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Advanced Design Tools for Energy Conscious Building Design:
Development and Dissemination

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ABSTRACT

This paper is concerned with building energy simulation and the prospects for the delivery of a new generation of simulation based, valid and easy to use design tools to the building construction industry. The issues relating to design tools development and use are discussed and the present state–of–the–art is described. Some medium to long term developments are then identified, including an intelligent 'front–end' and the notion of an advanced machine environment for the construction and maintenance of future models concerned with building energy and environment. The mechanisms for technology transfer are identified and experiences recounted of the first two years operation of an innovatory energy design advisory service. The paper finishes with a look to the future of the information technologies in building design.

Prologue

Design is the highest endeavour to which women and men can aspire. It is the complex human process through which we model and shape the future of the physical environment; an environment in which we, and the other creatures of the planet, depend for food, for shelter, and for a meaningful and dignified existence; but an environment which is increasingly under threat from the rush to wrest from it its irreplaceable and dwindling natural resources – not least the precious fossil fuels.

High on the list of culprits in the profligate use of fossil fuel energy is the Building Industry. Building is the UK's second largest industry accounting for some 18% of the Gross Domestic Product and employing, directly or indirectly, 1 in 12 of the working population.

If we look at the energy delivered in Western Europe in any year we see that 9% is attributed to iron and steel production, 21% to transportation, 2% to agriculture, 16% to the manufacturing industries and a massive 52% – more than all other demands put together – is consumed to in maintain acceptable environmental conditions within our building stock. The quadrupling of fossil fuel prices since 1973 has brought the recurring expenditure on energy in buildings to a staggering Λs8 billion per annum. The problem is not only economic but social. Those of us in conurbations north of London know the extent of the human misery occasioned by domestic fuel poverty and the gross indignity of bringing up a family in houses unfit for habitation because of dampness and decay.

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Estimates by the UK Department of Energy suggest that better design of new buildings could result in a 50% reduction in energy consumption and that appropriate design intervention in the existing stock of buildings could yield energy reductions of 25%; taken together, and universally applied, these initiatives could reduce the UK energy bill by up to As2 billion per annum.

But how to improve the complex, ill-understood human activity of design decision-making ?

In setting up ABACUS within the Department of Architecture and Building Science 21 years ago, the University of Strathclyde recognised the potential of computer modelling in predicting the formal, functional, economic and technical characteristics of building performance (Maver 1982). ABACUS set about developing an integrated suite of CAD software intended to allow designers to explore the consequences of their design decisions on the profile of cost and performance.

As the energy crisis deepened, the conviction grew that the main impediment to energy efficient building design was the lack of any real understanding of the complex way in which buildings respond to climate. ABACUS was well placed to play a central role in the Science and Engineering Research Council's specially promoted programme on computer based energy models and in the Commission of the European Community's (CEC) passive solar energy research and development programme.

The 'first principles' energy model known as ESP (Environmental Systems Performance) developed in sophistication and was subjected increasingly to the rigours of validation. The scale of the R&D effort and the fact that ESP was adopted as the standard reference model for CEC passive solar energy programme encouraged the University, in 1988, to create the Energy Simulation Research Unit (ESRU) to carry the energy and environmental simulation work into the 1990's.

The paper continues with a look at this emerging technology and how it might evolve in the coming years.

Energy Simulation: What is it ?

Consider figure 1, which shows the interacting energy flow-paths encountered within buildings and their environmental control systems. From a modelling viewpoint, such a system is often considered to be equivalent to an electrical network of time dependent resistances and capacitances subjected to time dependent potential differences. In such an analogy, the electrical currents to result in each branch of the network are equivalent to the heat flows encountered within and between the building's parts. Rooms and constructional elements are treated as finite volumes of fluid and solid material characterised by thermo-physical properties such as conductance and capacitance, and possessing "variables of state" such as temperature and pressure. Since different building regions (floors, windows, floor slabs, etc.) have different thermal capacities, the problem is essentially a dynamic one; these regions responding at a different rate as they compete to capture, store and release energy. It is this dynamic behaviour that makes the building modelling problem such a complex one.

A further layer of complexity derives from the behaviour of the heat transfer mechanisms themselves; the fact that they are often highly non-linear, interact and are dependent on design parameters which, in turn, might change with time. For example:

- Surface convection is caused by buoyancy and mechanical forces and is influenced by surface finishes, geometry and temperature distribution.
- Inter-surface longwave radiation exchanges are caused by temperature differences and are influenced by geometry and surface finishes.
- Surface shortwave gains are caused by the date dependent sun path and influenced by site location and obstructions, building geometry and the transmittance, absorptance and reflectance characteristics of constructional materials.

- Shading and insolation is dictated by surrounding and facade obstructions and is influenced by site topology and cloud conditions.
- External surface longwave exchanges is influenced by sky conditions and the degree of exposure of the site.
- Air movement in the form of infiltration, room–to–room air exchange and intra–zone circulation is caused by temperature and pressure differences and is influenced by leakage distribution, occupant behaviour and mechanical phenomena.
- Casual gains – those stochastic processes associated with internal heat sources as caused by people and equipment and influenced by social and comfort factors.
- Plant interaction in the form of convective, radiant or mixed heat exchange and influenced by control action and occupant response.
- Control action involving distributed sensing and actuation, various response characteristics and the processing of a potentially vast array of signals.
- And a range of other complexities as caused by thin film technologies and a variety of solar capture and possessing features; the so–called passive solar elements as summarised in figure 2.

From a mathematical standpoint, several complex equation types are required to accurately represent such a system. And because these equations represent heat transfer processes which are highly inter–related, it is necessary to apply simultaneous solution techniques if the performance prediction is to be both accurate and preserve the spatial and temporal integrity of the thermodynamic system.

In a traditional design tools approach, it is usual to reduce the complexity of the system equations in order to lessen the computational load and the input burden placed on the user. Some portion of the network may be neglected, time invariant values may be assigned to one or more of the state variables or network resistances, simplifying boundary conditions may be imposed or it may be assumed that the system has reached its steady state. In a simulation approach, none of these assumptions are made. Instead a mathematical model is constructed to represent directly the heat flow paths and interactions observed in the reality. In this sense a simulation model is an emulation of the reality.

The evolution of design tools, from the traditional to the present day simulation approach, is summarised in the following table (from Clarke 1987).

1st Generation (Traditional)	Handbook orientated Simplified Piecemeal		Indicative Application limited Difficult to use
2nd Generation	Dynamics important Less simplified Still piecemeal	Feedback loop	increasing integrity vis–a–vis the real world
3rd Generation (Current)	Field problem approach Move to numerical methods Integrated view of energy sub–system Heat & mass transfer considered Better user interface Partial cabd integration		leading to
4th Generation (Next)	CABD integration Advanced numerical methods Intelligent knowledge based Advanced software engineering	Feedback loop ——— ?	Predictive Generalised Easy to use

The following section profiles one 3rd generation model, the ESP system developed at the University of Strathclyde and currently the subject of several technology transfer initiatives. A later section describes current research which is continuing the evolutionary process and aims to bring into existence the 4th generation by the mid 90's.

The ESP System: From 3rd Towards 4th Generation

Figure 3 shows the program modules of ESP; a system for the simulation of the energy and environmental behaviour of any building. Within ESP all heat and mass flow–paths (as identified in figure 1), and flow–path interactions, are assigned a counterpart mathematical model. These models are then contained within a single numerical framework. The theoretical basis of ESP is fully reported elsewhere (Clarke 1985). What follows is a summary overview.

The first stage is to define some proposed or existing design in terms of its three dimensional geometry and constructional and operational attribution. At simulation time, the building and plant so defined is made discrete by subdivision into a number of interconnecting, finite volumes. These volumes then possess uniform properties which can vary in the time dimension. Volumes represent homogeneous and mixed material regions associated with room air, room surface and constructional elements on the building side, and component interface heat transfer on the plant side. It is not uncommon to have as many as 250 such volumes per building zone, with around 5 volumes per plant component. Then, for each of these finite volumes in turn, and in terms of all surrounding volumes deemed to be in thermal or flow contact, a conservation equation is developed in relation to the transport properties of interest – heat energy or mass exchange for example. This gives rise to a whole system equation–set where each equation represents the state of one finite volume as it evolves over some small interval of time. These are termed state–space equations. Control equations are then added to this equation–set to prescribe, limit or impose conditions on system behaviour. Once established for a particular increment in time, the equation–set is simultaneously solved – by a numerical method – before being re–established for the next time–step. In this way ESP time–steps through some user–specified simulation period to produce a time–series of state variables which characterise building/plant performance. In support of equation–set generation, many algorithms are required to compute such information as solar and casual gains, sky and ground temperatures, heat transfer coefficients, control states and so on.

To test the acceptability of the model's predictions, many validation studies have been initiated. One of the most significant of these is known as project PASSYS (Gicquel & Cools 1986). With funding from the Commission of the European Communities, PASSYS involves the use of highly engineered and instrumented Test Cells which are used to capture real performance data for comparison with ESP's predictions. These Cells are located at eight sites throughout Europe thus ensuring that the model is tested under a range of climatic conditions.

Application of Simulation

Given the emergence of simulation as a viable prospect, how might it be applied in practice, especially in the context of non–traditional buildings embodying climate responsive design features and advanced control. Consider the following two generalised examples.

The Basics: Form and Fabric

It is entirely possible to determine, by simulation, the optimum combination of zone layout and constructional schemes which will best complement a high degree of operational automation or provide a climate responsive design of high efficacy. Several simulations are conducted to determine a zoning strategy which not only satisfies the functional criteria, but also will accommodate sophisticated multi–zone control and the re–distribution of excess energy. Some simulations might focus on the choice of constructional materials and their relative positioning within the multi–layered constructions for example, so that load and temperature levelling is maximised. And alternative facade fenestration, air movement and shading control strategies may be investigated in terms of comfort and cost criteria.

The Intelligence: Control and Response

Once a fundamentally sound design has emerged, well tested in terms of its performance under a range of anticipated operating conditions, a number of alternative control scenarios can be simulated. For example, basic control studies will lead to decisions on the potential of optimum start/stop control, appropriate set-back temperatures, the efficacy of weather anticipation, the location of sensors and the interrelation of thermal and visual comfort variables. Further analysis might focus on 'smart' control, where the system is designed to respond to occupancy levels or prevailing levels of luminance intensity or solar irradiance. As the underlying relationships emerge, the designer is able to assess the benefits and the problems of any given course of action before it is implemented.

The appraisal permutations are without limit. For example a model such as ESP can be used to answer such questions as

- What are the maximum demands for heating, cooling and illumination and where and when do they occur ? What are the causal factors ?
- What will be the effect of a particular design strategy, such as adopting 'super-insulation', specialist glazing systems or sophisticated control regimes ?
- What is the optimum plant start time or the most effective algorithm for weather anticipation ?
- How is energy consumption affected by alternative lighting control schemes ?
- How will infiltration or temperature stratification be affected by a particular management strategy and will condensation become a problem ?
- What is the contribution to energy saving and comfort level of a particular of passive solar feature ?

The approach allows a designer to better understand the interrelation between design and performance parameters, to then identify potential problem areas, and so implement and test appropriate design modifications. The design to result is more energy conscious with better comfort levels attained throughout.

ESP is a highly graphical, interactive program, driven by menu command selection. Traditionally, this type of program has required a mainframe environment with a remotely attached graphics terminal. In recent years, with the advent of personal workstations, a new era of low cost, graphics orientated supercomputing has arrived which offers a substantially improved level of cost-performance. For example, for around Λs7,000 (late 1989) it is possible to obtain an advanced workstation capable of approaching 10MIPS (Millions of Instructions Per Second: a VAX 11/780 is often referred to as a 1MIPS processor), and providing high capacity hard disks, colour bit-mapped display technology, Unix^{TM} operating system, ethernet, window manager and so on. With prices roughly speaking halving every 4 years, it is now possible to contemplate the provision of a new generation of simulation based design tools which derive their ease of use from the elegance of their user interface.

As describes in the section which follows, it is this new technology which is enabling the introduction of more advanced interfaces (supporting animation and networked graphics for example) and the incorporation of a degree of expert knowledge in support of system use by designers unfamiliar with the model or with computers in general.

Future Developments in Energy Simulation

At the present time there are several software engineering trends which are influencing the way in which models are being constructed. Most significantly there is the emergence of the object-oriented programming paradigm which encourages software re-use through techniques of data encapsulation and functional inheritance. There is also the general emergence of the means to provide more intuitive user interfaces which embody knowledge about the subject nbeing addressed. Two recent developments in particular should, in the medium to long term, greatly improve the quality and ease of use of simulation based design tools.

Intelligent Front End (IFE)

One of the principal barriers to the use of a simulation approach to environmental appraisal is the problem of building and appraisal definition in the face of uncertainty. Energy models require a substantial amount of input data, much of which is difficult to obtain, especially at the early stages of the design process. This is not necessarily a justification for the use of simplified design tools which can be forced to operate with a reduced data set. An alternative possibility is to retain the best representation of reality – a high integrity simulation model – and to generate its data requirements by inference applied to the information the designer is able to offer at any time. Consider the following figure which shows the architecture of one IFE (Clarke & Mac Randal 1989).

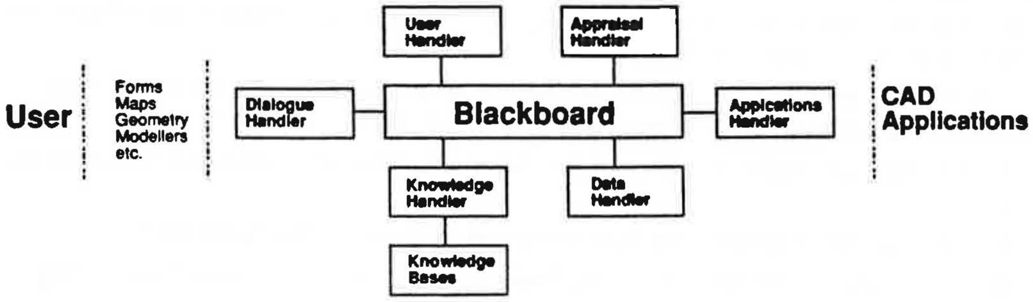

Figure 4 The Intelligent Front End

This IFE is an intricate synthesis of user modelling, human–computer interaction techniques, contextual knowledge and the interface to the CABD applications. It is built from cooperating modules organised around a communications module, the Blackboard, to facilitate multiple use of information. Several other modules exist and can examine this Blackboard for information, posting results back to it. These modules include:

- A *Dialogue Handler* to converse with the user, both textually and graphically, in a manner which is tailored to her/his conceptual class and level of experience. (In other words any question the user might not understand is never asked).
- A *User Handler* to track the user's progress and ensure the system responds in an appropriate manner.
- A *Knowledge Handler* to manipulate the knowledge concerning the application (building design), the domain (performance prediction), the application packages and the user class.
- An *Appraisal Handler* to identify the user's performance appraisal wishes and to determine the most appropriate appraisal methodology.
- A *Data Handler* to create, from the information supplied by the user and by the knowledge handler, the application specific data structure which describes the building under consideration in terms of its geometry, construction, occupancy and systems.
- An *Applications Handler* to drive the required application and supply it with the necessary data.

The functions to be handled by this IFE therefore include conversing with the user in the appropriate terminology, planning how to use the various CABD applications to achieve the user's objectives, collecting and organising the description of the building, generating the necessary data and control input for the model and storing both the domain knowledge and the strategy knowledge to be used to drive the package.

New Techniques for Software Engineering

Most contemporary models are written in a high level language, predominately FORTRAN. Because of poor software structure it is difficult, if not impossible, for individuals outside the author group to maintain the system or to evolve it in response to deficiencies exposed through use. Each system has customised input/ output procedures, uses unique variants of the heat transfer and numerical methods and focuses on a particular application. In short the systems are incompatible at their interface and, because of the many in–built assumptions, very often output significantly different results.

What is required is a better software engineering paradigm, one which encourages the better organisation of the methods which underlie models and facilitates model maintenance and task sharing evolution. These are the goals of a current research project to establish an Energy Kernel System (EKS; Clarke et al 1988). The specific objectives are:

- To separate the calculation methods, data structure and model architecture elements of future design tool construction.
- To establish validation within the model construction process.
- To promote state–of–the–art developments through ease of integration of new methods as they emerge.
- To encourage the mixing of simulation and other engineering applications software.
- To remove the burden of machine portability and other hardware/software problems from the model builder.
- And to enable and encourage inter–disciplinary collaboration between model developers, and between developers and end–users.

In essence the EKS is a computer environment which contains pre–constructed 'classes' which represent the physical objects (a wall, the sun, etc.) and abstract objects (time conversion, equation solvers, etc.) which are required to construct a simulation model. In this context a class is an encapsulation of data, together with a collection of methods which can operate on this data and represent, to the outside world, the behaviour of the object (for example a sun class might have a position method and a radiation source method). Consider figure 5 which shows the elements of the system.

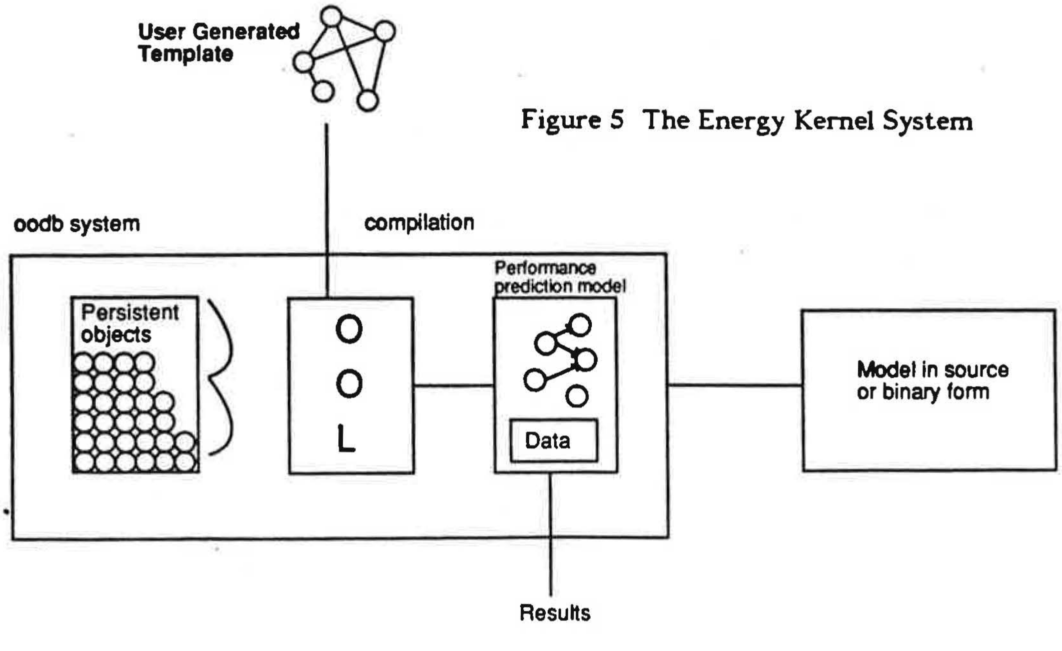

Figure 5 The Energy Kernel System

At the heart of the system lies an object–oriented database (OODB) which can contain and manipulate classes in much the same way as an ordinary database can contain and manipulate data. The OODB is also able to coerces these classes into the required model. The EKS template defines a proposed model as a collection of class instances and their initialisation data. This template is 'compiled' into the object oriented language used by the OODB to coordinate class creation and message passing.

The modularity offered by the EKS provides a flexible framework for future model evolution. In particular, research findings can be added in the form of new, accredited classes and experimental model templates can be rapidly prototyped, tested and refined.

Technology Transfer

This is the most important issue facing the new generation models. At the present time several initiatives are underway which are designed to encourage the use of the technology in practice. Signal among these in the UK is the formation of the Building Environmental Performance Analysis Club (Bloomfield 1987) to address the issues of model harmonisation, use in practice and future enhancement. With a membership drawn from the public and private sectors and academia, the Club mission is to critically examine the relevance, reliability, applicability and *modus operandi* of modelling systems. In North America a similar organisation – the International Building Performance Simulation Association (IBPSA) – has been incorporated to pursue similar objectives.

But as far back as 1986 there was a realisation that as the sophistication of models such as ESP increased, ready access to the models by the small and medium sized architectural practices was becoming more difficult. Notwithstanding the future promise of Intelligent Front Ends, a more immediate interface between the technology and everyday practice was needed.

Slowly but surely there emerged the concept of an energy design advisory service through which the power of the computer technology would be made available to architects, engineers and their clients. The service was seen also as a mechanism for technology transfer, from research into practice, and as a mechanism for the promotion of in–service Continuing Professional Development within the building design professions.

Together, the Royal Incorporation of Architects in Scotland (RIAS) and the University of Strathclyde evolved a brief for the service and set about finding sponsorship for it. They were, in fact, pushing on an open door: independently the Energy Technology Support Unit (ETSU) of the Department of Energy (DOE) had been campaigning for a similar initiative. The promise of pound for pound funding from the Scottish Development Agency was sufficient to persuade the DOE through its Building Research Energy Conservation Unit (BRECSU) to resource a two year trial period of operation of what has become known as the Energy Design Advisory Service (EDAS; Emslie 1988).

EDAS has been operated over the last two years by the RIAS on behalf of its members and their clients, as one of an increasing number of successful Practice Services. The Energy Officer employed by the RIAS stimulates and fields enquiries from the design professions and their client bodies on a wide range of energy related issues. The technical support is provided by ABACUS and ESRU through a consultant funded by an RIAS sub–contract.

The technical consultancy is offered at two levels. The first level is an initial free consultation, at which designers are given advice and information specifically related to the building currently on the drawing board. The resulting report may answer the designer's questions fully; alternatively, it may outline the nature, scope, cost and potential benefit of a full energy analysis in which the behaviour of the building and its plant is modelled by computer. The cost of this full analysis, which represents the second level of service, is subsidised by 50%.

Since becoming operational in Scotland in September 1987, EDAS has dealt with over 150 enquiries. The range of work has been immense, including such diverse applications as a medical surgery in Skye, a wind turbine in Shetland, a swimming pool in Aberdeen, a school in Fife, halls of residence at Strathclyde University, office buildings in Melrose and a water–world centre in Edinburgh.

The operation of EDAS over its first two years has been the subject of a monitoring study funded by BRECSU and carried out by independent research consultants. The intention was to quantify:

- user response to the service
- information provided by the service
- and the potential energy savings resulting from use of the service.

In broad terms, it is clear from the study that over 80% of the users of EDAS found it helpful and would be repeat clients. Equally important, it was clear that even within its first year of operation, conservatively calculated annual cost savings were running well above the total capital cost investment of the sponsors. Less easily quantified but, in the longer term, of perhaps greater significance is:

1. the improved quality of the environment within buildings
2. the increased awareness of designers regarding energy conscious design
3. the value of the case material in education and training.

On 28the September this year, Sir Monty Finniston, Chairman of the EDAS Steering Board, was able to announce a four–fold re–investment in EDAS, over the next 2 years, a widening of its scope (to harness other expertise, notably that of ETSU) and a careful examination of its potential as the model for a UK wide Design Advice Scheme.

Wider Issues

The confidence gained by ABACUS and ESRU in developing and disseminating sophisticated models of the energy behaviour of buildings has encouraged a more ambitious aspiration to bring the same evolving information technologies to bear on the wider issues of building design.

Collaboration with Phillips International BV has lead to a prototype version of an inter–reflective multi–chromatic lighting model which will not only predict the energy implications of alternative fenestration strategies in buildings but which will display objectively the visual quality of interiors.

The scope of computer aided design is being extended to model whole cities and to allow us a more direct and dynamic experience of the quality of the built environment.

Yet we are only on the threshold. The 'ascent of man' from prehistoric until the present day can be measured by our ability to design *amplifiers* of our human capabilities. The first two categories of amplifiers have brought human society from the hunters and gatherers of prehistory to the dying decades of the Industrial Revolution:

amplifiers of physical power:	sufficient to carry us to the moon and back; more than sufficient to destroy all earthly forms of life.
amplifiers of the senses:	which allow us to see into the outer reaches of space and into the sub–atomic anatomy of our physical world.

The enormous social impacts of these two categories of amplifier are likely to pale into insignificance in comparison to the potential of the third category:

amplifiers of the intellect:	which model and enhance the operation and application of natural intelligence to complex human endeavours such as design.

We are optimistic as we enter the last decade of the first millennium, that this potential will be fulfilled.

Conclusions

A new generation of building energy design tool is beginning to emerge and the first attempts are being made to transfer the technology for application in practice. With the rapid improvements in the performance/cost ratio of computing technology, such design tools are becoming cost effective and so more widely applied. At the present time a substantial research effort is being expended on improving the human–computer interface in order to deliver the power of simulation to a greater proportion of the design profession.

These activities, in technology transfer and improved interfaces, should, in conjunction with ongoing developments at the software engineering level, result in the emergence of the 4th software generation around the middle of the next decade. This generation will have improved functionality, greater CABD integration and will possess a high degree of knowledge about the domain.

Acknowledgements

Our optimism has been sustained over the last two decades by many institutions and individuals:

Research Sponsors:	The Environment Committee and Building Sub–Committee of SERC
	The European Community Non–Nuclear R&D Programme.
EDAS Sponsors:	Department of Energy (notably Adrian Brown of ETSU, David Bartholemew formerly ETSU and Deborah Brownlee of BRECSU).
	Scottish Development Agency (notably Richard Morris)
EDAS Board:	Primarily Sir Monty Finniston as Chairman, but all the staunch and supportive members.
EDAS Team:	Jackie Chalmers the RIAS Energy Officer, Stuart Emslie – the man who really made it work – and Lori McElroy, who will surely make it work even better.
Research Colleagues:	Our colleagues at ABACUS and ESRU.
	Those groups at the Building Research Establishment and Universities throughout the world with which we share our goals.
Individuals:	Those who, at a crucial moment have shown particular support: Malcolm Piggot of the West of Scotland Energy Working Group and Professor Sir Graham Hills, Principal of Strathclyde University.
Finally:	The Royal Society and ESSO who have not only honoured us with their award but have provided us with a platform to advance the case for an improved and more energy conscious built environment.

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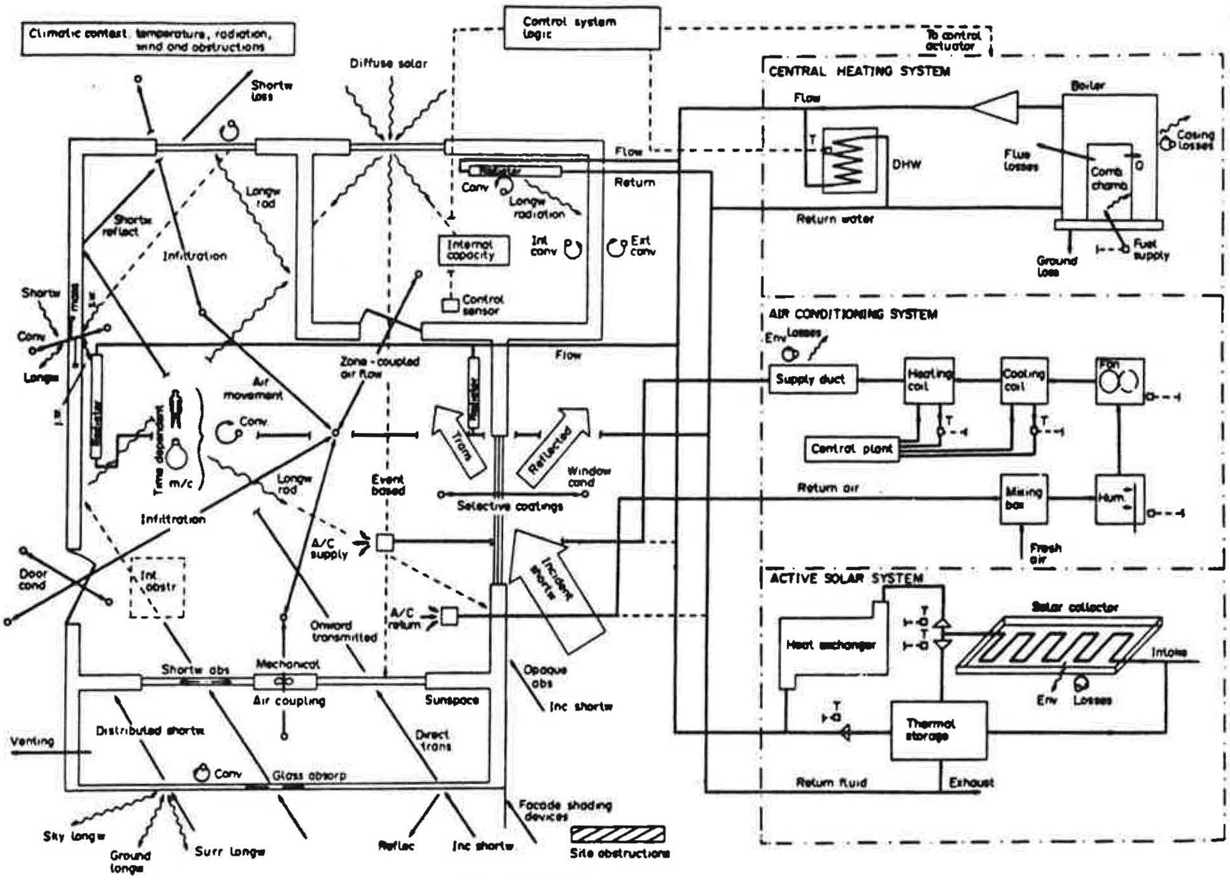

Fig. 1. Building energy flow-paths.

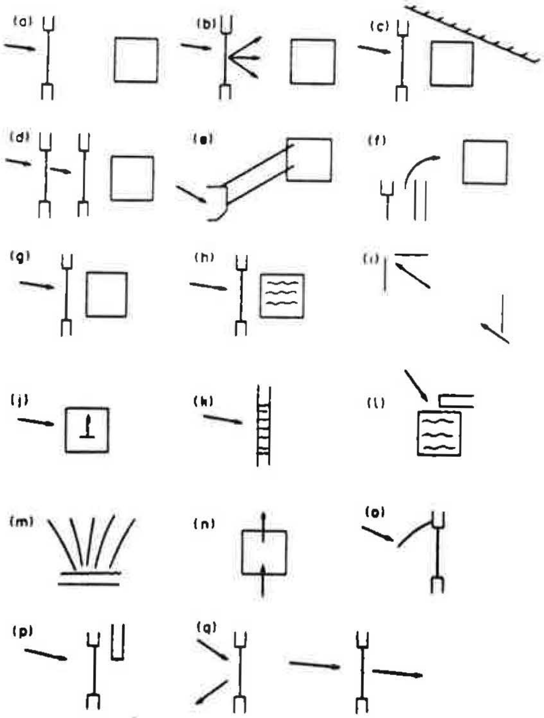

Fig. 2. Passive solar elements in architectural design. (a) Direct gain, (b) diffusing gain, (c) earth banking, (d) attached sunspace, (e) thermosiphon, (f) double envelope, (g) mass Trombe wall, (h) water Trombe wall, (i) induced ventilation, (j) phase change, (k) transwall, (l) roof pond, (m) evaporative cooling, (n) desiccant cooling, (o) moveable shading, (p) moveable insulation and (q) selective thin films.

Shown here are the connections between the various program and database modules which comprise ESP. These include:

ESPimp	A program which allows the interactive definition of the combined building/plant network to be subjected to some weather influence and simulated over time. All items, as input, are processed through legality and 'within acceptable range' checks before being located in an output file for transfer to the simulation engine ESPSIM. Other facilities include a range of interactive editting commands and automatic access to construction, casual gain profile and plant component databases.
ESPcon	A program to manage (create, modify, delete, list) a primitive constructions database containing the thermophysical properties (conductivity, density, specific heat, solar absorptivity and emissivity) of a number of miscellaneous homogeneous elements. This program will also allow the creation and editting of a second project-related database containing whole composite multi-layered constructions formed from elements extracted from the primitives database.
ESPpro	A program to manage a casual gain profiles database containing any number of standard or project-specific profiles defining the time varying heat gain from occupants, lights etc.
ESPplt	A program to manage the plant components database containing component descriptions, component models (in martix form) and essential manufacturers data.
ESPshd	A program to predict the time-series shading of external opaque and transparent surfaces as caused by surrounding site and facade obstructions.
ESPins	A program to predict the time-series insolation of internal opaque and transparent surfaces as caused by solar penetration through windows.
ESPvwf	A program to compute view factors between the surfaces bounding any building zone.
ESPair	A program which simulates the flow of air throughout any multizone system (where each zone is connected by flow resistances representing windows, doors, cracks, etc) subjected to boundary wind loading.
ESPwin	A program to perform a spectral analysis of a multilayered window system to determine overall transmission, reflection and absorption.
ESPclm	A program to manage the climatological database allowing creation (by prediction), modification and analysis of the hourly time-series values of the various climatic parameters retained.
ESPsim	Is the central simulation 'engine' which simulates energy flow by a heat balance matrix inversion technique of implicit enumeration. The technique is unconditionally stable for all computational time-increments and operates in conjunction with hourly values of various climatological parameters recovered from the climatological database. As the model steps though the user-defined time-increments it continuously predicts and environmental and energy status of the simulated building. This is done by placing 'nodes' at many points of interest, for each node performing a heat balance between all interacting regions (over time and space dimensions), and then simultaneously solving the resulting set of equations at each time-step.
ESPout	Is the output program which operates on the simulation results located in the results database by ESPSIM. A variety of output facilities are available: visualisation, result interrogation; graphical display; statistical analysis; and tabulations.

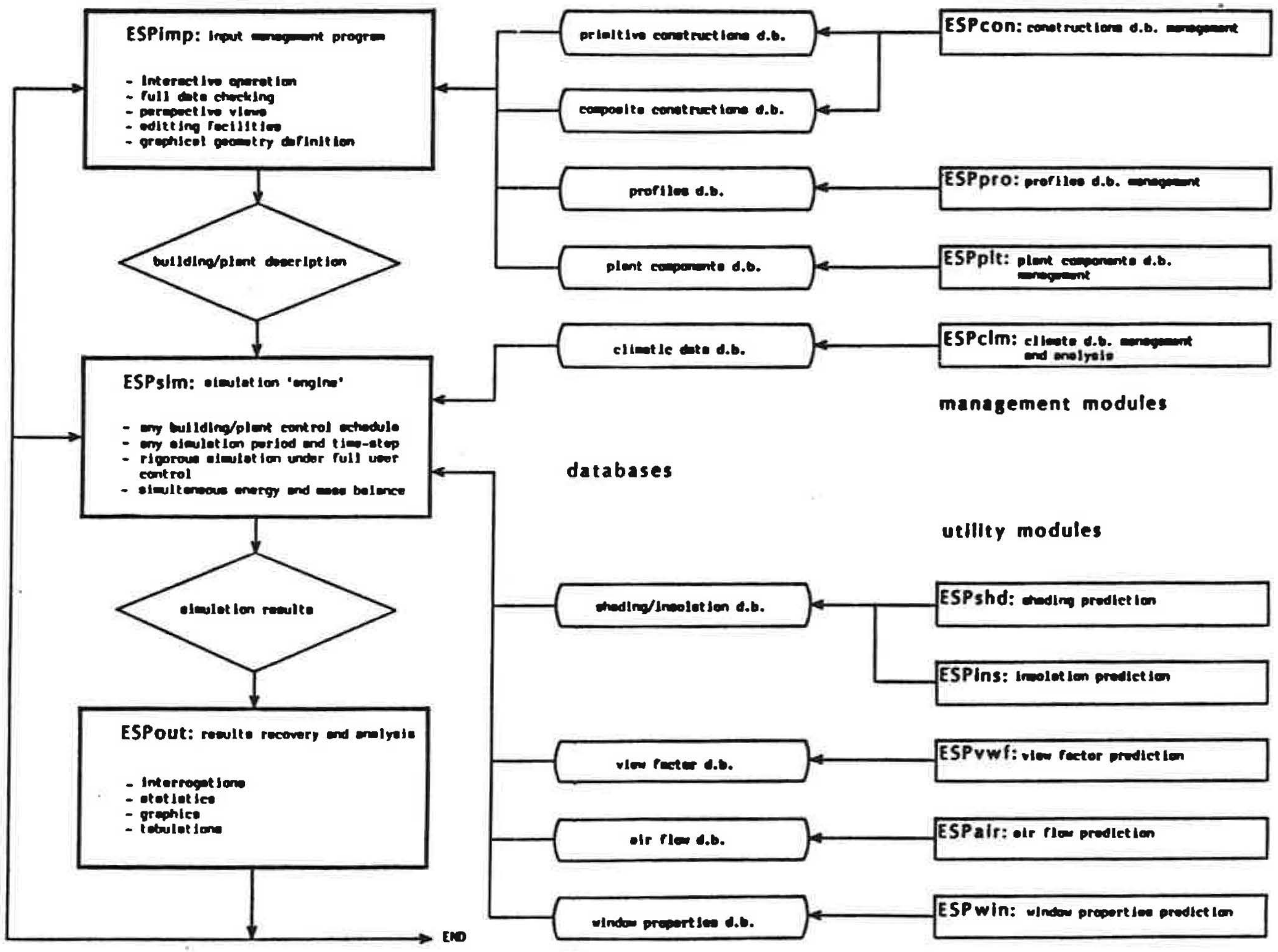

Figure 3 The ESP System