ME404 Use in practice

It is possible to use simulation at an early design stage to determine the optimum combination of building zone layout and constructional scheme that will provide a climate responsive solution and so minimise the need for mechanical plant. Some simulations might focus on the choice of constructional materials and their relative positioning within multi-layered constructions so that good temperature and load levelling is attained. Other simulations might address daylight capture and shading strategies to ensure glare avoidance, excess solar gain control and minimum luminaire usage. After a fundamentally sound design has emerged, well tested in terms of its performance under a range of anticipated operating conditions, optimum control scenarios can be investigated. For example, basic control studies will lead to decisions on the potential of optimum start/stop control, appropriate night set-back temperature, the efficacy of weather anticipation, and the location of sensors. Further analysis might focus on `smart' control by which the system is designed to respond to occupancy levels or indoor daylight illuminance. Yet further simulations might be undertaken to ensure acceptable indoor air quality or explore the feasibility of deploying local renewable energy conversion devices such as photovoltaic cells.

As the underlying relationships emerge, the designer is able to assess the benefits, or otherwise, of any given course of action before it is implemented. The appraisal permutations are essentially without limit and may be applied at any design stage to address relevant questions such as:

- what are the maximum demands for heating, cooling and lighting and where and when do they occur?
- what are the main causal factors?
- what will be the contribution of particular technologies – transparent insulation, advanced glazing, smart control etc. – when deployed independently or jointly?
- can new and renewable energy systems be used to match demand and/or operate co-operatively with the public electricity supply without loss of power quality?
- what combination of energy efficiency measures will give rise to a given target saving?
- is local co-generation feasible?

Simulation provides a way to assess the benefits of particular schemes, to improve life cycle performance, to enhance design quality, to appraise climate change mitigation measures, to undertake scenario based energy planning, to link energy and health, to enable inter-organisation partnerships, and so on. How else might such aspirations be achieved? That said, several barriers to uptake remain, which are being overcome by action on five fronts as follows.

1. Validation methods are being evolved to enable algorithms to be tested at the point of model development and application.
2. User interfaces are being evolved to protect users from the complexity of simulation while giving them access to its power.
3. Performance assessment methods are being established to guide users through the appraisal process.
4. Methods are being devised to cope with the uncertainties relating to the problem description and appraisal processes.
5. Mechanisms are being put in place to train and support those wishing to apply simulation in the real time, real scale context of design practice.

1. Validation

For a simulation program to be reliable, validation checks must be made on a regular basis. This is best achieved by encapsulating relevant checking devices within the program. Four such devices are regularly deployed.

Empirical validation: Ultimately, a program's predictive accuracy can only be assessed by comparing its outputs with results from buildings in use. This task is frustrated by the difficulties associated with data acquisition and the shortcomings inherent in even the most sophisticated program that render it impossible to model reality exactly. Empirical validation is expensive and time consuming and can therefore only be pursued within well resourced projects. A recurring message from such projects is that compensating errors can result in different programs fortuitously giving similar outputs.

Inter-program comparison allows new programs to be tested against well established ones. This is a particularly useful device where the input models can be established to stress a particular aspect known to be well handled by one of the programs.

Analytical solutions are a powerful verification device where the assumptions made to permit the solution can be equivalently imposed on a program.

Sensitivity analysis allows the influence of input parameters on outputs to be determined. This information can then be used to prioritise program refinement.

2. User interfaces

As the power of the integrated simulation approach has evolved, so the demands on the user interface have increased. In establishing an interface, there is a balance to be struck between allowing full access to a program's capabilities, and protecting users from unnecessary data inputs and advanced technical features. To add to the problem, this balance is dynamic because it depends on the user's evolving skills, the design stage/issue being addressed and the technical requirements of the project. This suggests the use of an adaptive interface that is able to change its style of interaction as a function of in-built user and process models.

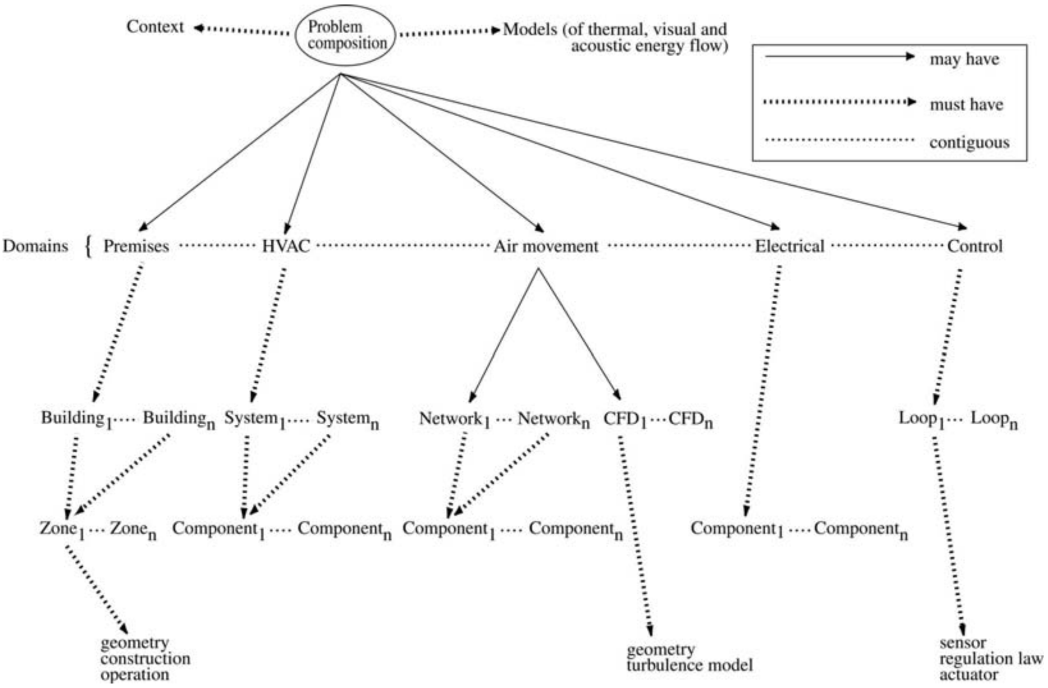


Figure 1: Integrated data model.

Figure 1 summarises the data model as required to support integrated modelling. Such an arrangement has three principal advantages as follows.

1. A problem can be composed of one or more domains. For example, initial simulations might focus only on the building domain in order to maximise the use of natural resources (e.g. natural ventilation, daylight, solar power etc.). As required, an air flow

network can be added to allow approaches to natural ventilation to be explored (e.g. night purge, atrium induced flow etc.). Where necessary, a plant network and control system might be added to allow HVAC system sizing and the evaluation of alternative approaches to system regulation. At a later stage, a CFD domain might be established to ensure adequate indoor thermal comfort and air quality. This implies that the user interface be flexible enough to support the incremental definition of domains in any order.

2. Any single domain can have several levels of abstraction. For example, initially a building model might be established as a small number of representative zones, each attributed with standard occupancy and infiltration profiles. While such a model is rudimentary, it is nevertheless a powerful aid to decision-making in relation to form and fabric and issues such as overheating potential. Likewise, an ideal controller might be used to represent the design capabilities of an entire HVAC system, which is only explicitly defined at a later stage. In other words, the interface must support the substitution of abstractions as the performance appraisal issues evolve.
3. Portions of a domain can be selectively enhanced to accommodate special cases. For example, the discretisation level of a wall might be enhanced to support the assessment of condensation and mould growth risk, or an electrical network added to a zone to support the study of daylight responsive luminaire switching. In other words, the interface must support targeted improvements in modelling resolution in order to allow specialist simulations to proceed within the overall scheme.

By arranging that the entities underlying each domain be contained within standard databases (e.g. material properties and plant/flow/electrical/control components) and ensuring that these entities are available at the point of domain definition, it is possible to establish an interface that embodies the above principles. The success of such an interface will depend on the user's ability to conceptualise a problem and co-ordinate the related data model as new aspects come into focus and old ones change.

To bring real benefit, simulation should be fully integrated within the design process. In such a computer-supported design environment (CSDE), the practitioner evolves the design hypothesis in such a way that the tools are able to automatically access the data describing the design and give feedback on all aspects of performance and cost in meaningful terms. The attainment of a CSDE is a non-trivial task involving the development of *integrated product models* and *intelligent interfaces*. In the former case, the complexity stems from the temporal aspects of the design process, the diversity of the applications to be served, and the different professional viewpoints and vocabularies. In the latter case, the complexity stems from the nature of the transactions (human-to-human, human-to-application and application-to-application) that require to be managed.

3. Performance assessment method

Table 1 summarises how predicted behaviour follows description or, in other words, how reward to the user follows from user effort in preparing the problem description. This table implies that significant decision support can often be achieved for little input effort. It also implies that more detail can be added to a model as the design progresses and the complexity of the domain interactions grow.

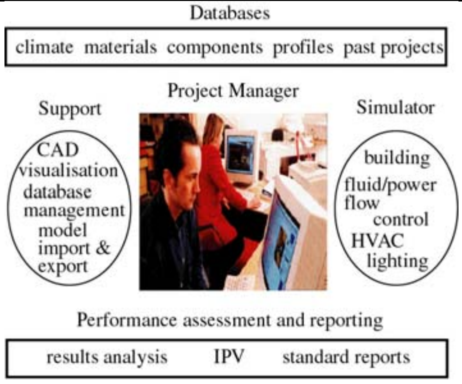
Table 1: Mapping of problem description to model behaviour.

Cumulative model description	Typical behaviour enabled at each stage
Pre-existing databases	simple performance indicators (e.g. material behaviour);
+ geometry	visualisation, photomontage, shading etc.;
+ constructions	embodied energy, thermal response etc;.

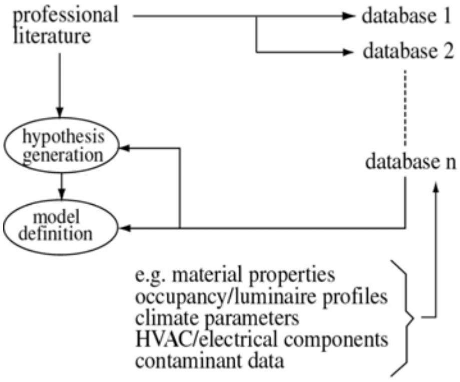
+ operation	casual gains, electricity demands etc.;
+ boundary conditions	realistic images, illuminance distribution, no-systems thermal/visual comfort levels etc.;
+ special materials	PV and advanced glazings evaluation etc.;
+ control system	energy use, systems response etc.;
+ flow network	ventilation and heat recovery evaluation etc.;
+ HVAC network	psychrometric analysis, component sizing etc;
+ CFD domain	indoor air quality, thermal comfort etc.;
+ electrical power network	load control, renewable energy integration etc.;
+ enhanced geometrical resolution	thermal bridging, multi-dimensional flow etc.;
+ moisture network.	local condensation, mould growth and health.

Consider the following program use scenario, the purpose of which is to highlight the integrated appraisal process and, by implication, indicate the nature of a possible future design activity. (This scenario employs the ESP-r system when its underlying data model is cumulatively refined according to the process of the previous table.)

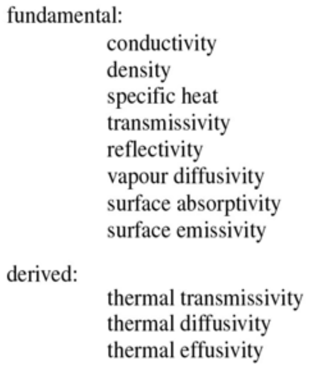
A Project Manager gives access to support databases, the simulation engine, performance assessment tools and a variety of applications for CAD, visualisation, report generation etc. It co-ordinates user inputs relating to the problem definition and, significantly, supports the incremental evolution of the model giving access to the simulation engine's corresponding functionality at each stage.



The support databases are pre-configured and maintained at the organisational level. These include hygro-thermal, embodied energy and optical properties for construction elements and composites, typical occupancy profiles, pressure coefficient sets for use in problems involving air flow modelling, plant components for use in HVAC systems modelling, mould species data for use with predicted local surface conditions to assess the risk of mould growth, and climate collections representing different locations and severities.

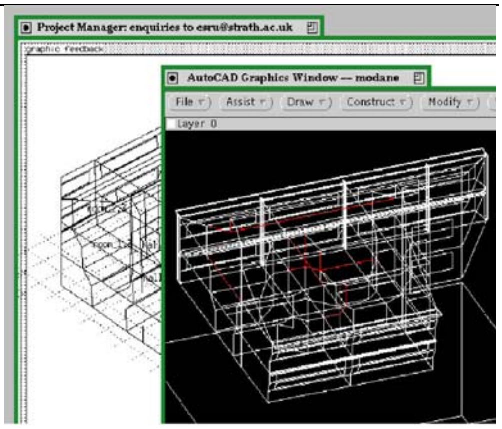


Embedded within the support databases is knowledge that might usefully assist the early stage design conceptualisation process, e.g. data on material embodied energy and thermal response which may be used to guide construction selections.

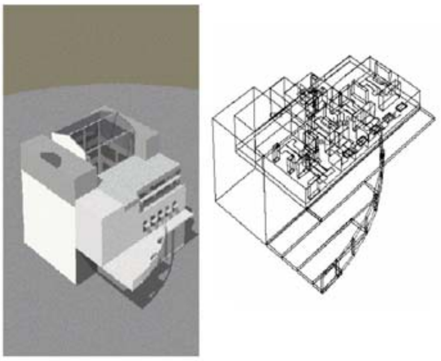

fundamental:
conductivity
density
specific heat
transmissivity
reflectivity
vapour diffusivity
surface absorptivity
surface emissivity

derived:
thermal transmissivity
thermal diffusivity
thermal effusivity

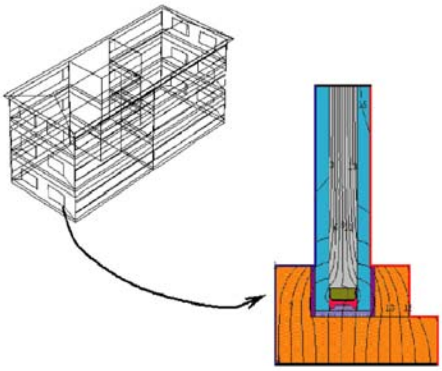
Typically, problem definition commences with the specification of building geometry using a CAD tool.



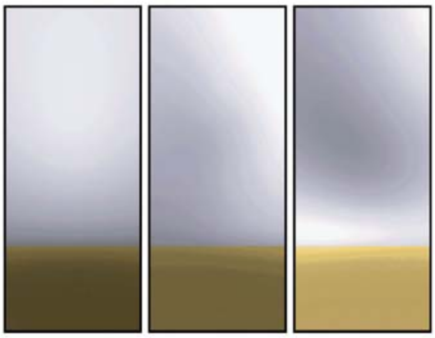
Wire-line or false coloured images can now be generated as an aid to the study of solar/daylight access or the communication of design intent.



Constructional and operational attribution is achieved by selecting products (e.g. wall constructions) and entities (e.g. occupancy profiles) from the support databases and associating these with the geometrical entities previously defined.

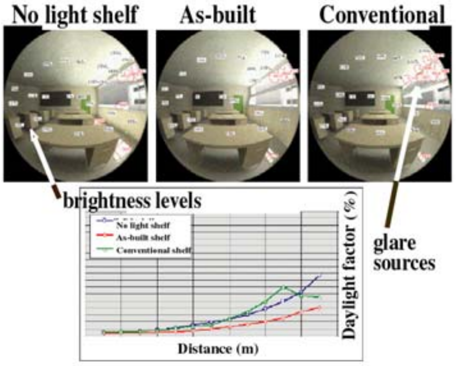


Temperature, wind, radiation and luminance boundary conditions of the required severity are now associated with the model to enable an appraisal of environmental performance (e.g. thermal and visual comfort levels throughout the year) and to gain an insight into appropriate remedial actions where problems are encountered.

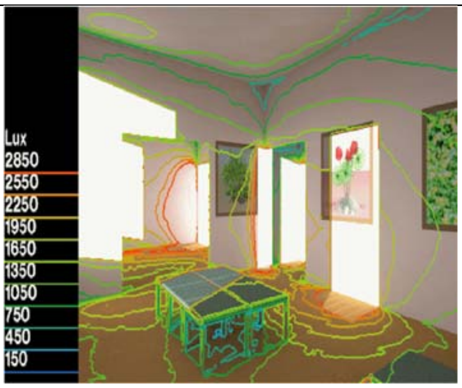


overcast sky intermediate sky clear sky

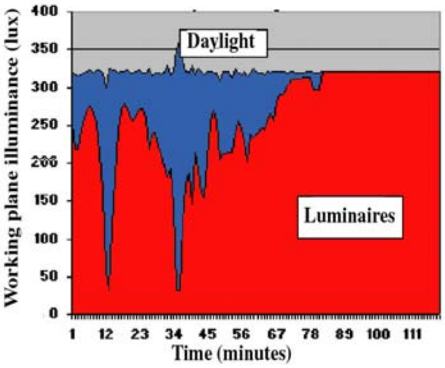
As required, geometrical, constructional or operational changes can be applied to the model in order to determine the impact on performance. For example, the impact of different approaches to daylight utilisation on glare might be investigated as shown here for the case of an office with a light shelf attached to the window.



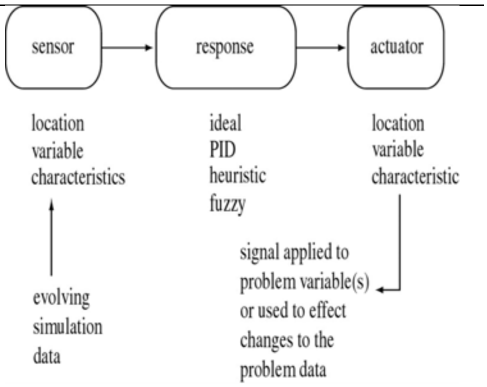
Special facade systems might now be considered: photovoltaic (PV) components to transform part of the solar power spectrum into electricity (and heat); transparent insulation to capture passively and process solar energy, or adaptable glazings (electro-, photo- or thermo-chromic) to control glare and/or solar gain. In each case, the contribution to improved environmental performance and reduced energy use can be determined; here the impact on internal illuminance distribution is shown.



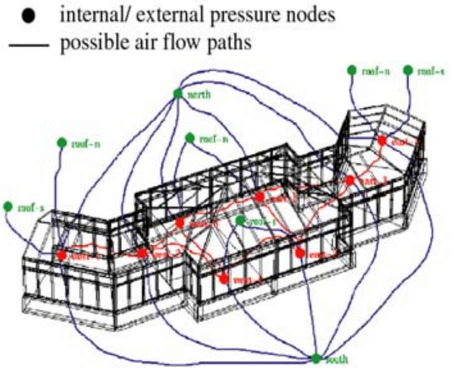
To access the energy displacement potential of daylight, a luminaire control system is introduced, comprising one or more photocells linked to a circuit switch or luminaire dimming device. Subsequent simulations can then be undertaken to optimise the parameters of this control system to maximise the displacement of the electricity required for lighting purposes.



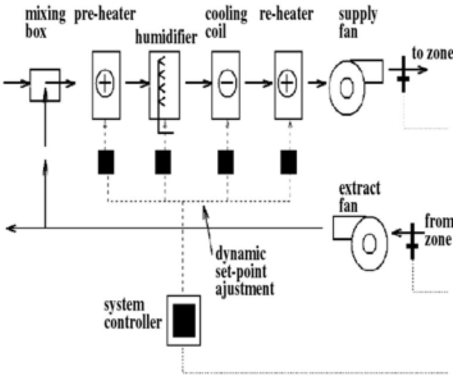
The issue of integrated environmental control can now be explored by establishing a control system conceived as a collection of open or closed loops. Some of these loops will dictate the availability of heating, cooling, ventilation, lighting etc., while others serve only to resolve conflict between these delivery systems. Previous aspects of the model may now be revisited in order to change the building's dynamic response to accommodate the intended control action.



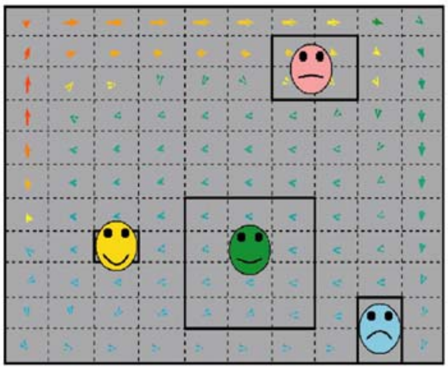
To study the feasibility of natural ventilation, a flow network can be associated with the building model so that the dynamic interactions are represented. The control definition may then be extended to include actions applied to the components of this network, e.g. to emulate window opening or flow damper control.



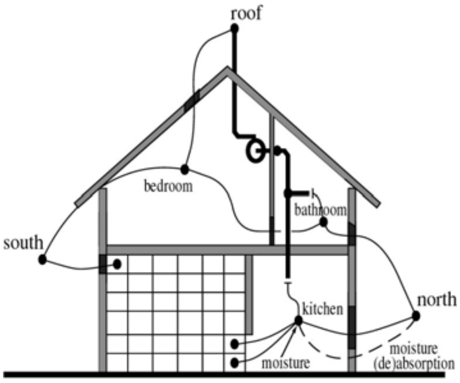
Where mechanical intervention is required, a component network can be defined to represent the HVAC system for association with both the building model and any active flow network. The control definition may be extended to provide internal component control and link the room states to the supply condition.



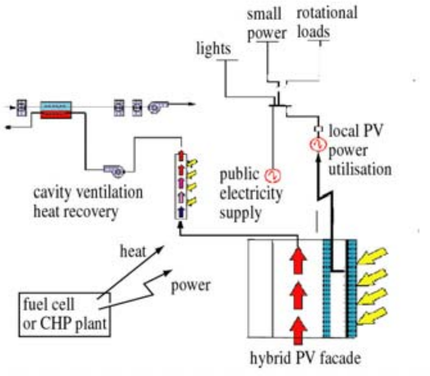
In order to examine indoor air quality, one or more spaces within the building model can be further discretised to enable the application of computational fluid dynamics in order to evaluate the intra-space air movement and the distribution of temperature, humidity and species concentration. These data may then be combined to determine the comfort levels and air quality at different points within the space.



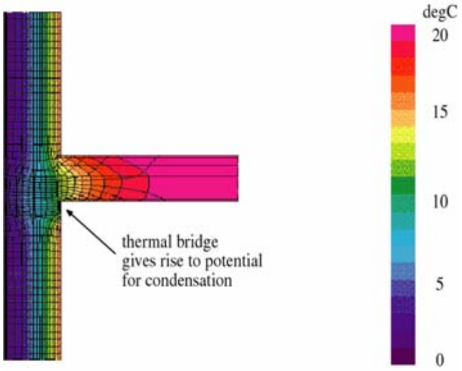
While the components of a model – the building, flow and HVAC networks, and the CFD domain – may be processed independently, it is usual to subject them to an integrated assessment whereby the dynamic interactions are explicitly represented. Here, a house model has been assigned a flow network to represent natural ventilation, an HVAC network to represent a ventilation heat recovery system, a CFD domain to enable the detailed analysis of comfort and air quality, and a moisture flow model to allow assessment of humidity distribution.



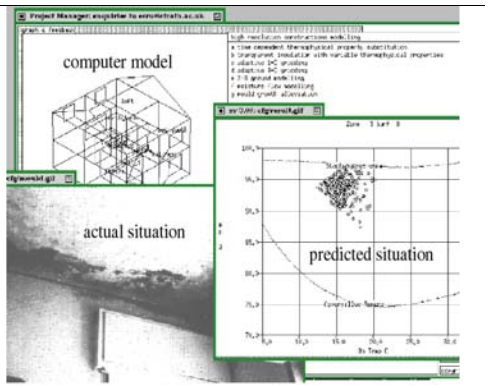
An electrical power network might now be added to the previously established models for facade-integrated photovoltaics, luminaire control, HVAC systems and air movement to study scenarios for the local utilisation of the outputs from building-integrated renewable energy components, co-operative switching with the public electricity supply, and the shedding of load as an energy efficiency measure. Other technologies, such as combined heat and power plant and fuel cells, an also be appraised at this stage.



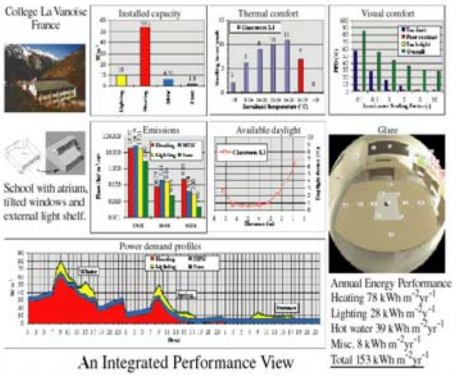
For specialist applications, the resolution of parts of the model can be selectively enhanced to allow the detailed study of particular issues, e.g. a wall might be finely discretised to enable the study of a thermal bridge and/or a moisture flow network defined to support an assessment of the potential for condensation.



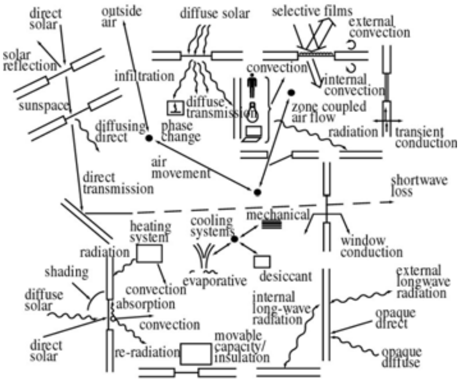
By associating the time series pairs of near-surface temperature and relative humidity (to emerge from the integrated building, CFD and network air/moisture flow models) with the growth limit data as held in the mould species database, it is possible to determine the risk of mould growth and explore different possible remedial actions.



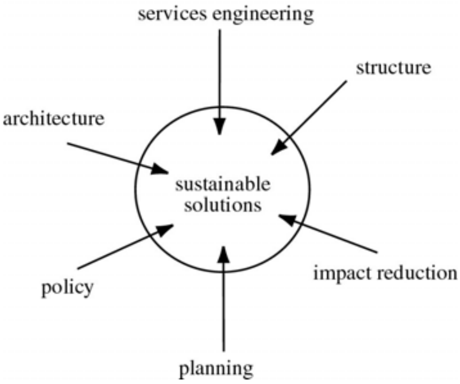
The Project Manager requires that a record be kept of the problem composition and to this end is able to store and manipulate text and images that document the problem and any special technical features. At any stage it is possible to bring together the results for the different aspects of performance and to present these in the form of an Integrated Performance View in order to summarise issues such as seasonal fuel use, environmental emissions, comfort, daylight utilisation, risk of condensation, renewable energy contribution etc.



The core message is that any problem – from a single space with simple control and prescribed ventilation, to an entire building with systems, smart control and enhanced resolutions – can be passed to the Simulator where its multi-variate performance is assessed and made available to inform the process of design evolution. By integrating the different technical domains, the approach supports the identification of trade-offs. This, in turn, nurtures sustainable approaches to building design and operation.



Significantly, integrated modelling supports team working because it provides a mechanism whereby the different professional viewpoints can come together and contribute equally to the final outcome.



To achieve effective application in practice, a performance assessment method (PAM) is required to direct the user's line of inquiry. Table 2 shows the stages of a generic PAM in which the action required at each stage is underlined and the knowledge required to implement this action is shown in *italics*.

Table 2: A generic PAM for energy simulation.

Stage	Activity
1	Establish a computer representation corresponding to a *base case design*.
2	Calibrate this model using *reliable techniques*.
3	Locate representative boundary conditions of *appropriate severity*.
4	Undertake integrated simulations using *suitable applications*.
5	Express multi-variate performance in terms of suitable *criteria*.
6	Identify problem areas as a function of *criteria acceptability*.
7	Analyse simulation results to identify *cause of problems*.
8	Postulate remedies by associating problem causes with *appropriate design options*.
9	For each postulate, establish a reference model to a *justifiable level of resolution*.
10	Iterate from step 4 until the overall performance is *satisfactory*.
11	Repeat from step 3 to establish replicability for other *weather conditions*.

Such a PAM can be attributed with alternative knowledge instances depending on the user's viewpoint, the application topic(s) and the program's capabilities. To illustrate the approach, consider the embedding of renewable energy systems within the Lighthouse Building in Glasgow. This project employed the integrated modelling approach to determine the best possible match between energy demand and the local renewable energy resource without compromising power quality.

A base case model, compliant with best practice, was established and its multi-variate performance determined against relevant weather conditions. A number of energy efficiency measures were then applied to the model (separately and together) to determine their potential to reduce energy demand and alter the demand profile to accommodate the integration of active renewable components. Figure 2 shows the cumulative impact of several measures: advanced glazing, daylight responsive luminaire control, façade-integrated transparent insulation, efficient lighting and dynamic heating set-point temperature control.

When compared with the original design, these measures resulted in a 68% reduction in annual energy demand (corresponding to a 58% reduction in heating and an 80% reduction in lighting). Significantly, the final demand profiles were better matched to the output from locally deployed renewable energy systems: a photovoltaic (PV) component operating in hybrid mode to provide both power and heat; and ducted wind turbines (DWT) with an integral photovoltaic aerofoil section to increase the output power density. Also shown in figure 2 are the predicted power outputs from these two RE technologies superimposed on the most favourable demand profile. As shown in figure 3, the hybrid PV component was subsequently incorporated within the south-facing facade of the building, while the DWTs were mounted on the south- and west-facing edges of the roof.

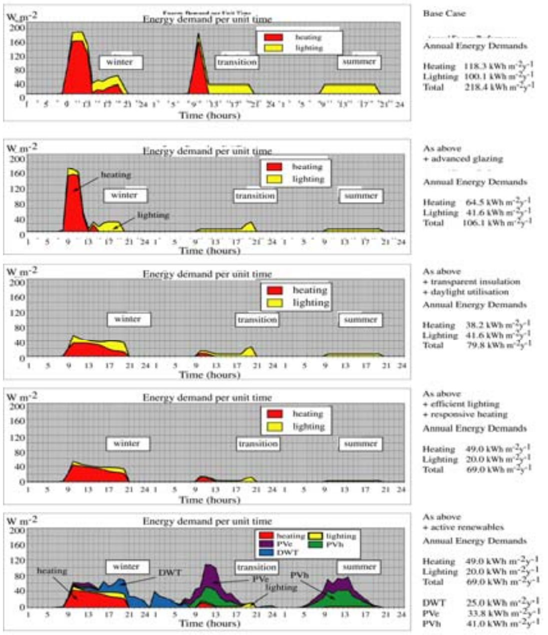


Figure 2: Energy efficiency measures facilitating the introduction of embedded renewable energy components

Figure 3: Renewable energy components as incorporated in the Lighthouse building in Glasgow.

4. Uncertainty

Of the issues confronting design tool refinement, one of the most problematic is how to quantify and process the uncertainties that are inherent in the problem description and appraisal process. Such uncertainties occur in relation to the building's dimensional, constructional and operational specification, in relation to climate and simulation parameter definition, and in relation to the assumptions inherent in a program's internal algorithms. To make effective use of simulation, designers require information on performance robustness, in the light of these uncertainties, rather than performance quantification with no account taken of uncertainty. It is a paradox that simulation is at its most powerful when used in conjunction with uncertain data. This is because it can be used to explore the impact of expected ranges in the design parameters and so inform the decision-making process.

When using simulation, it is important therefore to try to express the input parameters as possible ranges so that the resulting outputs may be used to express performance in probabilistic terms. Typical sources of uncertainty include the following.

Climate

As a stochastic system, weather is inherently uncertain. It is therefore important to subject models to a range of boundary conditions in order to test the robustness of a given design hypothesis. Micro-climate phenomena – such as wind hollows, urban canyons and vegetation related cooling – can also have a significant impact on performance. Either location specific data should be used or reference data modified to emulate the anticipated conditions.

Lighting

Atmospheric phenomena, especially clouds and pollution, will impact on the sky luminance distribution. The use of simulation to undertake realistic appraisals of the performance of daylight responsive luminaires, switchable glazings, daylight capture devices and the like, will require that a range of sky types be processed.

Indoor surface finishes, photocell response characteristics and lamp emissions each have an associated uncertainty which derives from the manufacturing process and calibration/maintenance considerations. Furniture will also modify daylight distribution and, because actual types and positions are largely unknown at simulation time, it is usual to assume optimistic and pessimistic scenarios in order to ensure an adequate lighting provision.

Glazing

The thermo-optical properties of glazings may exhibit a significant variation both within a given sample (e.g. from centre to edge) and between samples (e.g. uncertainty in convective heat exchange, particularly with solar shading devices).

Context factors – such as frame conduction, urban air pollution, window maintenance, shading device robustness etc – can have a significant effect on performance related properties. Where this is likely, a higher resolution should be adopted.

Form and fabric

The translation from design intent to on-site realisation gives rise to many uncertainties in relation to final dimensions, construction composition and tightness, and fenestration operation. Each of these factors can impact significantly on the final performance of the design. In addition, the operation and use of a building is likely to change during its lifetime.

Contemporary concepts, such as breathable facades, PV-integrated facades, transparent insulation, switchable glazings etc., will increase the level of uncertainty inherent in the problem definition process and associated with the selection of the thermo-physical properties of materials.

Ventilation

The quantification of a building's leakage distribution is an inherently uncertain task. Likewise, the determination of surface pressure distribution is dependent on the ameliorative effect of local wind shelter phenomena that are the subject of considerable uncertainties.
A sensitivity analysis, giving the variation of the results when input data are changed, is usually required.

Monitoring

All instruments have an intrinsic accuracy limit associated with their design and calibration. Further, an instrument's suitability of purpose is an important determinant of accuracy, e.g. the use of PRTs rather than thermocouples where the accuracy of temperature measurement is an important consideration.

Errors are also associated with each of the steps following data acquisition: averaging, filtering and filling. These errors can accumulate so that the inherent uncertainties render the empirical data useless for program validation or calibration. Furthermore, monitoring campaigns must be comprehensive and detailed if resulting data are to be used for comparison with predicted data.

Occupant interactions

The physiological and psychological processes that give rise to particular occupant responses to their environment are not well understood and few models exist for use in predicting how people interact with ventilation, lighting and heating/cooling systems. The levels of heat and moisture production can vary significantly, both between individuals and as a function of the context.

Electrical systems

All electrical systems are characterised by fundamental parameters (impedance, capacitance, inductance etc.) that are affected by variations in temperature, moisture and demand. As a stochastic process, demand, in particular, gives rise to a significant uncertainty.

Many electrical systems – such as PV components, power electronics and rotary generators – are characterised by parameters that relate to standard test conditions (STC). As conditions depart from STC so the applicability of the parameter values, and hence the uncertainty, will grow.

Modelling

Techniques exist for the modelling of the overall impact of uncertainty where the individual constituent uncertainties can be defined, and these techniques are increasingly being incorporated within modelling systems. Example include the Differential and Monte Carlo sensitivity analysis techniques.

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5. Training and support

Many designers are reaching the stage where they wish to try simulation. There are many useful sources of information on program availability and application. The following three are particularly relevant.

1. The US Department of Energy's Web site (www.eren.doe.gov/buildings/tools_directory/) gives information on the many programs available from commercial vendors and research groups worldwide.
2. The CIBSE/BEPAC application manual (*Building Energy and Environmental Modelling*, ISBN 0 900953 85 3) provides an introduction to the issues surrounding practical modelling.
3. The long established International Building Performance Simulation Association (www.mae.okstate.edu/ibpsa/) has regional affiliates who organise seminars and software demonstrations, publish support documents, and provide low cost training. For example, IBPSA Scotland (www.sesg.strath.ac.uk/) offers a Supported Technology Deployment service whereby in-house support is given by application specialists

seconded to the design team for part of a project.

7. Example applications

The integrated simulation approach both deepens and broadens the appraisal capability of practitioners. Consider the following short descriptions of typical applications of integrated simulation (IS).

Resource allocation

Many government agencies own housing which dates from the middle of the last century and much of this stock has fallen due for upgrading. IS has been used to help establish the most cost-beneficial upgrading strategy. A sample of houses in any estate are simulated, firstly in their original form, and subsequently with a range of design modifications formulated on the basis of the results to emerge from the initial simulations. Typically, the analyses will focus on issues relating to construction, fenestration, ventilation and condensation.

Building conversion

IS has been used by local authorities to appraise options for the conversion of existing buildings. One study entailed an investigation of diversity of heating demand as affected by a variety of proposed zoning strategies, plant operating schedules and building modifications. It was observed that the total cost incurred in the modelling exercise was approximately half the cost incurred in a parallel manual exercise which involved only the straightforward calculation of individual zone peak heating loads under steady state conditions.

Passive solar architecture

In an attempt to achieve energy savings, practitioners are increasingly attempting to harness solar energy as a supplementary and renewable fuel source. The technical problems inherent in such passive solar design are often considerable and require sophisticated modelling methods. IS has been used to optimise the performance of passive solar elements such as direct gain systems, sunspaces, Trombe-Michel walls, movable insulation and advanced glazings.

Innovation in design

IS is particularly well suited to design innovation. One application involved the design of a solar wall construction as part of a new laboratory complex. The need to move large quantities of air had suggested to the design team a scheme in which this air could be used to capture solar energy by passing it over the south-facing facade when contained within an outer glass skin. This scheme was simulated in order to determine the heat recovery potential.

Load diversity

The conversion of a building to house a computer facility and ancillary activities required the use of IS to determine the effect of altering the building envelope from a lightweight to heavyweight cladding system while increasing the glazing extent from 25% to 40%: the effect of these changes on the air conditioning system had to be determined. The results showed that the cooling loads in different areas occurred at significantly different times of the day. While the individual VAV terminal box duties had to be increased, diversity considerations meant that no significant modifications were required to be made to the central plant.

Atrium air flow

Accompanying improved living standards is an increased demand for leisure and shopping facilities. Many of the proposed designs incorporate atria. Because of the pressure and temperature induced air movement, the prediction of likely environmental conditions will require the simultaneous treatment of heat and air flow. In one application the intention was to create a large shopping, office and recreation complex within an outer glass construction. A model was constructed and simulations undertaken to assist the design team in relation to issues such as overheating, shading control, smoke extraction, condensation prevention and local comfort maintenance.

Electrical storage heaters

In some applications it is necessary to explicitly model electrical systems. In one project fan-assisted electrical storage units were to be incorporated within a building conversion to small workshop units. A computer model of the building and storage units was established and used to investigate issues such as local comfort, unit control, charge/discharge characteristics, weather anticipation and running cost. It was shown that the units would only perform well if fitted with relatively sophisticated control of heat output.

Parametric studies

A parametric analysis of building performance can lead to the identification of effective energy saving measures. In one case IS was used to study the cost-benefit associated with different window designs when placed in Scandinavian and UK climates. Simulations were performed for combinations of orientation, window size, window type and building structural mass. The results identified those design parameters that were best suited to the two climates.

Plant simulation

Simultaneous building and plant modelling supports the study of HVAC design and control. In one case the design team wished to compare a conventional air conditioning design with a system based on displacement ventilation using a sub-floor plenum. Issues to be studied included the effects on energy consumption and comfort conditions of a number of alternative control options.

Detailed models were established for both systems and combined with a multi-zone building model. The models were then subjected to various control regimes including intermittent and continuous plant operation, solar reset of the perimeter heating, and the night purging of the plenum with outside air in anticipation of the next day's cooling demand. In each case the impact on central plant energy consumption was determined and assessed relative to the level of comfort achieved in the occupied zones.

Urban renewables

IS can be used to identify technologies that can be deployed to so reshape demand profiles that local, small-scale, renewables energy systems may be cost-effectively deployed to match the aggregate demand. A building model is established and used to study the impact on temporal demand of a range of possible design changes. At the same time, a range of new and renewable energy systems models are established and used, in various combinations to determine the temporal availability of heat and power. The best scheme is the one exhibiting a good match between supply and demand attainable at acceptable cost.