

Use of sophisticated building energy simulation tools

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ABSTRACT: the combination of building, HVAC plant, and solar energy features forms a highly integrated, dynamic system. To predict the performance of such a configuration, a designer needs to have proper tools. In recent time there has been an impressive evolution in building energy simulation tools and their application capabilities. However there are also signs that there is (a risk of) an increasing gap between sophisticated simulation tools and building design professionals.

This paper addresses two approaches aimed at bridging this gap: (1) user training, which is a solution with immediate effect; and (2) future work in terms of development of intelligent front-ends which will act as intelligent assistants to the user when employing energy simulation in building design.

1. INTRODUCTION

Solar energy systems are usually highly integrated with the building and the heating, ventilating, and/or air-conditioning (HVAC) plant. This is certainly true for active solar systems but even more so for passive solar systems. Effectively we want to address a highly integrated, dynamic system comprising sub-systems like the occupants, the building structure, auxiliary and solar systems - each of which is subjected to a control strategy and to (dynamic) outdoor climate conditions. There is a growing realization that traditional design tools cannot cope with this complexity.

Both with respect to environmental impact and economics, the ability to make sensible and well based decisions regarding such designs, is of the utmost importance. One of the most powerful techniques currently available for the analysis and design of complex systems, is computer modelling and simulation. (Modelling is the art of developing a model which faithfully represents a complex system. Simulation is the process of using the model to analyze and predict the behaviour of the real system.)

With current computers, performance analysis by simulation of complex building and plant configuration became available for most of the research community and to leading edge engineering and design practices.

However there are also signs that there is (a risk of) an increasing gap between sophisticated simulation tools and the users. Currently a non-trivial investment is required to use the current generation of tools. The practical efficiency of building energy simulation tools is dependent not only on the facilities offered by the tools and the rigour of the underlying (dynamic thermal) calculations but depends also on the skills of the user in terms of abstracting the essence of a problem into a model, choosing appropriate boundary conditions, setting up simulations and interpreting the results.

After a brief description of the evolution and the current capabilities of building energy simulation tools, two approaches aimed at bridging the increasing gap between sophisticated simulation tools and their users, will be addressed.

The first approach may have an immediate impact, and concerns user training. The second approach is related to future work in terms of development of intelligent front-ends which will act as intelligent assistants to the user when employing energy simulation in building design.

2. STATE-OF-THE-ART IN SIMULATION TOOLS

Early 3rd (current) generation approaches to building energy simulation, often focussed on either the building side of the overall problem domain (especially workers with building engi-

neering backgrounds), or on the (solar) plant side (often mechanical engineering backgrounds). In the former approach the influence of the plant system is more or less neglected by over-simplification of the plant; it was/is common practice to base the estimation of energy consumption on some presumed, imposed indoor air temperature profile. In the latter approach the complex building energy flow paths are usually grossly simplified, and the building (or each building zone) is commonly regarded as just another component which in this case imposes a thermal load on the plant.

Now it is felt that neither approach is preferable for the majority of problems which are affected by the thermal interaction of building structure and solar or auxiliary system.

It is better to start from the principle that both building and plant have to be approached on equal levels of complexity and detail while taking into account all major fluid flow and heat transfer couplings.

3. USING SIMULATION

It has been found that the efficacy of dynamic thermal performance simulation tools in the classroom, laboratory, design office or consulting practice is dependent not only on the facilities offered by the tools and the rigour of the underlying calculations but on the skills of the user vis-a-vis abstracting the essence of the problem into a product model, choosing appropriate boundary conditions, setting up simulations and interpreting their results (Hand and Clarke 1992).

How users acquire such skills and how simulation tools can be made more accessible is therefore a topic of some importance. Many aspects of simulation training are generic rather than application specific, this paper will concentrate on the generic as much as possible. Where specifics are required the point of reference will be the ESP-r building and plant energy simulation environment (Clarke 1985; Hensen 1991; Aasem et al. 1993).

Many of the difficulties associated with the integration of simulation into the design process can be traced to the following causal factors:

- Training having been almost exclusively on the mechanics of interaction with the tool.
- Exemplars were almost always "toy" problems - minimal complexity in terms of the form, fabric and temporal nature of the problem.
- Novices attempting complex problems and being swamped by the combinatorial explosion of topology and project management tasks.
- The importance of paper, pencil and planning. One of the most irrepressible urges, afflicting the novice as well as seasoned users, is to immediately approach the workstation when given a thermal appraisal to carry out. Without exception this

has been observed to be a costly mistake.

- **Confidence in the system** - not in terms of formal validation exercises, important as they are, but the confidence gained by use over time where the user begins to pay less attention to the interface and more to the purpose of undertaking simulation.

The power and, at the same time, the weakness of ESP-r (and likely other tools) is its ability to offer users multiple ways to represent and analyze problems in an attempt to emphasize particular design aspects and deal with parameter uncertainty.

While an expert will derive great power from this, a novice will typically feel unnerved. The differentiation of an elegant definition of reality in pursuit of a complex problem (by an expert) from syntactic correct garbage (of the novice) is one area where current tools inevitably fall down as they have no internal capability to check semantics. This problem is to some extent mitigated as applications introduce more unambiguous feedback of their product models but the responsibility is still on the user to confirm the correctness of the model.

3.1. User Types & Training

Based on case study reviews, observing, training and working with a range of users, several user classes became apparent (Hand 1993). Each user class has a different affinity for simulation, differing training needs and varying success in attaining proficiency. The following is a summary of those observed:

- **Previous users of simulation:** Having absorbed the syntax and the philosophy of one simulation model, such users usually adapt quickly to the syntax, philosophy and product model of another as well as appreciating the importance of simulation methodology.
- **Background in building physics:** This class of user generally has a reasonable aptitude for learning advanced simulation techniques and using them as a tool for investigating specific heat and mass flow issues. Typically, such a user will access source code, derive sophisticated parametric studies but not venture into problem descriptions which had any great geometric or control detail.
- **Technicians:** Users who absorb the techniques of how to manage data input and run simulations, but are not attracted to higher simulation issues make useful members of a team but are inclined to be ill-equipped to define product models, plan strategies or manage simulation work. Their ability to learn is variable as is their confidence.
- **Single issue users:** This class of user has one overriding use/focus for simulation and it is difficult for them to absorb skills which they label as outside of this focus. As such they often make poor use of a simulation tool.
- **Traditionalists:** This group of users do not easily cope with iterative use of simulation, concepts of simulation methodology, abstraction of reality into models. More profoundly, they consistently demanded that the rich set of flow, temperature and flux patterns be re-expressed in terms of lumped indices.
- **Students:** Being truly naive they attempt the impossible, take prompts literally, happily ignore pages of warnings and believe simulation results are carved on stone tablets. Having no concept of time and an infinite capacity to explore they will eventually be able to navigate almost any simulation tool. They are worth their weight in gold for the robustness they can force on an application.

3.2. Current Training Methods

As with most advanced engineering applications, the learning curve associated with any simulation system which is capable of modelling a diverse set of problem types, is non-trivial.

Among other skills the user must acquire 0) (often) knowledge of the English vocabulary/jargon associated, 1) basic skills related to the machine environment, 2) a command syntax and interface interaction skills, 3) a hierarchy of descriptive entities

which make up the product model, 4) a sequence of tasks required to create a product model, verify it, present it for simulation and explore simulation results.

From previous experiences with techniques ranging from formal workshops to on-site training in the context of actual projects, the following training methods can be summarized:

- **By the book:** Access to a workstation, users manual and sufficient time to 'sort things out' by trial and error is a common training technique. It occasional works. However, without direction most self-taught become "tool-led". In recognition of this ESP-r was equipped with an on-line tutorial, context sensitive help and documented exemplars.
- **Formal tuition:** As a technique this is particularly good to get users past the initial part of the learning curve. In the case of ESP-r, many novices progress to an intermediate level during a standard three day course involving an instructor to user ratio of 1:4 to 1:7.
- **Informal tuition:** This is a variant wherein the user gets limited formal training and then ad-hock access to expert users as they progress in a self teaching mode, often with a goal of adding new facilities or contributing to a joint project.
- **Workshops:** Simulation has many facets, some of which are best approached after experience with a system. Workshops have been successfully used to explore the setting up and interpretation of mass flow networks, simulation of passive solar test cells, and the like. An instructor to user ratio of 1:3 to 1:6 is sustainable.
- **Within a project:** An organization which has a "real" simulation based project can train "on the fly" by obtaining the services of an expert who then directs and trains nominally competent staff as the project progresses. This mode is particularly good for exploring methodology, problem description techniques and project management skills and can result in highly proficient staff.

3.3. Emerging Training Topics

As mentioned above "toy" problems have only a limited training potential. Much of the art of using simulation is in the composition of problems. ESP-r now includes in the system distribution documented and annotated exemplars ranging from dwellings to office blocks. Many of these are drawn from consulting projects and, having evolved under time constraints, are elegant solutions in support of design. The use of such exemplars is proving to be one of the best vehicles for technology transfer and advanced instruction.

Methodology deals with flows of information, decision points, relationships between simulation facilities, generation of patterns and their interpretation. It is methodology which allows one to elegantly and cost effectively use simulation to provide support for the design process. It is methodology which gives the expert power and the lack of it which drags the technician down.

Current generation simulation tools presume that the user has the background and intuitive or analytical faculties to confirm simulation results as being within the probable. This is problematic for the novice who, unlike the veteran, has a tendency to not subject simulation results to critical review. It is mostly beyond the state-of-the-art for the system to recognize non-intuitive results as being from ill-defined problems as from correct interactions within the scheme. Such limitations stem from the inherent interconnectedness of thermal problems. It falls to training to provide the attitudes and skills necessary for users to recognize and cope with the complexity of simulation.

4. DESIGN SUPPORT VIA SIMULATION

In the field of building energy related issues, there is a certain tradition of using computer simulation for design support,

involving the generation of knowledge which is subsequently transferred to the design profession. This kind of design support is thus based on knowledge transfer from "specialists" in a certain part of the overall problem domain, towards the design profession. With respect to the transfer process itself, there are many different approaches. At one end of the spectrum of possibilities one finds the so-called design-aids, while consultancy work for a specific design could be located at the other end of the spectrum. To demonstrate both these approaches by an example:

"Design-Aids"

This is a form of knowledge transfer in which the "specialists" try to generate generic knowledge which is supposed to be suitable for a range of buildings and which is usually aimed at being used by the designers. This kind of knowledge is commonly based on regression techniques applied to the results of multiple parametric runs of more powerful modelling systems. The results to emerge can often be reduced to simple relationships or presented in tabular or graphical form. Figure 1 is a typical example (from CEC 1986) showing summer overheating assessment graphs for medium-weight houses.

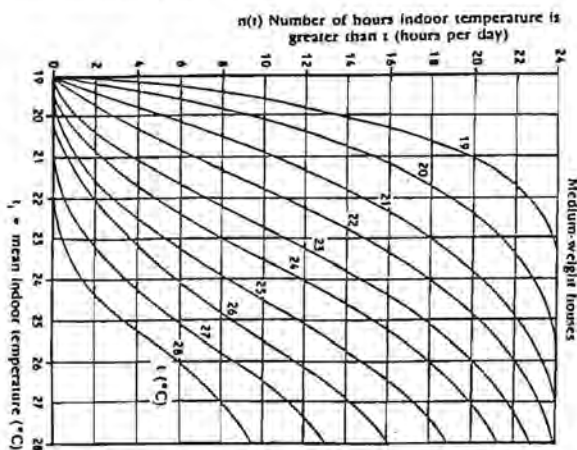


Figure 1 Summer overheating assessment graphs for medium-weight houses (from CEC 1986)

It is obvious however, that there are a number of drawbacks from such an approach, the most important ones being: (1) a particular aspect is regarded in an isolated manner, (2) this approach is only possible for a limited number of variables, and (3) the results are only valid for a certain combination of environment, building, installation, and occupancy pattern which is quite similar to the one used to generate the results.

"Consultancy Work"

In the current context this involves the generation of specific knowledge for a particular design by a specialist. A particular case study concerned an environmental assessment of hospital spaces located in central Scotland, where air flow rates were judged to be critical in limiting summer overheating in zones with significant solar radiation gain (Hand 1990). Figure 2 shows the part of the hospital under consideration, which consist of a dayroom and adjoining dining room. As can be seen, the dayroom has very large glazing areas.

It was requested to advise on useful operating strategies and/or possible modifications to the building in order to better control its summertime indoor thermal environment.

After reduction of solar gain, the primary means of preventing summer overheating is 'free cooling' by increasing the infiltration of ambient air. This may be achieved by for example opening of windows. Both the resulting cooling load by infiltration air and the indoor temperature, are influenced by the temperature difference between outside and inside, and by the actual air flow rates. In building thermal performance simulations, it has thus far been very problematic and time consuming

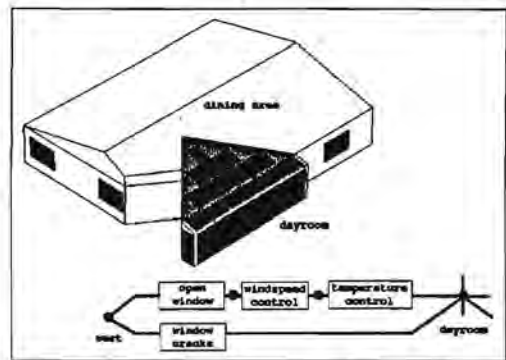


Figure 2 Schematic representation of the dayroom and adjoining dining room, when viewed from the south-west.

to realistically incorporate the air flow rates. The main reason for this is that the rate of air flow depends on pressure differences which may be caused by wind or by stack effects due to temperature differences. Especially with a free floating indoor air temperature problem - like in the present case study - heat removal and air flow are closely coupled.

This is also a typical example of a problem for which it is "impossible" to devise some simplified design tool, while a simulation based approach is readily available for the design profession.

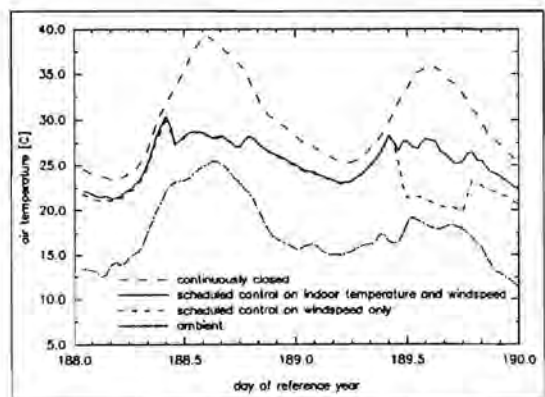


Figure 3 Predicted dayroom air temperature for July 7 and 8, assuming various window control strategies.

For the dayroom and dining area, a building thermal simulation model (representing dayroom, dining area, air leakages, and wind pressures) Occupant behaviour was simulated Figure 3 shows predicted dayroom air temperatures for July 7 and 8 of a reference year, and assuming various window control strategies. Of course these control strategies are just examples and may be changed at will.

These are merely two examples, more or less demonstrating both ends of the spectrum of knowledge transfer / design decision support possibilities in the area of building energy use. Obviously there are various intermediate approaches; these often take the form of some simplified calculation method. The envisaged user profile usually shifts from more designer-like towards more specialist-like as the method shifts from design-aids towards the full simulation model.

Since buildings are complex mechanisms, involving phenomena such as transient conduction and air movement, there is a growing realization that traditional design tools cannot cope with this

complexity.

Particularly at the earlier stages of the design process, there is a need for rapid feedback on the cost and performance consequences of alternative design scenarios. The present system of specialist consultants, while adequate for the detailed design and final specification phases, fails to provide this immediate 'ad hoc' advice.

4.1. Future Directions

It may be apparent that while development of sophisticated building performance evaluation tools as indicated above will comprise a valuable addition to the building engineer's toolkit, they also create new problems deriving from the conflict between the necessity for the tools to be powerful, comprehensive and according to first thermodynamic law principles to adequately represent the real world complexity while also being simple, straightforward and intuitive to facilitate user interaction. Such problems are not restricted to novice users but they apply to experienced users as well.

As Clarke (1991) points out, the conflict between power and ease of use is further exaggerated by the divergence of the conceptual outlook of the design orientated program users and the technically orientated program developers. And to complete the confusion, there is the subtly different terminology of the various engineering professions. One - very promising - way to tackle these problems, is by utilization of Knowledge Based System (KBS) and Human-Computer Interaction (HCI) techniques to create an Intelligent Front End (IFE).

Using these techniques it is possible to construct a user interface which incorporates a significant level of knowledge in relation to building description - in the face of real world uncertainty and realistic performance assessment methodologies. Such a system would direct a user's line of enquiry, allowing 'What do you suggest?' and 'Why do you ask?' type responses. It would also be expert enough to devise an appropriate performance assessment methodology and to coordinate model operation against this.

Using an IFE, the powerful simulation core may be invoked much earlier in the design process, because it is readily

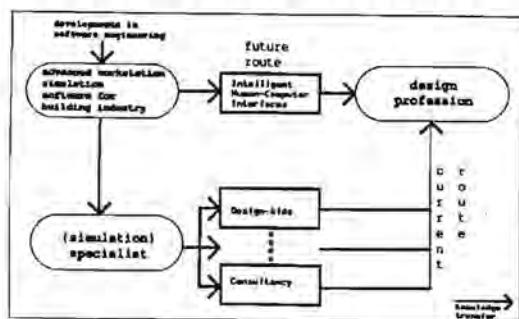


Figure 4 Current and future route of knowledge transfer / design decision support starting from simulation tools with an integral approach of building, solar and HVAC system.

available to the designer. Obviously specialist consultancy will still be necessary, but this can be limited to the more common questions / problems.

This shift from the more traditional approach using design-aids and via specialist consultancy, towards future direct application of powerful simulation tools by the design profession, is indicated in Figure 4. This future kind of design decision support in the area of building energy and indoor climate thus derives its power from its simulation core and its ease of use from some intelligent interface.

5. CONCLUSIONS

From observations, applying various training techniques and feedback the main conclusions are:

- One should not underestimate the need for training and software support or the resources required to become *au fait* with performance assessment tools.
- Training should begin with an emphasis on simulation methodology, problem abstraction and the rationale/ approach of the simulation tool to major performance appraisal topics. Next the focus should shift to the environment within which the simulation tool operates and only when the user appreciates its implications should the user learn the syntax and procedural aspects of the simulation tool and associated productivity aids.

It is counterproductive to give the impression that simulation does not require careful attention to detail, that complex interactions are not involved or that it is a particularly easy task to undertake. The more the user appreciates this and confirms it at a limited scale the more probable that the mind-boggling complexity needed to support the design process will be attained.

There is a very promising future prospective in the form of intelligent front-ends which will act as intelligent assistants to the user when employing energy simulation in building design. This will "automatically" bridge the gap between sophisticated simulation tools and building design professionals. However, until then (and maybe still thereafter) we will have to provide proper training.

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