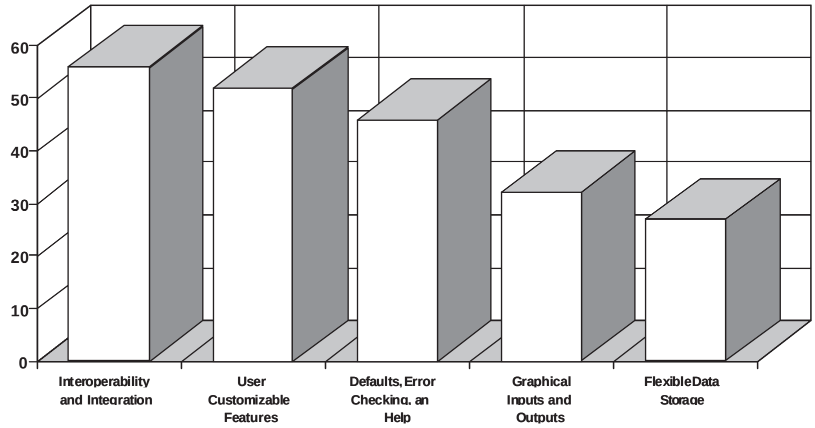

Figure 3 Program Interface Priorities of the Users Workshop

Table 4 Program Methods and Structures: Priorities of Developers

Solution Techniques and Numerical Methods	
Developers	**Votes**
Simultaneous solution of loads plant and controls	5
Stochastic methods	5
Macroscopic air-flow modeling (non-CFD)	4
Numeric nodal approach for maximum future flexibility	4
Powerful differential-algebraic equation solvers	4

Data Representation and Storage	
Developers	**Votes**
Extensive and extensible libraries of building components and systems	13
Online documentation, structuring information	6
Flexible structure to allow quick change in systems configuration	5
Standardized data structures	5
Case studies database for decision-making	4

Model and Program Development Methods	
Developers	**Votes**
Object-oriented representation	12
Model reduction	6
Modularity of components	6
Equation-based models—NMF format	5
Tool able to be used by a team (concurrency)	5

Pre and Post Processing Methods	
Developers	**Votes**
Adaptable interface according to user type and stage of design process	21
Knowledge-based front end with intelligent defaults	15
Visualization of complex outputs, including virtual reality display	10
CAD integration	7
Validation by empirical, analytical, and comparative techniques	7

Table 3 Program Interface: Priorities of Users

Interoperability and Integration	
Users	**Votes**
Interoperable with other tools	22
Interoperable with CAD programs	20
Integration of components and analysis modules	10
Multi-platform applicability	4
Public domain and open code	0

User Customizable Features	
Users	**Votes**
Multilevel inputs	13
Simple input options	13
Clear separation of interface and computational engine	10
Customizable output and reports	7
Customizable interface	6
Adaptable to multiple uses	3

Graphical Input and Output	
Users	**Votes**
Graphical representation of inputs	12
Graphical output of results	10
Three dimensional spatial displays	10

Defaults, Error Checking, and Help	
Users	**Votes**
Context sensitive and "smart" help	17
Knowledge-based analysis of inputs and output	10
Automated error and range checking	7
Tutorials and documentation	7
Online support	5

Flexible Data Storage	
Users	**Votes**
Component libraries	16
External databases and manufacturer's catalogs	11

❖

The issues addressed in this article will be revisited at a Study Day in Liege between CLIMA 2000 and Building Simulation '97 in September - see page 27

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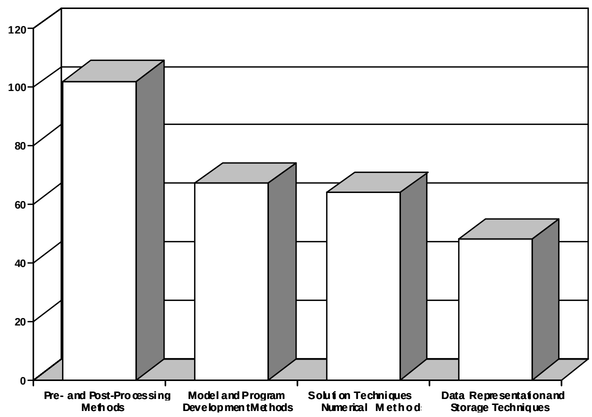

Figure 4 Program Methods and Structures Priorities of the Developers Workshop

continued from page 3

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The authors participated as leaders and facilitators in the developers and users workshops. They wish to thank the participants for their contributions to the workshop and the long range planning efforts that will evolve from them.

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BESTEST: Comparing Predictions of Building Energy Simulation Software

Ron Judkoff[1], Joel Neymark[2]

CONFIDENCE IN COMPUTER-SIMULATION PREDICTIONS

Numerous software programs simulate energy performance in buildings. But these programs—even if considering identical structural designs, energy-related equipment, and energy usage patterns—often produce widely divergent results when calculating overall energy performance. Consequently, architects and engineers have not trusted the programs, and instead, have continued to design buildings without focusing on energy use.

To improve the accuracy of energy software and help designers gain confidence in computer predictions, the National Renewable Energy Laboratory (NREL), in cooperation with International Energy Agency (IEA) Task 12 and Annex 21, developed IEA BESTEST—the International Energy Agency Building Energy Simulation Test and Diagnostic Method.[1] This procedure systematically compares whole-building energy software packages and determines the algorithms—or computer-coded computational routines—responsible for prediction differences.

BESTEST BASICS

The energy, comfort, and lighting performance of buildings depends on many complex interactions. And computer simulation is the only practical way to bring such a large-scale systems integration problem within the grasp of building designers.

To study these simulation models, the BESTEST technique applies a series of carefully specified test-case buildings that progress systematically from the extremely simple to the relatively realistic. Output values for the cases—such as annual loads, temperature ranges, and peak loads—are compared and used with diagnostic logic to pinpoint the routines responsible for prediction differences.

In IEA BESTEST's 36 cases, *qualification* cases represent a set of buildings with relatively realistic thermal characteristics. These cases test a program's ability to model such features as windows at different orientations, external shading devices, setback thermostats, night ventilation economizer cooling, a passive solar sunspace, and ground coupling. *Diagnostic* cases attempt to isolate the effects of individual algorithms by varying a single parameter from case to case, to minimize confusion caused by interacting heat-transfer phenomena.

BESTEST example results are compared using eight programs run by the various IEA participants as described in Table 1.

HELPING TO DEVELOP ENERGY SOFTWARE

BESTEST helps software developers in several ways. Predictions from a building-energy program of interest can be compared to the reference results from detailed programs already studied, or the algorithm-based differences in predictions observed between several simulation programs can be diagnosed. A previous version of a program can be checked against itself after a programmer has modified the code to ensure that only the intended changes actually resulted. And the sensitivity of an algorithm to changes may be investigated by checking the modified version against the original.

By itself, the BESTEST procedure is not a complete validation method, which would also include analytical and empirical techniques.[2] Instead, it compares a given program with other state-of-the-art programs that have been analytically verified and field-validated with actual buildings. Anomalous results or "failing" a test do not necessarily indicate a faulty program, but rather, differences to be studied and understood.

In practice, the diagnostic procedures have revealed bugs, faulty algorithms, and modeling limitations in every one of the world-class building-energy computer programs studied by NREL and IEA researchers. Figure 1 (next page) indicates results from six simulation programs that fell within the shaded envelope; results from a version of TRNSYS[3] then being used in Europe (TRNSYS 12.2v1) shown by the dotted curve deviate drastically from the other programs. When computer code "bugs" revealed by BESTEST diagnostics were fixed, the results fell within the range of the other programs.[4]

As another example, DOE2[5] is one of the U.S. Department of Energy's most advanced building energy simulation programs. One series of diagnostic tests on DOE2.1D detected problems with the treatment of solar absorptivity on exterior surfaces. Use of IEA BESTEST traced the problem to a bug in the solar absorptance

Table 1 Participating Organizations and Computer Programs

Computer program	Authoring organization	Implemented by
BLAST-3.0 level 193 v.1	CERL[a], U.S.	NREL[b], U.S. Politecnico Torino, Italy
DOE2.1D 14	LANL/LBL[c], U.S.	NREL, U.S.
ESP-RV8	Strathclyde University, U.K.	De Montfort University, U.K.
SERIRES/SUNCODE 5.7	NREL/Ecotope, U.S.	NREL, U.S.
SERIRES 1.2	NREL/BRE[d], U.S./U.K.	BRE, U.K.
S3PAS	University of Sevilla, Spain	University of Sevilla, Spain
TASE	Tampere University, Finland	Tampere University, Finland
TRNSYS 13.1	University of Wisconsin, U.S.	BRE, U.K. Vrije Universiteit (VUB) Brussels, Belgium

[a]CERL—Civil Engineering Research Laboratory
[b]NREL—National Renewable Energy Laboratory
[c]LANL/LBL—Los Alamos National Laboratory/Lawrence Berkeley Laboratory
[d]BRE—Building Research Establishment

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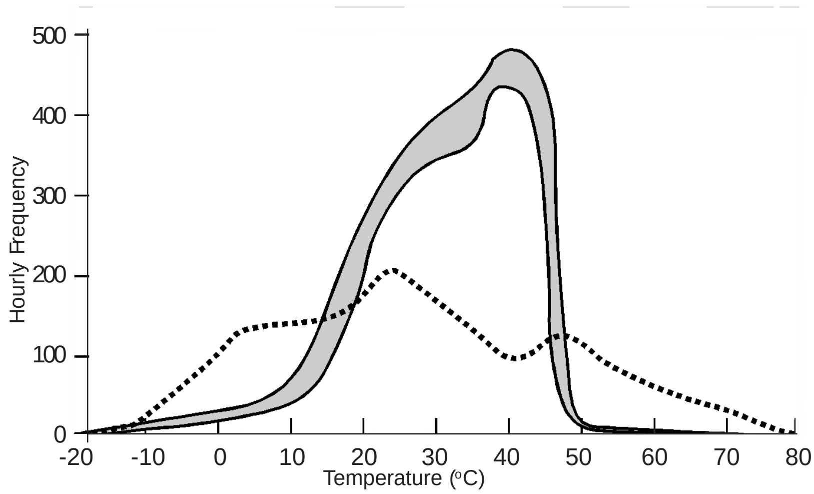

Figure 1 BESTEST Case 900FF: Annual Hourly Temperature Frequency

algorithm associated with surfaces defined as doors. Once the algorithm was corrected, the problem disappeared.[4] Similarly, BESTEST helped isolate a bug that caused improper calculation of weighting factors in a beta-test version of PowerDOE; this bug, which has now been corrected, did not exist in the preceding version of DOE2 (DOE2.1E).[6]

USING VALIDATED ENERGY SOFTWARE

BESTEST is designed to help develop reliable energy software. But the ultimate goal is to assure potential software users that a particular simulation program gives reasonable results or that a program is appropriate for their particular application. NREL has also developed a version of BESTEST that is the basis for testing software in the US National Home Energy Rating System initiative (see **box** below).[7]

The list of BESTEST users continues to grow. The American Society of Heating, Refrigerating, and Air-Conditioning Engineers is adopting BESTEST as a "standard method of test." Additionally, California's State Energy Commission approved the method for evaluating its building-energy analysis software. Other prominent BESTEST users include:

- New Zealand (for certifying software used for energy code compliance)
- Canada Department of Natural Resources
- National HERS Program (Cited by NOPR 10 CFR 437 and HERS Council Guidelines)
- National Weatherization Program (US)
- Energy Bureau, Iowa State Department of Natural Resources

BESTEST will improve building-energy software and will increase confidence in its predictions among architects and engineers, enabling them to design increasingly energy-efficient buildings.

To obtain a copy of IEA BESTEST[1] and/or HERS BESTEST[7] please contact:

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CERTIFYING SOFTWARE FOR THE HOME ENERGY RATING SYSTEM (HERS)

In the US, the National Energy Policy Act of 1992 calls for certifying the technical accuracy of analysis tools that determine building energy-efficiency ratings. NREL has developed software testing protocols with the HERS council, a U.S. group representing utilities, government, environmental and consumer groups, and members of the real estate, finance, and building industries. The protocols are based on NREL's HERS BESTEST—an adaptation of BESTEST specific to residential building models.

Mortage companies willing to make larger loans to cover energy efficiency improvements are especially interested in the accuracy of home energy rating systems. Lenders want some confidence that the energy cost savings will more than offset the increased loan amount. Use of HERS BESTEST increases the credibility of home ratings by screening out inaccurate HERS software.

Software used by NREL in developing example results for HERS BESTEST includes:
DOE2.1E - W54
BLAST 3.0 Level 215
SERIRES/SUNCODE 5.7.

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Modelling Temperature and Human Behaviour in Buildings

Fergus Nicol and Iftikhar Raja[1]

Do people *really* value the tight temperature control that most building designers try to provide? Letting internal temperatures change with outside conditions, even a little, could save massive amounts of energy - and require modellers to provide new measures of comfort. This paper, presented at BEPAC's *Sustainable Building* conference, reviews the evidence and describes some forthcoming work that will challenge conventional wisdom.

INTRODUCTION

Current indoor temperature standards[1,2] provide an estimate of the temperature which people will find comfortable based on work at constant temperatures carried out in climate chambers. The relevance of such results to comfort in the variable conditions found in naturally ventilated buildings has been questioned[3,4]. Temperature standards based on such work favour constant indoor temperatures only possible in highly-serviced, energy-hungry buildings. Recent questions about the consistency of the Fanger[5] theoretical model on which many standards are based[6] emphasise the need to question standards such as ISO7730[1].

The adaptive approach to thermal comfort[7,8] is now widely accepted and the subject of a growing body of research. The finding on which the approach is based is that people adapt to the conditions which they experience in everyday life in such a way as to decrease the likelihood of discomfort. This is achieved by behavioural changes to their own thermal balance (by changes in clothing, posture etc) or by changes in their thermal environment. This means that people are generally comfortable at a temperature which approaches their everyday norm[9] and which, less directly, is a function of the mean of the outdoor temperature[10] in a relationship of the form:

$$T_c = aT_o + b \qquad (1)$$

where T_c is the comfort temperature and T_o is some measure of the outdoor temperature (see below).

This paper describes a project to explore the use of an adaptive approach to set design values for indoor temperatures in terms of T_o and to determine the best measure of T_o. The aim of the research is to provide standards for comfort which take account of the dynamic-interactive relationship between building and occupants. This adaptive approach would allow a wider interpretation of acceptable indoor environments thus encouraging the use of natural ventilation in buildings. It has been shown that by using an adaptive algorithm[11] to set control temperatures in highly serviced buildings it is possible to reduce the energy used for indoor climate control by as much as 25%[12].

TIME AND COMFORT TEMPERATURE

One problem with the interpretation of the adaptive approach is that the monthly mean of the outdoor temperature has been used to define the outdoor temperature T_o in equation 1. But a monthly measure of T_o will not reflect changes in comfort temperature which occur within the month. This could result in conditions which are comfortable being interpreted as uncomfortable and vice versa. Humphreys and Nicol[11] have proposed an algorithm for indoor temperature which uses the running mean of the outdoor temperature as a defining variable.

A second problem with the adaptive approach is that it can be misinterpreted to mean that almost any temperature can be found comfortable. In fact conditions for comfort are subject to social and physical constraints on the ability to adapt which depend on context. In essence the mechanism is a feedback between building and occupants driven by the climate. The relationship between comfort temperature and running mean temperature is effected by these constraints on the ability to adapt.

The main part of the work described in this paper was a comfort survey conducted over a period of almost two months to shed light on these problems. The experimental results are fully presented in Nicol and Raja[13]. They explore the effect of rate of change of outdoor temperature on comfort temperature indoors, on the way in which buildings react to outdoor temperature and on the way this effects the use occupants make of the environmental controls available to them.

EXPERIMENTAL PROCEDURE

A field survey was conducted in buildings at Oxford Brookes University over a period of seven weeks in August and September 1994. The 20 subjects who took part in the survey were administrative and academic staff of the university and post graduate students. They occupied four buildings on the campus. These buildings can be variously characterised as lightweight or of mixed heavy and lightweight construction. One building was air conditioned.

The thermal environment (air and globe temperatures, relative humidity and air movement) close to each subject was monitored at intervals of a quarter of an hour and recorded using a small data-logger. Subjects were asked to fill in a form three times a day (morning, midday and afternoon) to record their comfort vote, thermal preference and skin moisture together with their clothing, activity and use of thermal controls (use of blinds/curtains, opening of windows/doors, use of fans, heaters etc.). Meteorological data were obtained from the Radcliffe observatory (about 2 km distant). Comfort vote was recorded on the seven-point Scale based on that of Bedford[14] and the preference vote on a five-point scale similar to that of McIntyre[15].

ANALYSIS OF THE RESULTS

The analysis of the results of the experimental results was in three parts:

- calculation of comfort temperatures, running mean outdoor temperature and other basic statistics
- analysis to show how comfort temperature changes with time and its

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relation to conditions inside and out
- analysis of the way in which building temperature varied with time and of the use of controls by building occupants.

Calculation of comfort and running mean temperatures

The data were consolidated to provide datasets[8] of simultaneous subjective, environmental and meteorological data. An estimate of the temperature which subjects would find comfortable was made from the comfort vote C and the globe temperature T_g using the method suggested by Griffiths[16]:

$$T_c = T_g - 3C \qquad (2)$$

The relationship gives the temperature which the subject will find comfortable with no change of clothing or metabolic rate.

The theoretical value of the exponentially-weighted running mean temperature for day n ($^nT_{rm}$) is calculated from the series:

$$^nT_{rm} = (1-\alpha)\{^{(n-1)}T_{od} + \alpha.^{(n-2)}T_{od} + \alpha^2.^{(n-3)}T_{od} + ..\} \qquad (3)$$

where $^nT_{od}$ is the mean outdoor temperature for day n and α ($0 \leq \alpha \leq 1$) is a time-constant. Each day's value of T_{rm} can be calculated from that of the previous day using the simple formula:

$$^nT_{rm} = (1-\alpha).^{(n-1)}T_{od} + \alpha.^{(n-1)}T_{rm} \qquad (4)$$

The mean outdoor temperature (T_{od}) each day was calculated from the data obtained from the Radcliffe Observatory. The running mean temperature (T_{rm}) was calculated using the mean value of the temperature for each day of the survey.

To calculate values of T_{rm} an assumption must be made about the value for the constant α. A larger value for α implies a greater weighting for values of T_{od} in the past. The theory approximates to that of radioactive decay with the half-life of T_{rm} given theoretically by $0.69/(1-\alpha)$[17]. Table 3.1 shows the theoretical half-life associated with selected values of α.

Values of T_{rm} were calculated using different values of the constant α. Values used for α varied from 0.05 at intervals of 0.1 to 0.95 with extra interpolations at 0.7, 0.8 and 0.9. Figure 1 shows the value the mean outdoor temperature and the running mean temperature (T_{rm}) for each day of the survey and for selected values of α.

Change of comfort temperature with time

There was found to be a continuous change of the comfort temperature over the period of the survey (Figure 1) which generally reflected the drop in outdoor temperature towards autumn, though not its short-term changes. This suggests that a running mean of the outdoor temperature will be an appropriate measure of comfort temperature.

The first concern was to find out which value of a gives the best correlation between comfort temperature and outdoor running mean temperature. The mean value of the comfort temperature for all subjects who took part on any day was calculated by finding the mean values of C and T_g and substituting them in equation 2. This value of comfort temperature was correlated with different values of T_{rm}. The results are shown in Figure 2 in which the correlation coefficient r for T_c on T_{rm} are plotted for different values of α. The maximum value of r is at $\alpha_{max} = 0.8$. A similar process was used to find the value of α for maximum r of clothing insulation on T_{rm} and give a comparable value for α_{max}. The regression equations for daily mean comfort temperature T_c and clothing insulation (I_{clo}) calculated from

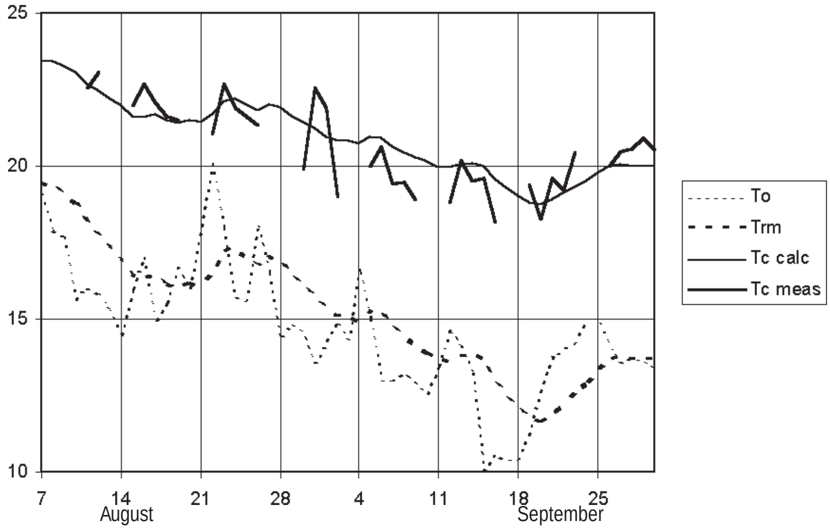

Figure 1 Changes in comfort temperature and outdoor temperature during the survey (all buildings)

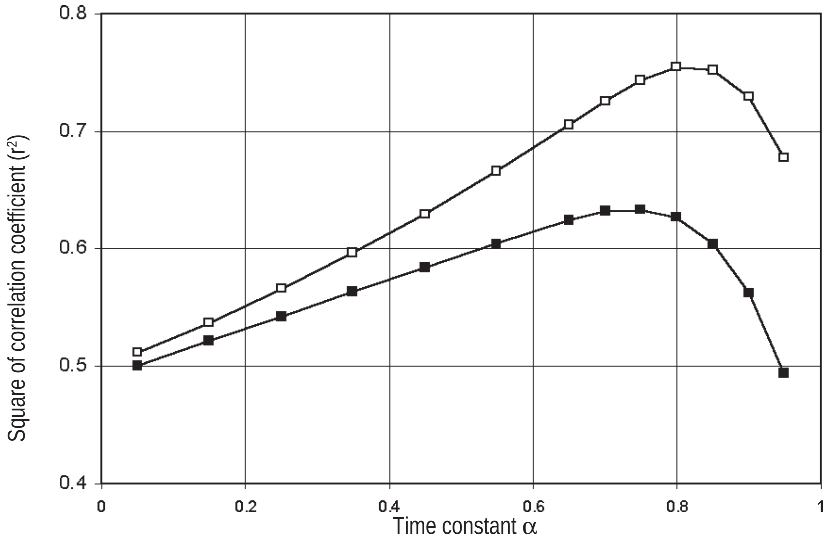

Figure 2 Change in correlation coefficient r for clothing insulation (I_{clo} open symbols) and comfort temperature (T_c filled symbols) on running mean temperature (T_{rm}) for different values of the time constant α NOTE: the square of r is used to exaggerate the change

standard tables[18] are:

$T_c = 0.602T_{rm} + 11.7$ (r = 0.79) (5)

$I_{clo} = 1.28 - 0.035T_{rm}$ (r = 0.87) (6)

Indoor temperature and use of controls

A similar process can be used to evaluate α_{max} for indoor temperature as a function of outdoor running mean. As expected α_{max} is much smaller for buildings than for people giving a value of 0.35 overall, but of only 0.05 in the lightweight building. In the case of one basement room however, the value of α_{max} was 0.7 and discomfort in here was least (6%) of all the buildings surveyed.

Although some subjects never made use of window opening, subjects in rooms prone to overheating often used window opening as a means of cooling them down. An analysis was made of the dependence of window opening on instantaneous outdoor temperature T_{oi}. The relationship between the proportion of windows open P_w (in %) and T_{oi}, obtained by regression analysis was:

$P_w = 6T_{oi} - 66$ (7)
(limits: $0 < P_w < 100$, r = 0.9)

The outdoor temperature is a better measure than the indoor temperature. High indoor temperatures can be caused by lack of an open window as well as providing an incentive to open it: the causal relationship is therefore muddled.

Subjects with blinds or curtains on their windows used them against glare rather than overheating. The use of blinds correlates to the solar intensity (r = 0.38) and not on the outdoor temperature with which it is practically uncorrelated.

DISCUSSION AND CONCLUSIONS

The aim of this work is to provide simple rules for deciding whether a building with a variable indoor climate will prove comfortable. Current Standards tend to assume that the required indoor temperature is not affected by the weather outdoors except for a small seasonal difference. They also assume that the indoor temperature can be controlled.

Indoor temperatures in naturally ventilated buildings change in a way which is semi-random. The outdoor weather has a random variation about a more predictable mean. The indoor temperature reacts to this in a way which can be predicted from the characteristics of the building but includes many semi-random elements (occupancy, wind speed, window opening etc.).

To achieve the aims of the project we need a method to calculate the temperatures in buildings, both as an expected temperature and as a probabilistic variation about it. This research provides a method for forecasting the indoor temperatures which people will find comfortable. It could be used to classify buildings in terms of the predicted percentage discomfort.

The pilot study has confirmed that a relationship exists between the running mean of the outdoor temperature and the comfort temperature indoors. The project also threw light on the way in which building occupants use the controls at their disposal. In particular the finding that the probability of open windows in buildings prone to overheating is related to the outdoor temperature. Such relationships could be incorporated, even in simple simulations such as the admittance method[19], to give a most likely indoor temperature and an expected distribution about it. Dynamic building simulations can be used to play a crucial role in the evaluation and application of Standards based on an adaptive algorithm.

Eventually the risk of discomfort could be assessed a variety of typical buildings. This can be done by modelling the range of indoor temperatures which result from different outdoor conditions and using the algorithm to assess whether the comfort zone falls within the range of conditions predicted. The adaptive approach shows that occupants will attempt to ensure their own comfort if this is within the range of options open to them.

Another use for the adaptive algorithm is in the control of air conditioning systems. Wilkin[12] has shown that by using an algorithm relating indoor set-points to outdoor conditions, energy savings of up to 25% are possible.

The research described provides a framework for standards for comfort which take account of the dynamic-interactive relationship between climate, buildings and occupants. It is expected that the exact algorithm will be modified by the characteristics of the building, its control systems and other pertinent inputs such as management style. A full research programme is now under way using 12-month surveys of some 800 occupants of 17 buildings in Oxford and Aberdeen.

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Sustainable Building

BEPAC's first virtual conference

Marion Bartholomew, BEPAC Administrator

IBPSA's UK affiliate BEPAC has linked up with the Engineering and Physical Sciences Research Council (EPSRC) to mount its first 'Virtual conference', ***Sustainable Building***, on BEPAC's Web site:

http://www.iesd.dmu.ac.uk/bepac/

The conference opened in February (to coincide with a parallel physical conference) and will run until late summer.

There are 29 papers, on 7 themes:

- sustainable cities
- harnessing renewable energy
- energy management
- acoustic environment
- health and comfort
- component monitoring and modelling
- ventilation and smoke control.

Abstracts can be reviewed in HTML, and all the papers are available for downloading as Adobe Acrobat PDF files, complete with tables and figures, for reading offline. Acrobat files can be viewed on almost any platform (Windows 3.x, 95, NT, Mac, UNIX): Readers are free and can be downloaded via the BEPAC site.

The files are print-disabled. Full printed copies of the 198 page Proceedings are available from BEPAC Administration as long as stocks last. The price is £35 + £3 post and packing to BEPAC members and £45 + £3 p&p to others.

The physical ***Sustainable Building*** conference was sponsored by EPSRC as a way of getting feedback from 'customers' on the shape and value of the research programmes that it funds. Accordingly, attendance had to be limited to paper authors and building designers and other 'customers'. Held in the pleasant town of Abingdon on the river Thames on 5 and 6 February, the conference was attended by over 70 delegates, roughly half authors and their colleagues and half 'customers'. 10 papers were presented in full. Other authors were given 2 minute speaking slots to attract interest in their posters. It made for a lively occasion.

The virtual ***Sustainable Building*** is an exciting development for BEPAC — and IBPSA. Virtual conferences have several potential advantages over physical meetings for associations whose members are busy and geographically dispersed, like ours:

- virtual conferences can be organised on a much shorter timescale than is possible for a conventional one, so information can be right up to date. The timetable for ***Sustainable Building*** was:
  - abstracts due 11 December
  - abstracts reviewed within 3 days
  - draft papers due 8 January
  - drafts refereed within a week
  - final papers due a week later
  - conference opened 5 February.
- virtual conferences can be visited at any convenient time, for as long as visitors want, with no overheads of travel time or cost. This is particularly attractive for people who are only interested in part of the conference.
- if organisers wish, papers can be made printable, making hard copy available at much lower cost than conventional printed Proceedings;
- alternatively, Proceedings can be published on CD-ROM at low cost, using the same files as on the Web;
- with lower costs, it will be possible to have more events.

So, virtual conferences can greatly improve the flow of information between research and practice, and cut costs for everybody. Designers benefit from information that is much more quickly, readily and cheaply accessible, and the research community benefits from greater visibility and takeup of its work.

Do you have any views on virtual conferences? If so, please email or fax Marion Bartholomew. Your opinions will help shape the future.

And do visit ***Sustainable Building*** on the Web!

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Sustainable Building papers:

Sustainable Cities

The impact of feedback on domestic energy consumption *Day and Brandon, University of Bath*

Urban densities, travel behaviour and the limits to planning *Breheny and Gordon, University of Reading*

Energy modelling of building estates *Alexander et al, Welsh School of Architecture*

Closing the action/awareness gap: applying limiting factors theory to individual environmental action *Bowman and Goodwin, De Montfort University and Jones et al, University of Wales*

A land-use, transport and energy model of a medium sized city *Brown, University of Manchester and Steadman, The Open University*

Identifying the environmental potential of 'smart' metering technologies: mapping home systems for sustainable futures *Chappells et al, University of Newcastle*

Harnessing Renewable Energy

Wind energy associated with buildings *Graham and Jenkins, Imperial College, London*

Photovoltaic roof tiles: design and integration in buildings *Bahaj and James, University of Southampton*

A dynamic lighting system: background and prototype *Cropper et al, De Montfort University*

Energy Management

Achieving relevance through facilities management *Barrett and Sexton, Salford University*

Prediction of energy use in food retail stores using artificial neural networks *Tassou and Datta, Brunel University*

Model-based solutions for full scale HVAC VAV systems *Virk et al, University of Portsmouth and Loveday, University of Loughborough*

Acoustic Environment

The prediction of sound levels and room acoustic parameters using a ray-tracing computer model *Dance and Shield, South Bank University*

On the modelling of diffuse reflections in room acoustics prediction *Lam, University of Salford*

Health and Comfort

Thermal comfort requirements for people with physical disabilities *Webb and Parsons, University of Loughborough*

Modelling temperature and human behaviour in buildings - 1) Scoping study *Nicol and Raja, Oxford Brookes University*

Modelling temperature and human behaviour in buildings - 2) Thermal comfort field studies: 1996-1997 *Nicol and McCartney, Oxford Brookes University*

New guidelines for the design of healthy office environments *Jones et al, Welsh School of Architecture and O'Sullivan et al, Bartlett Graduate School*

Chilled ceiling and displacement ventilation environments: airflow, radiant asymmetry and thermal comfort effects *Loveday et al, Univ. of Loughborough and Taki, De Montfort Univ.*

Movement and deposition of aerosol particles in buildings *Riffat et al, University of Nottingham*

Component Monitoring and Modelling

HVAC system simulation: modelling the performance of boilers *Hanby and Li, University of Loughborough*

Empirical validation of the glazing models in thermal simulation programs of buildings *Eppel and Lomas, De Montfort University*

Measurement of moisture migration in building materials *Saidani-Scott and Day, Univ. of Bristol*

Investigaton into heat transfer mechanisms in enclosures *Awbi and Hatton, University of Reading and Ward, University of Sheffield*

Ventilation and Smoke Control

An experimental and theoretical study of the stability of stratified hot smoke in tunnel fires *Tabarra et al, South Bank University*

Measurement and CFD modelling of room air flows *Vazquez et al, University of Loughborough*

Investigating the effects of wind on natural ventilation design of commercial buildings *Alexander et al, Welsh School of Architecture*

Guidelines for the design and operation of natural and mixed mode ventilation systems in commercial buildings *Jones et al, University of Wales, O'Sullivan et al, Bartlett Graduate School, and Bowman and Patronis, De Montfort University*

The use of dynamic and diffusive insulation for combined heat recovery and ventilation in buildings *Taylor and Webster, Robert Gordon University and Imbabi, University of Aberdeen*

IBPSA on the Web

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IBPSA has a presence on the world wide web at:

http://www.mae.okstate.edu/ibpsa/

The web pages currently general IBPSA information, a mission statement, a link to the Building Simulation '97 home page, tables of contents for past Building Simulation conferences, ordering information for past conference proceedings, and links to other building related pages.

The IBPSA web pages had over 3500 accesses from over 25 different countries in its first year. By the end of the year, we were averaging about 400 accesses per month.

Including the table of contents of each of the past Building Simulation conference proceedings allows us to be found by people searching the web for topical information. For example, using the Dec Alta Vista search engine (http://altavista.digital.com) with the terms "buildings CFD", a reference to the Building Simulation '93 Table of Contents is found, which contains listings for:

Lam, J., R. Yuen, T. Lau. 1993. Improvements to User-friendliness of a Computational Fluid Dynamics (CFD) Code for Simulation of Air Movement in Buildings. Proceedings of Building Simulation '93 : 77-83.

Stankovic, S., A. Setrakian. 1993. Thermal and CFD Modelling vs Wind Tunnel in Natural Ventilation Studies. Proceedings of Building Simulation '93 : 457-462.

Other references to Building Simulation '89, '91, and '95 are found with the same search.

The IBPSA web pages are still very modest in scope – suggestions and contributions are welcome! For further information, contact Jeff Spitler.

Empirical Validation of the Glazing Models in Thermal Simulation Programs of Buildings

Herbert Eppel & Kevin Lomas[1]

Buildings are employing progressively higher levels of glazing on their outer facades. Heat gains by solar radiation and the heat losses due to longwave radiation and convection dominate the thermal characteristics of the glass. Detailed thermal simulation programs are often called upon to predict the heating energy demands and internal temperatures in highly glazed spaces. Previous work had shown that the algorithms that constitute the models of glazing systems may differ such that they have a large impact on program predictions. This paper, presented at BEPAC's *Sustainable Building* conference in February, describes work to evaluate the glazing models in three thermal simulation programs, using validation data from Test Room 3000.

INTRODUCTION

Sealed glazing systems occupy ever greater proportions of the external envelope of non-domestic buildings. The UK government currently advocates the use of daylight as a way of reducing energy consumption in non-domestic buildings[1], and is exploring the benefits of low U-value glazing systems. In the domestic sector, passive solar design is being promoted as a cost effective method of reducing energy consumption[2]. The energy consumption of, and the thermal environment within, both domestic and non-domestic buildings are often dominated by the thermal performance of the glazing system.

Detailed thermal simulation programs are widely used to predict the thermal performance of buildings, however, they employ different models of the glazing. Extensive program validation work at De Montfort University (DMU) and elsewhere has shown that these differences result in divergent predictions even for modestly glazed spaces[3,4].

To study the performance of glazing systems under real weather and room operating conditions, the Energy Monitoring Company (EMC) operates an outdoor test facility. Using data from this test facility, the objectives of this EPSRC funded project were to:

(a) evaluate the accuracy of the native glazing models embedded in at least three well known public sector programs: ESP[5,6]; HTB2[7] and SERIRES[8];

(b) to evaluate, by direct measurement, the accuracy of the external and internal longwave radiation and surface convection algorithms;

(c) to evaluate the accuracy of short-wave solar transmission algorithms; and

(d) to produce at least 6 well documented data sets which can be made openly available for validating glazing models.

This article provides an overview of the work and describes some results.

SIMULATION OF GLAZINGS

The glazing models used by thermal programs differ significantly in their complexity. Simple models employ concepts such as solar aperture and U-value for solar gain and heat loss calculations. More sophisticated models rely on the correct operation of a number of component algorithms. These involve accurate evaluation of: convective exchange at internal and external surfaces, longwave exchange at the inside & outside surfaces and convective and longwave exchange in cavities between glazing panels (Figure 1).

Internal convective heat transfer coefficient (ihtc) algorithms employed in DSPs vary significantly and have a marked influence on the predicted performance of glazed spaces[3,4,9]. Some laboratory work to measure ihtc's[10] has shown that conventional ihtc values, as found for example in the CIBSE guide[11], may be significantly in error.

The algorithms dealing with internal longwave exchange to the glazing are also important[12]. However, the fundamental physics is well understood and can, with effort, be modelled exactly, e.g. by a radiosity or ray-tracing approach. Errors arise due to the approximations made in thermal simulation programs, e.g. to reduce calculation times.

The lack of confidence in extant external heat transfer coefficient algorithms led the EPSRC to support work in this area. The results of the project were published recently[13,14,15]. Convection and longwave exchange across the cavities in glazing systems has a large impact on the heat losses through low U-value windows. The coating on the glazings, the cavity widths, and the type of gas fill all influence the heat flux [16].

It is clear that changes to the component algorithms in a glazing model can, individually, have a noticeable effect on the

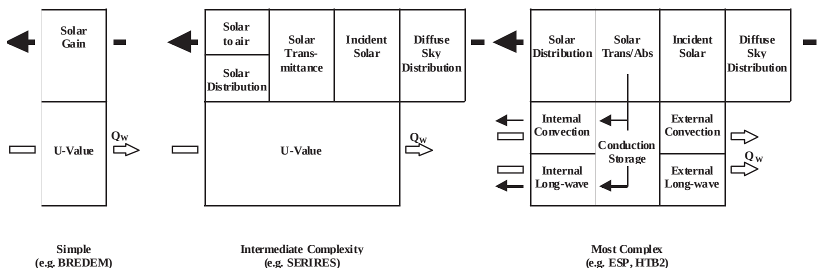

Figure 1 Glazing model algorithms of different complexity

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predictions obtained from the complete thermal simulation program. Since, in the complete program, all the algorithms are operating simultaneously, the total effect on predictions is likely to be even more pronounced. This project sought to understand the influence of individual algorithms as well as the total influence when they are combined in the way that is adopted by the latest versions of ESP, SERI-RES and HTB2.

MEASUREMENT OF GLAZING PROPERTIES

A high performance window test facility, called Test Room 3000[17], was built by the Energy Monitoring Company (EMC) in 1990 **(Figure 2).** The facility is the same size as a typical room and so realistic thermal regimes can be established. There is one glazed façade which can contain any glazing system. The back-loss from the room can be controlled or totally eliminated by heating the air in the surrounding cavities (Q_B=0). Infiltration was completely eliminated (Q_A=0). All internal walls were thermally light-weight thereby avoiding the complexities introduced by long thermal time constants. The facility was completely unshaded and on an unobstructed site.

The net heat flux (Q_{net}) through the glazing is given by

$$Q_{net} = Q_W - Q_I = Q_H - Q_S$$

where

Q_W = heat loss through the glazing;
Q_I = solar gain;
Q_H = heater output;
Q_S = heat loss through south wall.

In the experiment, Q_H and Q_S were measured and so the net heat flux could be deduced. At night Q_I = 0, and so the actual heat loss through the glazing could be found. Detailed temperature measurements allowed the individual convective and radiant components of this to be obtained.

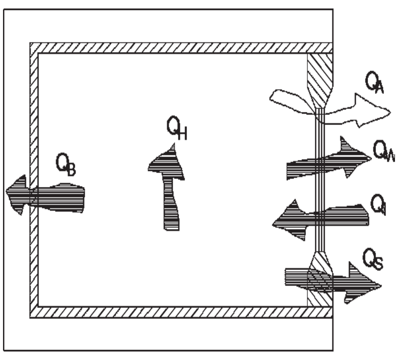

Figure 2 Schematic diagram showing heat flows in Test Room 3000

Table 1 List of Experiments

Exp. Code	Glazing System[1]	Date of Exp.[3]	Duration (days)	U-Value [W/m²K] Assumed	Measured
1	Opaque Panel	15:2 - 24:2	10		
1a	Opaque Panel[2]	27:2 - 01:3	3		
2	Single	06:3 - 17:3	12	5.5	5.21
3	Double - 6mm cavity	25:3 - 3:4	10	3.1	2.93
4	Double - 12mm cavity	21:4 - 30:1	10	2.7	2.4
5	Double - 12mm cav., 1 low-e layer	11:5 - 22:5	12	1.9	1.73
6	Double - 12mm cavity, 1 low-e layer, argon filled cavity	24:5 - 3:6	11	1.6	1.6
7	Triple - 12mm cavities, two low-e layers, argon filled cavities	9:6 - 16:6	8	0.9	0.93

[1] Nominal glass thickness 6mm for all systems
[2] Room setpoint 28°C, cavity set-point 22°C : in all other experiments cavity and room set-point 25°C
[3] All experiments in 1995

Error analysis showed that Test Room 3000 could, in principle, measure the net heat flux through glazing to an accuracy of better than ±5% even for systems with U-values as low as 1.0 W/m²K[17]. Test Room 3000 therefore offers: (a) the opportunity to accurately quantify the thermal behaviour of high performance glazing systems; and (b) the possibility of measuring the heat fluxes through glazings and at their surfaces. The project sought to establish whether the potential of the facility could be realised in practice and thus that the data could be used to validate thermal simulation programs.

In this project, 8 experiments were undertaken. The glazing systems tested and the dates and duration of the experiments are shown in **Table 1.**

INFERRED WINDOW U-VALUES

To determine the on-site U-values of each glazing system, the deduced flux per unit area through them was plotted against the temperature difference at each night-time hour when the room air set-point was within ±0.1°C of 25°C (e.g. **Figure 3**). All regression lines passed very close to the origin; the correlation coefficients were 0.61 or better; and except for single glazing, the correlation coefficients got smaller, i.e. a worse correlation, as the glazing U-value decreased. This effect might be expected because it is more difficult to deduce Q_W, and hence U-values, when the absolute flux through the glazing is smaller. The greater scatter for the single glazing may be because the fluctuations in surface heat transfer coefficients are causing genuine differences in the U-value. (The resistance to heat flow is almost entirely due to their surface resistances).

The U-values assumed in the simulations were based on manufacturers' data. These were compared with the slope of the graphs, i.e. the measured values (Table 1). The assumed values had the same rank ordering as the measured values. Using the measured values derived by forcing the regressions through the origin, the difference from the assumed values was up to 0.30 W/m²K, i.e. a difference of about 0.7W per °C temperature difference. Be-

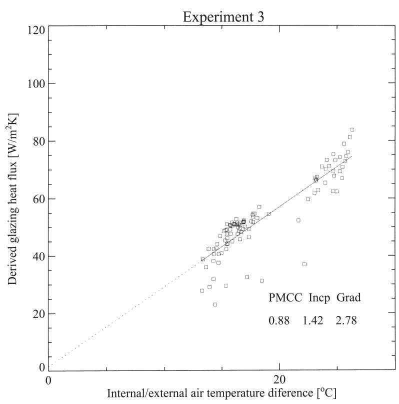

Figure 3 Comparison of derived heat flux through the glazing with the temperature difference across it

cause the assumed U-values were between 6% and 13% above the values assumed in the simulations for experiments 2 to 5, one would expect the predicted heating energy demands to be above, rather than below, the measured values. The whole model comparisons explore this issue further.

WHOLE MODEL COMPARISONS

ESP predicted hourly energy demands in all the experiments which were lower than those predicted by the other programs. These differences can be attributed directly to the differences in the algorithms adopted by the programs. The ESP predictions were also virtually always lower than the measured heating energy demands and by considerably more than the 2.5% assumed total uncertainty (e.g. Figure 4). In all the experiments (except 3) HTB2 predicted heating energy demands which were closer to the measurements than the predictions of the other two programs. (In Experiment 3, SERI-RES and HTB2 produced similar results). SERI-RES tended to predict the highest energy demands, and these exceeded the measurements in all the experiments except 1a. The higher U-values assumed in the simulations could explain this.

In the recent IEA 12/21 empirical validation exercise[18], ESPv7.7a, HTB2v1.2, HTB2v1.10 and SERI-RESv1.2 were all used to predict the heating energy demands of intermittently heated test rooms located on the EMC test site. Rooms with either double or single glazing or no glazing at all, were studied. For the double glazed and opaque rooms, the predictions were also compared with field measurements. In those tests, ESP also predicted heating energy demands which were lower than those predicted by the others and also below the measurements. Similarly, in empirical validation work using data from a double glazed, passive solar test building at the National Institute of Standards and Technology, ESP-r predicted lower energy demands than HTB2 and SERI-RES. The predictions were also significantly below the measured values[19].

The results from this study are thus very similar to those seen in previous work. In this work, detailed measurements were made so it was possible to study the performance of the component algorithms in the glazing models to shed light on the reasons for the differences in predictions.

EXAMPLE OF ALGORITHM VALIDATION

The procedure used to evaluate individual algorithms will be illustrated for ESP and results shown. Prior to evaluation, the diagnostic output from the program was checked. The output for each experiment was tested to ensure that it produced an energy balance for the whole room, and to ensure that the sum of the convective and longwave fluxes at each surface of the glazings were equal to the total predicted flux. The excellent agreement which was produced for all the experiments indicated that the ESP results are internally consistent (e.g. Figure 5). The measured and predicted heat fluxes at internal and external surfaces were compared with the values measured at night in experiments 2 to 4. In those, the fluxes were greater and so less susceptible to experimental error.

Heat exchange at external surfaces

The external convective heat flux predicted by ESP was generally lower than the measured value in the experiments where double glazing was installed (under conditions of high heat flow). This was reflected in the lower predicted external convective coefficients, particularly in the experiments with double glazing. These results are consistent with the low heating energy demand predictions of ESP compared to the measurements. In contrast, the predicted external heat flux due to longwave radiation was generally higher than the measured values. This counteracted the higher convective losses and so the total heat flux from the external surface, and hence the deduced external combined surface coefficient was similar to the values inferred from the measurements (Figure 6).

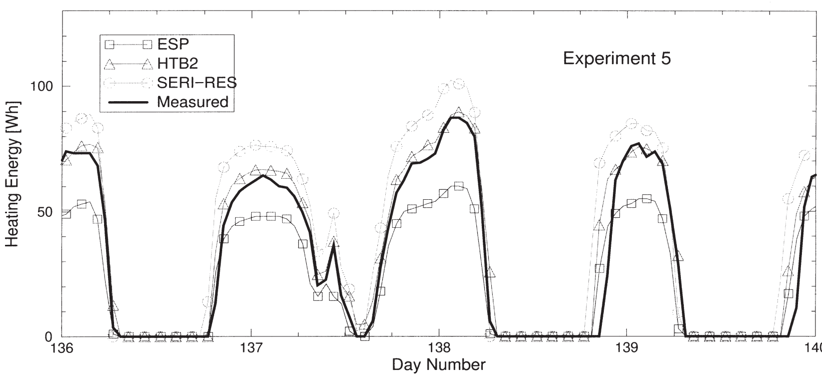

Figure 4 Typical hourly heating energy results

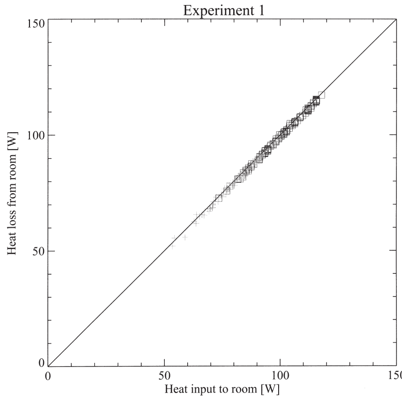

Figure 5 ESP room energy balance

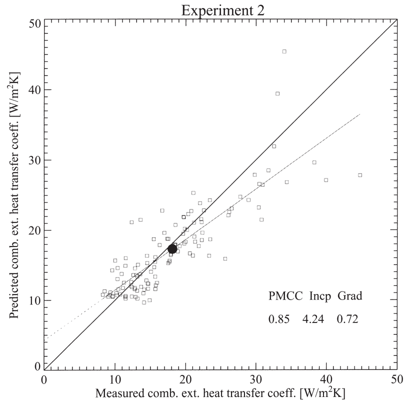

Figure 6 Comparison of measured and predicted external combined coefficients

Heat exchange at internal surfaces

The measured internal longwave exchange between the glazings and the inner surfaces of the room was calculated, and by dividing by the difference between the window surface temperature and the air temperature, an effective longwave exchange coef-

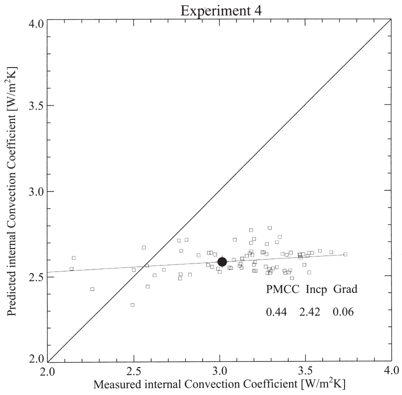

Figure 7 Comparison of measured and predicted internal convection coefficients

ficient could be deduced. Such a value could also be inferred from the diagnostic ESP output. The room was rectangular with all internal surfaces at the same constant temperature, so the internal longwave exchange could be calculated as 4.7 W/m^2K. In the experiments, the differences between the measured and predicted heat fluxes were generally small with a slight tendency for, on average, over- rather than under-prediction of fluxes. However, when the magnitude of the fluxes was greatest (which occurs under conditions of peak heating energy demand) the predicted fluxes were close to the measurements.

The predicted internal convection coefficients were invariably lower than the measured values. The predicted values were between 2.4 and 2.8 W/m^2K in the double glazed rooms, whereas measured values were generally between 2.4 and 4.2 W/m^2K (Figure 7). The higher values occurred under cold conditions, and so the measured heating energy demands were likely to be greater than the predicted values. The predicted values did not correlate well with the measured ones, having a regression line of almost zero gradient.

The internal heat transfer coefficients were numerically smaller than the external coefficients, and so they had a larger impact on the overall resistance of the glazing to heat flow than the external coefficients. It is evident that the lower heating energy demands predicted by ESP could be largely due, in this room, to the convective heat transfer coefficient being lower than the measured values. It is worth noting here that the measured average convective coefficient of 3.0 to 3.4 W/m^2K is close to the standard CIBSE value of 3.0 W/m^2K[11]. As noted above, the average ESP value was much lower.

To investigate further, the ESP default algorithm (after Alamdari & Hammond[20]) was replaced with an alternative algorithm (after Khalifa and Marshall[10]) and the simulations repeated. The algorithm predicted values from 2.6 W/m^2K to 3.5 W/m^2K which was much closer to the measured mean values. As a consequence, ESP produced higher heating energy demand predictions than previously obtained and these were much closer to the measured values. It was beyond the resources of this work to investigate these matters further, however, the primary reason for the low heating energy demand predictions of ESP observed in this, and in other research work, appears to be due primarily to the low internal heat transfer coefficient values.

The eight data sets from Test Room 3000 have been made available electronically and a site handbook has been produced so that others can use the data effectively.

CONCLUSIONS

- Dynamic thermal simulation programs play an important role in the design of energy efficient UK buildings. This is likely to remain so for the foreseeable future. Differences in their numerical predictions are likely to be due to the algorithms of which the glazing models are comprised. The algorithms may also produce heat flux predictions which are different from those which actually occur in real buildings.
- Test Room 3000 is an experimental facility which has been shown to be capable of measuring the U-value of glazing systems exposed to real weather conditions. It can also provide data to validate thermal simulation programs.
- Of the three programs tested (ESP, HTB2 and SERI-RES), ESP predicted heat fluxes through the glazing which were lower than the measured values, whilst, on some occasions, SERI-RES predicted marginally higher fluxes. The ESP predictions are consistent with work reported elsewhere.
- The lower ESP predictions were attributed to the algorithm used to predict convective heat flux at internal surfaces. An alternative algorithm provided predictions which were much closer to measured values.
- The eight data sets from Test Room 3000 have been made available electronically and a site handbook has been produced so that others can use the data effectively.
- Vendors and users of simulation programs have given a high priority to validation. This work is a further contribution to these efforts.

ACKNOWLEDGEMENTS

The authors are grateful to the EPSRC for funding this work. Thanks are due to Dr. Chris Martin of the Energy Monitoring Company for excellent data and continued advice and assistance throughout the project, and to colleagues at De Montfort University, in particular Dr. John Patronis, John Mardaljevic and Jenny Watson, who gave invaluable assistance to the project.

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The directory includes more than 70 tools—from research grade software to commercial products with thousands of users. The common thread for all the software is improving energy efficiency or incorporating renewable energy concepts in buildings. In the first version of the directory (August 1996), most tools were sponsored by DOE at some point in their life-cycle. We continue to expand the directory and are actively looking for software to include—not limited to government supported software. Commercial software is welcome. The directory is intended to be an impartial clearinghouse—providing consistent information about a broad variety of building software available worldwide.

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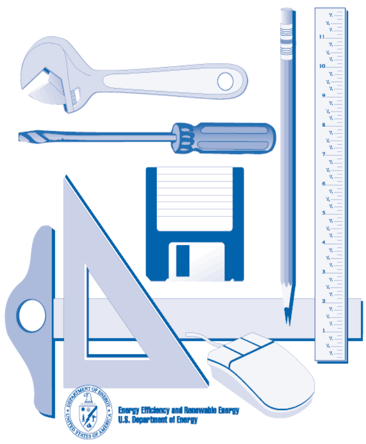

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A Dynamic Lighting System: background and prototype

Paul Cropper, Kevin Lomas, Arthur Lyons and John Mardaljevic.[1]

Using natural light it is possible to significantly reduce the reliance on - and hence the electrical energy consumption of - artificial lighting installations in non-domestic buildings. The higher efficacy of natural light also lowers the level of internal heat generation and thus reduces the electrical energy consumption of air conditioning systems. Until now, it has not been possible to accurately predict time-varying illuminance in geometrically complex spaces lit by any combination of natural and artificial lighting arrangement and lighting control system. This paper, given at BEPAC's *Sustainable Building* conference, describes a computerised Dynamic Lighting System (DLS) which achieves this, along with some initial validation results. The system should be capable of accurately predicting time-varying illuminances, the status of artificial lights and their energy demand.

INTRODUCTION

In an increasingly energy conscious world, architects and designers are ex perimenting with innovative building design and glazing systems to reduce overall energy consumption. By using natural light it is possible to significantly decrease the use of artificial light, reducing not only the energy consumed by lighting but also that consumed by air-conditioning required to remove excess heat.

It is possible to predict internal illuminances, using either scale models and an artificial sky, or computer modelling. However, the cost of making accurate scale models can be high, and most artificial skies are limited in there capabilities, particularly in the range of luminance they can provide. Computer modelling is more flexible, and can accommodate a mix of natural and artificial sources, therefore it can take several minutes (or longer) to calculate the illuminance at a single point when there are complex inter-reflections. This time penalty may not be significant if only a few values are required, but to examine how illuminance changes over long time periods, e.g. hourly interval throughout a year, simulation times can be prohibitive. The *daylight coefficient* approach, developed by Tregenza and Waters[1], will, in principle, allow computer modelling to be used whilst keeping simulation times manageable.

The aim of this project is to develop a computer based system, the Dynamic Lighting System (DLS), able to predict illuminances from both natural and artificial light, and the energy consumption of lighting systems combined with real control systems. The calculations will be performed at short time steps, using realistic sky models and real building geometry, to provide time-varying outputs of illuminances, electrical energy demand and the status of artificial lights.

THEORETICAL BASIS

The term daylight refers to light from the sky, excluding light from the sun. The *daylight coefficient* approach to calculating illuminance is to divide the sky dome into a large number of patches, and treat each patch as a separate light source. A *daylight coefficient* is the fixed relationship between the luminance of a patch of sky and the resulting illuminance, both direct and indirect (figure 1), produced by that patch at a point of interest. The illuminance resulting from any sky can be quickly determined by summing the luminance values of all the patches, scaled by the corresponding coefficients. The accuracy of predictions can be improved by dividing *daylight coefficients* into two components[2,3]: the *direct daylight coefficient,* for the light arriving at a point directly from a sky patch, and the *indirect daylight coefficient* for the light which arrives at a point after inter-reflection.

The DLS uses an advanced physically-based ray-tracing program, RADIANCE[4], to predict illuminance. RADIANCE was chosen because it is capable of calculating complex inter-reflections, and places no theoretical limitation on the complexity of the building geometry. Previous research at De Montfort University has validated the numerical accuracy of RADIANCE, when used in its native mode, for calculating illuminance values under complete skies[5], and when it was used in a proof of concept study, to calculate *daylight coefficients*[3].

This research extends the *daylight coefficient* approach to predict illuminance due to the sun, using *sunlight coefficients*, and illuminance due to artificial lights, via *artificial light coefficients*.

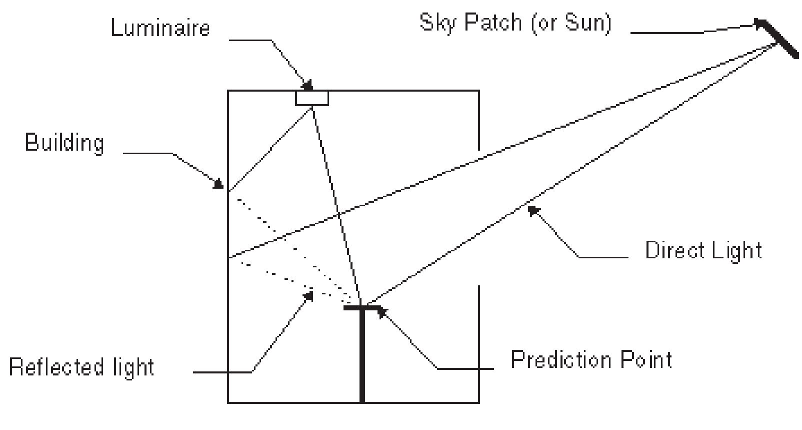

Figure 1 Sources of illumination

[1] *Institute of Energy & Sustainable Development, De Montfort University, The Gateway, Leicester LE1 9BH, UK*

THE DYNAMIC LIGHTING SYSTEM

The DLS program (figure 2) has two distinct functions: (i) to generate coefficients; and (ii) to use those coefficients to evaluate the performance of the lighting scheme under consideration. The first function uses RADIANCE to calculate coefficients. This operation is performed only once for a given building geometry. The program's second function uses the coefficients to predict illuminances, by assigning the actual luminance values to each light source and summing the light arriving at each prediction point, after weighting by the pre-calculated coefficients. This function may be used repeatedly, i.e. at each time step of the calculation, without re-calculating the coefficients.

If alternative light switching algorithms are investigated, the same coefficients can be used. The *artificial light coefficients* must be re-calculated if different luminaire designs are specified, but this is relatively quick. Only if the building geometry changes do the *daylight coefficients* and *sunlight coefficients* need to be re-calculated.

CONSTRUCTING A SKY DOME

The approach chosen was to divide the sky hemisphere into a series of spherical triangles, as illustrated in figure 3. Triangles were chosen because they are suitable for recursive sub-division, which allows the degree of discretisation to be varied. When using RADIANCE, distant light sources, i.e. sources with a small solid angle, are described by a direction vector and a cone angle. The cross-sectional shape of the source is therefore irrelevant. The triangular patches were used to supply a centre vector and a cone angle (equivalent to each triangle's solid angle), each patch being treated as a separate light source.

CALCULATING COEFFICIENTS

The description of each sky patch, which is given unit luminance, is combined with the building geometry, to calculate its *indirect daylight coefficients* using RADIANCE. *Indirect daylight coefficients* are derived in two stages. The scene is first simulated, to calculate an approximate coefficient for the total light, both direct and indirect (inter-reflected), arriving at a point. The simulation is then repeated to calculate an approximate coefficient for the direct component only. This direct coefficient is then subtracted from the total value to leave an accurate value for the *indirect daylight coefficient*. The process is repeated for each patch / prediction point combination.

Direct daylight coefficients are predicted, using direct sampling. The scene is simulated with a complete hemispherical sky dome, and single rays sent from each prediction point towards the centre of each sky patch. The resulting values will be either zero, if the ray hits part of the building, or the sky luminance value (attenuated by any participating media such as glass), if the ray hit the sky dome. This method of calculating the *direct daylight coefficients* is both fast, as it requires only a single RADIANCE simulation, and accurate, as it allows a higher level of discretisation to be used.

The coefficient approach can be used to model light from the sun. Due to the potentially very high luminance of the sun, and the small angle it subtends, an error in the position of the sun when calculating its coefficients, can cause large errors in illuminance prediction. This could be avoided by calculating *sunlight coefficients* for every sun position, but this could yield a very large number of coefficients. If a high level of sky dome discretisation is used to calculate *direct daylight coefficients*, the nearest *direct*

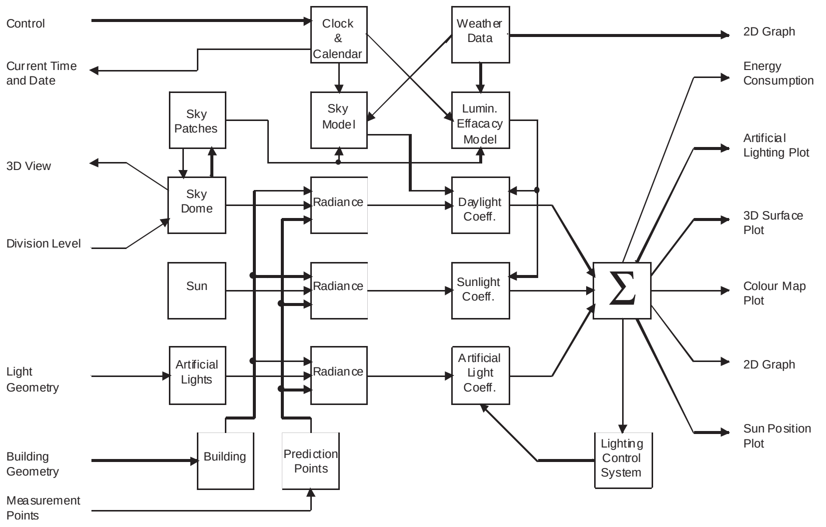

Figure 2 DLS system diagram

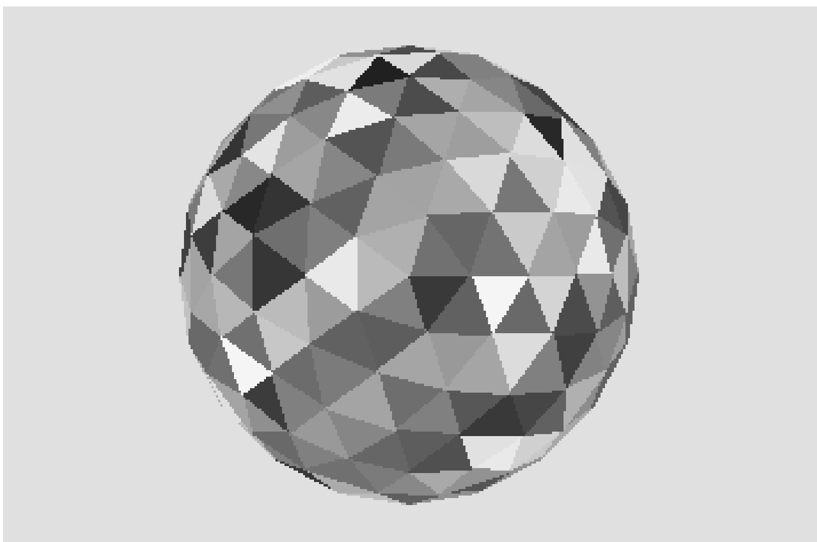

Figure 3 160 Patch Sky Dome

daylight coefficient can be used for the *direct sunlight coefficient*. Similarly, the nearest *indirect daylight coefficient* can be used for the *indirect sunlight coefficient*. This method accepts a small sun position error, in exchange for greater flexibility of the software

The coefficient approach will be used to predict illumination from artificial lights. A definition of each luminaire, which can include complex distribution patterns, will be used as the luminance source. This aspect of the project has not yet begun.

USING COEFFICIENTS

The internal illuminance at each point due to daylight is found by assigning realistic luminance values to each sky patch, scaling those luminance values using the corresponding *daylight coefficients*, and summing the resulting illuminances. The luminance values for each sky patch are predicted using a *sky model*, such as the Perez All-Weather Model[6]. The Perez model, like many others, uses values from locally measured *weather data*, diffuse horizontal irradiance and direct normal irradiance, along with the sun position, to produce a luminance distribution pattern, similar to the distribution of the real sky. A *luminance efficacy model* is used to convert diffuse horizontal irradiance in the *weather data*, to diffuse horizontal illuminance, used to scale total illuminance from the *sky model* to match the real sky.

The illuminance due to sunlight is found by scaling the sunlight luminance using the *sunlight coefficients*. The sun's luminance is obtained from direct normal irradiance, which is converted to illuminance, also using a *luminance efficacy model*.

The illuminance due to artificial lights will be found by scaling the luminance of the luminaires using the *artificial light coefficients*. The total light output of individual luminaires, may be determined by the feedback from the lighting control system. Control may be manual or by photo-cell, leading to simple on / off switching or dimming. As the calculations proceed, the length of time the luminaires are active will be recorded, enabling the total energy consumption to be calculated.

TARGET COMPUTER PLATFORM

The RADIANCE programs are written in C, and are primarily designed to run under the UNIX operating system. UNIX workstations are currently thought to provide the best environment for performing the computationally intensive RADIANCE calculations. The initial target platform for the DLS is therefore a UNIX workstation, although with the exception of the RADIANCE modules, the DLS is designed to be platform independent.

The programming language chosen for developing the DLS is Java[7]. Java programs can provide a common Graphical User Interface, running on any platform which provides a Java Virtual Machine, e.g. UNIX, PC or Apple Macintosh. Java provides extensive network features that would allow the DLS to be constructed in a Client / Server configuration, permitting coefficient calculation and data analysis to be performed on different systems.

The DLS is designed so that it can be extended easily. The Object-Oriented nature of Java encourages a highly modular design, features such as Interface Specifications allow new modules to be added, e.g. alternative sky models, without the programmer having to understand the whole system.

VALIDATION

The illuminances predicted by the DLS, for natural light only, using the Perez All-Weather[6] *sky model*, have been compared with equivalent predictions, produced by RADIANCE operating in its native mode. Previous validation studies by Mardaljevic [3][5], have confirmed the accuracy of RADIANCE by comparing predictions with illuminance measurements made in a typical office. The same test room was used for this inter-model comparison.

The deep-plan test room (9m deep, 3m wide and 2.7m high), was lit by daylight and sunlight from a window of plain glass located at one end. Illuminances were predicted for a row of points, at working plane height (0.7m), spaced along the centre line of the room.

As an illustration, the predicted illuminances at a point 1m from the window, are compared with the predictions produced by native RADIANCE in figure 4. Each data point is for one sky condition. These were defined from diffuse horizontal irradiance and direct normal irradiance, measure in the UK during 1992. The 710 data points represent a wide range of sky conditions. Sky conditions, for which there is not a valid equivalent Perez *sky model* distribution, have been excluded. DLS simulations were performed using a sky dome discretisation of 640 patches, for *indirect daylight coefficients*, and 2560 patches for *direct daylight coefficients*.

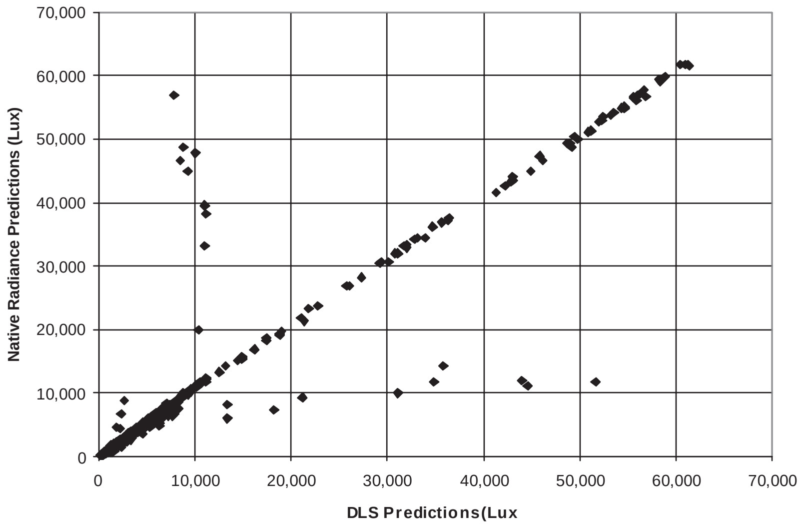

Figure 4 Comparison of illuminance predictions

It can be seen that although the predictions produced by the two methods compare reasonably well in most cases, there are a few instances where the values are significantly different. These occur when small imperfections in the sun's placement causes it to be visible to the prediction point (in the DLS), when it is actually hidden (in native RADIANCE), and visa versa.

CONCLUSIONS

A Dynamic Lighting System has been produced that predicts internal illuminance.

- It has been shown so far that the DLS is capable of accurately predicting internal illuminances from natural light, under a wide range of sky conditions.
- The DLS program, written using Java, will run on a PC, Apple Macintosh or UNIX workstation.
- When the project is completed it will be possible, for the first time, to quantify the electrical demand of lights in any space, with any lighting control strategy, when combined with natural light delivered by an innovative glazing systems.

Work is currently in progress to extend the coefficient approach to include artificial lights and lighting control systems.

ACKNOWLEDGEMENTS

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❖

Buildings, When Properly Designed, Enhance Mission Execution

says Thomas R. Rutherford[1]

Productivity gains of five to thirty five percent are achievable when the facility work space is designed to provide the occupant maximum personal control of the environment. My independent work to date indicates that a productivity gain of **only 3.8% is required to pay for all facility costs over the thirty life of the building.** This discovery is startling when first understood, but even more surprising is the lack of appreciation of this by the business-industrial-and academic community in America at large.

When the Leader in charge of a mission, begins to understand this concept, the facility becomes an investment in the bottom line versus an overhead expense to be reduced. People are the most costly element of most business processes in America. My work indicates **people consume more than 95% of all costs, in terms of building life cycle** cost evaluations, when the cost of the people in the building are included. Certainly it is unwise to focus on reducing building costs, when the people are the primary cost element, and the building while consuming only 5% of costs, has a such a significant impact on productivity. My judgment is that the facility must be designed to enhance mission execution versus reduced to the lowest possible first cost. Additionally **if the building is designed for maximum flexibility to meet changing missions in the future, the building can be looked at as an appreciating asset, vice a depreciating liability.**

My work with the U.S. Army Civil Engineering Research Laboratory (CERL), ABSIC at Carnegie Mellon University and discussions with colleagues across America, all confirm that productivity can be dramatically enhanced or degraded, depending on how well the facility supports the people. Dr. Volker Hartkopf, Director of the Center for Building Performance and Diagnostics, and the Advanced Building Systems Integration Consortium at Carnegie Mellon University, speaks to a 40% swing. Hartkopf indicates that productivity can easily swing upward by 20% or degrade by 20% from the baseline of a "so called average building". Some forty five studies uncovered by CERL in the literature search that I commissioned, confirm great opportunity to improve productivity through excellent facilities.

What are the key elements to be considered, when designing or selecting a building **to enhance mission?**

1. **Adequate Space** — probably at least 100 square feet or better 10 square meters
2. **Privacy** — people must have time to work in deep concentration without interruption
3. **Personal control** of heating, cooling
4. **Outside air supply** — quality air at all times
5. **Ergonomic Furniture**
6. **Day lighting,** access to windows; adequate indirect area lighting and task lighting
7. **Responsive telephone, communication and computing service**
8. **Flexibility** — the ability to meet changing mission and reorganizations.

In summary, **there is great opportunity to enhance mission execution, improve the company bottom line, and build morale of workers by providing work space that is inspiring, comfortable, healthy, safe and sustainable.**

[1] *Assistant for engineering and construction, Office of the Secretary of Defense*

DECADE: Domestic Energy and Carbon Dioxide Emissions

Pernille Schiellerup[1]

DECADE (Domestic Energy and Carbon Dioxide Emissions) is a research project funded by the European Commission under the SAVE Programme and by the UK Department of Environment running from 1.1.94 to 30.6.97. The purpose of DECADE is to develop an end use model of domestic energy use capable of informing policy choices on the reduction of carbon dioxide emmissions in the domestic sector. As such DECADE is already providing a framework of analysis which assists the policy choices of the UK Government and the EU.

Electricity is the most polluting domestic fuel accounting for 25% of household CO_2 emissions. In addition, domestic lighting and appliances account for an increasing proportion of total UK electricity consumption: between 1970 and 1996 the proportion of UK electricity consumption going into this type of energy service increased from 20% to 25%.

DECADE has the capacity or the potential to inform discussion, for domestic appliances and lights, on the:

- impact of various policies and strategies, either generically or specifically to an appliance group;
- general effect of new design standards for manufacturers, either in the UK, Europe or in total;
- implications for energy distributors and generators, both in terms of total demand or at peak hours;
- levels of fuel-related emissions, particularly carbon dioxide, but also the oxides of nitrogen and sulphur dioxide;
- opportunities to reduce a broader range of environmental impacts, for instance water consumption, the resources used in appliance manufacture, the ability to design for recycling, either through life cycle analysis or other methodologies.

THE STOCK MODEL

DECADE models domestic lighting and appliance electricity use and assesses the influence of cultural and behavioural factors on determining demand. The project has the most detailed and comprehensive database of UK domestic electricity consumption, covering the period 1970 to 1994 and including projected trends to 2020. These trends cover changes in technology, behaviour and demographic factors in order to give a detailed breakdown of electricity consumption and the resultant CO_2 emissions. The majority of the data refers to the UK, but is supplemented by data from a wide range of European and other studies. Even so, the quality of the data varies substantially: ownership information is of a generally high standard, whereas there is less behavioural detail on how appliances are used.

A major advance in the DECADE project has resulted from the way in which the data have been modelled, particularly in the development of the profile of the stock of appliances that already exist in people's houses. This has been made possible with the accession of sales, ownership, technical and usage data through time.

DECADE uses a bottom-up approach to modelling electricity consumption, based on the number of households and the average consumption by each appliance in an average household. The model is a vintage stock model, the same as that used for the Group for Efficient Appliances (GEA) wet appliances study (Hinnells *et al* 1995). This type of model allows for the time related effect of appliances moving through the stock of appliances in houses. It also enables the evaluation of the effect of policy options (especially technological ones) on consumption, and can be used to estimate the amount of electricity consumed by an appliance type each year. For example, the electricity consumption of colour TVs in the year k (for years k = 1970...2020) is given by equation 1:

$$Electricity(k)=\sum_{j=1970}^{k} Sales(j) \times Remain(j,k) \times Technical(j) \times Usage(k)$$

where:

Electricity(k) is the estimated consumption (kWh) of all the TVs in year k
Sales(j) are the sales of the TVs in year j
Remain(j,k) are the proportion of TVs sold in year j and still remaining in the stock in year k
Technical(j) is the average power consumption (kW) per TV sold in year j
Usage(k) is the usage (hours) of the TVs in year k

This means that the electricity consumed in 1990 (k=1990) will be based on all the machines sold up to this year and still remaining in the stock (j=1970...1990), the average new technical performance in these years (j) and the number of hours in use in 1990.

Sales may be historical data or estimated from ownership data and appliance lifespans. Projections of sales (1995-2010) are derived from projected ownership levels and average appliance lifespans. Ownership data are smoothed using a low-pass filter which smoothes out high variation from year to year, when this is due to noisy data, and, more importantly, interpolates missing data point from time series data. The IRWSMOOTH algorithm used, is a two pass filter which essentially acts as a two sided exponential smoothing window. The function *Remain(j,k)* assumes the lifespan of an appliance takes a normal distribution, with two parameters: the mean and the variance.

Where data on average new technical performance or usage data (eg number of washes pa) are not available but where the average amount of electricity consumed in one year by the average appliance has been measured, a reduced form may be used (equation 2):

$$Electricity(k) = Household\ Numbers(k) \times Ownership(k) \times UEC(k)$$

The unit energy consumption (UEC) is the average amount of electricity consumed in one year by the average appliance. It is a combination of technological performance and behavioural usage (equation 3):

$$Electricity(k) = Household\ Numbers(k) \times Ownership(k) \times SEC(k) \times Usage(k)$$

where *SEC(k)* is the average technical performance of the stock in year k. There are

[1] *Environmental Change Unit, University of Oxford, 5 South Parks Road, Oxford OX1 3UB, UK*

few measures of historical UEC data, a notable exception are the Electricity Association's measurements.

Figure 1 shows an example of the output of the stock model, for fridge-freezers. Each band represents the stock of appliances in UK households bought in a particular year. This number declines over time, as individual appliances break down or are discarded, with the average lifetime depending on the appliance. The lifetime of a fridge-freezer is 16.5 years, but there will still be appliances in the stock in 1994 that were bought in 1977. The lifetime of an electric kettle is shorter, but longer for free-standing cookers. In any one year, the sales of new appliances are made up of those that replace old appliances and those that add to the stock as they go to first-time buyers. As a result the number of households owning that appliance increases over time, and the profile, in this example, rises.

There are good data for ownership and sales of the major appliances and these can be rationalised to provide an estimate of the lifespan of the average appliance. Measured data on electricity consumption in people's homes can be used to validate the stock model, since the model estimates consumption in the home from other data sources. The stock model also permits a more detailed analysis of policy by taking into account the time it takes to replace the stock. Thus, the development of the stock model has considerably strengthened the detail and internal consistency of the DECADE modelling process, despite the known data weaknesses.

A further benefit is that the energy efficiency of the stock can be estimated using the efficiency of the average model sold in any particular year. This is based on limited performance figures for old appliances and have not incorporated the effect of deterioration - the appliance is still assumed to be as efficient as the day it was purchased. Refining the efficiency levels modelled is an important task of the DECADE project. The stock model provides the basis for estimating the rate at which new levels of efficiency would permeate into the stock. The additional detail obtained from the stock models has increased confidence in the overall totals. Where measured consumption and sales data are available, the cross-comparison between the different data sets allows for internal validation and confirmation. For these reasons, the team have confidence in the revised historical data and the projections for the future.

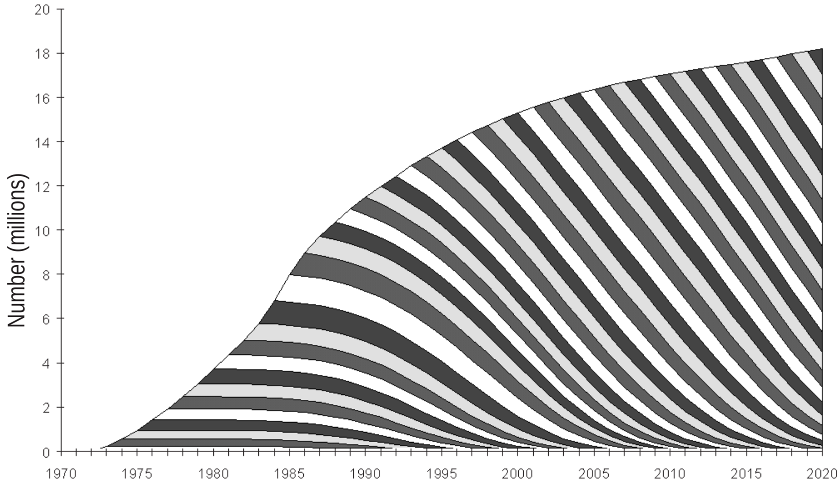

Figure 1 Profile of the stock of fridge-freezers, UK 1970-2020

So far the findings of DECADE indicate that the historic electricity consumption in UK domestic lights and appliances is 7-8% higher than previously estimated and projected consumption is 10% higher than Department of Trade and Industry projections to 2005. DECADE calculations also shows that, despite a descrease in household size, each household is now using 50% more electricity for domestic lights and appliances than in 1970. This is due to increased levels of appliance ownership and usage and a demand for higher standards of service, such as the service level embodied in frost-free freezers and larger TV screens. This together with the increase in the numbers of households due to the decrease in average household size, constitute the main drivers in the increase in domestic electricity consumption on lighting and appliances. The dynamic is illustrated in figure 2 below, using washing machines as an example. All the variables have been converted to indices with 1970 as a base year.

The changes in the underlying variables result in an increase in total energy consumption.

In order to make policy decisions concerned with energy efficiency and energy conservation, it is important to have some idea about what the potential for savings is. This can be conceptualised in a variety of ways. DECADE has so far focused on the Economical and Technical Potential (ETP) for electricity savings. This is defined as the maximum technical potential which is justifiable to the consumer over the lifetime of the appliance. The ETP is based on

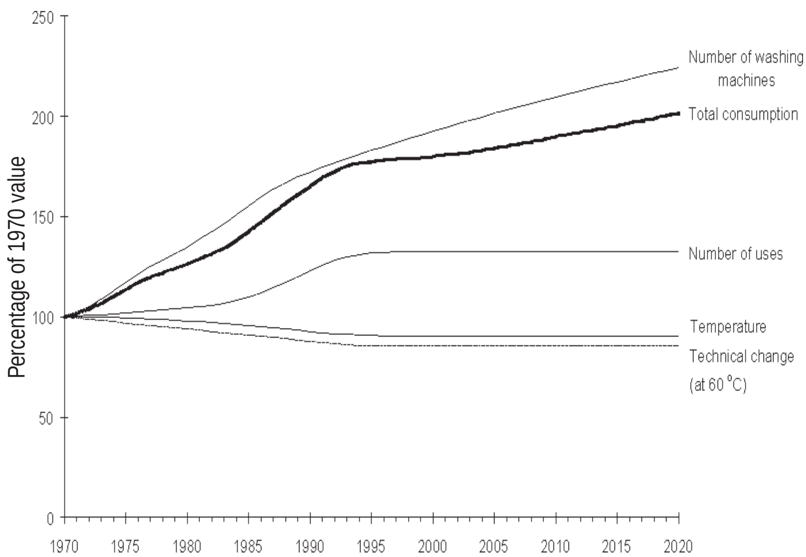

Figure 2 Indices of washing machine variables (base year = 1970)

proven technology, average usage patterns, current electricity, water, and equipment prices, with average mark-ups and an 8% discount rate. It includes no further technical improvements after 2000. If energy or equipment prices change significantly, or if new technologies become available, then the ETP may change. The ETP scenario assumes that all purchases by 2000 fullfil the ETP requirement. It does not include any reduction in consumption from changes in behaviour and so does not represent the technical limit or the lowest limit on consumption. Figure 3 below gives ETP for light and appliances. It can be seen that if all the ETP were realised for all the major appliances then electricity consumption could be reduced to 51 TWh, a saving of 32 TWh equivalent to 39% of projected consumption by domestic appliances and lighting in 2020.

The savings identified under the ETP scenario are 'potential'. There are policies which could access this potential, but it remains to be seen whether they are politically realizable, especially in the short term.

The emphasis of this article has been on the more technical and quantitative aspects of DECADE. However the project contains several other important constituent parts. It involves the detailed analysis of relevant policy initiatives including the factors that determine their success or failure. Here the main focus has been on policies introduced by government, rather than the utilities. DECADE has also involved in depth research on the factors affecting consumer purchase and the use of appliances, in particular those which may be predictive of a concern for environmental issues and energy efficiency. This work combines both an extensive literature search and a survey of people who bought a cold appliance in Oxford since the introduction of the EU energy labels.

The policy analysis and the study on consumer behaviour are used to support the development of a Policy Response-Interaction Model for Energy (PRIME). This module is being developed to provide the basis for assessing both the cumulative impact of policies over time and to identify separately the effect on manufacturers, retailers and consumers.

Finally DECADE demonstrates that a reduction in electricity consumption requires a range of policy initiatives and that the involvement of manufacturers, retailers, consumers and government is essential to ensure that these policies are effective.

The findings of the DECADE project are described in Boardman et al, 1994, DECADE First year report; Boardman et al, 1995, DECADE Second year report, and in Strang, July 1996, Environmental Values and the EU Energy Label.

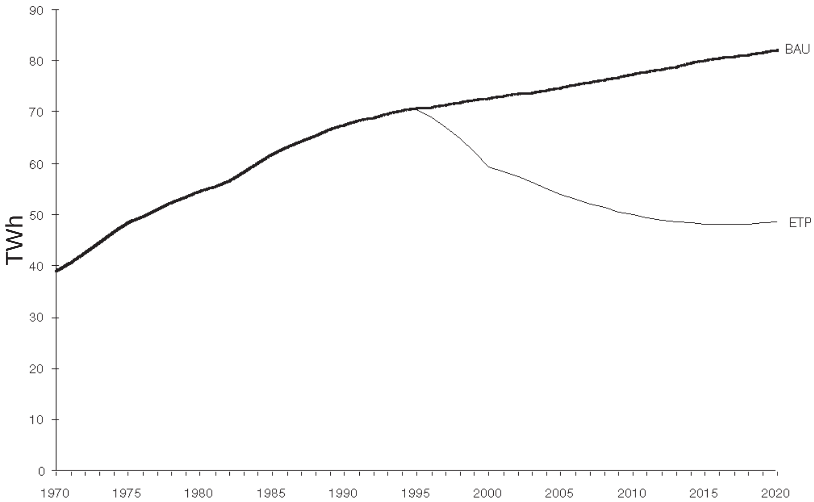

Figure 3 The BAU and ETP scenarios for UK domestic appliance and lighting consumption

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IBPSA Mission and Goals

The professional association devoted to improve the built environment through computer simulation and analysis

Mission

The International Building Performance Simulation Association (IBPSA) was founded to advance and promote the science of building performance simulation in order to improve the design, construction, operation and maintenance of new and existing buildings worldwide.

Goals

Along with building designers, owners, operators and developers, identify problems with the built environment that may be solved by improved simulation tools and techniques.

- Identify the performance characteristics of buildings on which simulation should be focused
- Identify building performance simulation R & D needs and transfer new developments to the user
- Promote standardization of the building simulation industry
- Inform and educate its members and the public regarding the value and the state-of-the-art of building performance simulation.

Activities

- Biennial International Building Simulation Conference
- Resource publication on simulation tools (under development)
- Newsletter announcing upcoming events and software tools
- Sponsorship of regional workshops and seminars on simulation

Contact

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BUILDING SIMULATION '97

Fifth International IBPSA Conference
Prague, Czech Republic
8-10 September 1997

UPDATE

AIMS

Building Simulation '97 aims to be a high quality, low budget conference in order to attract as many participants as possible. IBPSA international conferences provide the ideal forum for the exchange of information and ideas on building modelling and simulation between researchers, educators, and practitioners in engineering, architecture, and computer science.

A special aim of BS'97 is "Introducing Building Simulation in Central & Eastern Europe".

CURRENT STATE

Far more acceptable abstracts have been submitted than for any previous Building Simulation conference:

- abstracts submitted: 215
- abstracts accepted: 198

In view of the large number of papers to be reviewed, the Scientific Committee was extended with 27 auxiliary reviewers!

Notification of acceptance of the paper is scheduled for April 15, 1997. Camera-ready papers are due on June 15, 1997.

We intend to make the Building Simulation '97 Proceedings available both as a book and on CD. All technical papers will be included in the proceedings.

PROGRAMME

The technical programme comprises a combination of plenary sessions, parallel oral sessions, poster introduction/presentations, and software introductions/demonstations.

Posters will be displayed throughout the conference.

Software can be demonstrated during various times throughout the conference.

The social programme consists of an early-bird reception, reception + concert, and conference banquet. A side programme for accompanying persons will be arranged.

The conference will include an exhibition of organizations or companies. This can be organized either as an individual exhibitor, or - alternatively - IBPSA Region could organize a joint exhibition incorporating various organizations/companies from their region. In the latter case this activity is regarded as a form of sponsorship generation by the IBPSA Region.

Exhibition space will be available both in wide spacious passageways connecting the various conference rooms and in separate rooms.

VENUE

Prague (or Praha), the city of the hundred spires or the "Golden City" in the picturesque valley of the Vltava river, is the capital and centre of industry, science, and culture of the Czech Republic.

Prague is located in the centre of Europe and belongs among the best preserved historical cities with unique collections of architectural and cultural monuments.

The Dean of the Faculty of Mechanical Engineering welcomes you to the Czech Technical University in Prague (CTU) which will host BS '97.

CTU is situated just north of the centre of Prague, and is in easy reach from almost anywhere in Prague by the excellent metro system.

ACCOMMODATION

CTU co-owns the 810-bed Hotel Krystal which charges very competitive rates. Due to its popularity, Prague has accommodation available to suit every taste, from very economic to world-class.

REGISTRATION FEES

There is still time to take advantage of the early registration discounts for BS'97.

Registration fees and dates are:

Early registration (before 15 May 1997):

ECE participants	US$ 125
Full time students	US$ 125
Others	US$ 250

Late registration (after 15 May 1997): US$ 300

Accompanying persons: US$ 100

IBPSA members will receive a **US$ 25 discount**.

The registration fee includes conference attendance, proceedings, lunches, morning and afternoon refreshments, early-bird reception, welcome reception, and banquet. The accompanying persons registration excludes conference attendance and proceedings.

SPONSORSHIP

BS'97 already has an impressive list of sponsors, but the organisers would be very interested in additional sponsorship.

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If you wish to attend Building Simulation '97, or if you would like to be on the mailing list to receive further information, please complete and return a Xerox of this page.

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IBPSA international conferences provide the ideal forum for the exchange of information and ideas on building modeling and simulation between researchers, educators, and practitioners in engineering, architecture, and computer science.

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If your organisation would like to sponsor BS'97, please get in touch.

Announcements

CIBSE/ASHRAE Joint National Conference and CyberCIBSE97

CIBSE will be celebrating its centenary at its 1997 annual conference from 5-7 October at Alexandra Palace in London, UK, organised jointly with ASHRAE. A parallel virtual conference, CyberCIBSE97, opened last month with a virtual exhibition and will include the full text of the national conference papers from early September until 5 October at **www.virtual-conference.com/cibse97/**

The **Joint National Conference** focuses on **Quality for people**, with the themes **Quality in specification, Quality in construction, Quality at hand-over, Quality in operation** and **Quality overall.**

CyberCIBSE97 has the special theme of **Quality in Information**, focusing on seven areas: Impact of IT on buildings (public address, signage, movement management etc); Climatic data for design (opportunity for on-line information providers); Information for costing; Information for construction; Information for operation (FM tools); Building simulation and modelling.

For more information about the CIBSE/ASHRAE Joint National Conference or CyberCIBSE97, contact:

CIBSE
Delta House
222 Balham High Road
London SW12 9BS, UK *Phone: 44 181 675 5211*

CLIMA 2000

The 6th CLIMA 2000 conference is in Brussels, Belgium from 30 August through 2 September 1997 (just before the BS'97 in Prague). Its main objective is to make it possible for researchers, educators, consulting engineers, manufacturers, operators, etc. to talk to each other, and to provide the opportunity to government employees, building owners, architects, developers, general contractors, and others involved in the building sector to meet with large numbers of building services engineers.

The technical programme includes sessions on the indoor environment; HVAC applications in domestic, commercial, industrial and agricultural buildings; energy and environment; control and management; refrigeration; building envelope physics; modeling; and software.

For more information, contact:

CLIMA 2000 '97
c/o SRBII
Ravenstein 3 *Phone: 32 2 5117469*
B-1000 Brussels, Belgium *Fax: 32 2 5117597*

Study Day on Simulation Use in Design and Management of HVAC Systems

This study day will be organized on Wednesday, September 3rd in Liege (Belgium) just after CLIMA 2000, in cooperation with the universities of Tsinghua (Beijing, China) and Gliwice (Poland) and with the Belgian organizations ATIC, FNRS and the Walloon Region.

The aim of the day will be to identify the limitations of simulation for the design and management of HVAC systems, and to define the capabilities (energy calculation, indoor air quality, control, etc) and the utilities (default values, databases on component product information, etc) practitioners want in the next-generation building simulation software. The day will include presentations of practical applications of simulation in the design and management of HVAC systems, a brainstorming session, and demonstrations of simulation software; detailed documentation will be available.

The meeting is intended to complement IBPSA's BS'97 conference in the following week (September 8-10).

For information, contact :

Jean-Pascal Bourdouxhe
Laboratory of Thermodynamics
University of Liege
Campus du Sart Tilman *Phone: 32 4 366 48 23*
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