THE APPLICATION OF BUILDING PERFORMANCE ASSESSMENT TOOLS IN PROFESSIONAL PRACTICE

Jon W. Hand
Energy Simulation Research Unit
University of Strathclyde
131 Rottenrow
GLASGOW G4 0NG
Scotland

ABSTRACT

The Energy Simulation Research Unit of the University of Strathclyde has recently undertaken a major effort to support the application of building performance assessment tools within architectural and engineering practices, universities and research groups around the UK. This has taken the form of a support service, funded by ETSU of the Department of Energy, to assist members of their Passive Solar Programme who are using the ESP suite of thermal simulation tools. This paper reports on the activities of the support service and draws conclusions from the work to date and observations on several factors which influence the application of such tools. It has been found that simulation programs which are well integrated within a workstation environment require a substantial investment in staff training, riot only for proficient use of such applications, but to harness the operating environment and software utilities which are available. Further. it has been observed that care and attention to how the user abstracts reality into a description for the simulation and defines the purpose of the exercise and the simulation facilities required is needed early in the learning process to shape and focus the use of simulation programs - otherwise a substantial waste of computing and staff resources is likely.

INTRODUCTION

The emergence of simulation as a tool for assessing building performance by those outside the academic research community has been given a boost by the introduction of low cost workstations and the evolution of many simulation programs which are increasingly able to make use of the rich set of utilities and software tools which are available on UNIX workstations. The Energy Simulation Research Unit (ESRU) of the University of Strathclyde has been involved in the application of one such building performance assessment tool, ESP#, in a number of sites around the UK based on its activities within the Passive Solar Programme of the Department of Energy.

The term ESP refers to the research version of the system as currently under development at various centres throughout Europe. A separate version is being commercialised by a private company, ABACUS Simulations Limited.

Observations carried out during this work have identified a number of causal factors which may explain some of the difficulties encountered by the professional community in making simulation an integral part of their methodology for carrying out building performance appraisals and design studies. These factors are introduced below and then discussed in detail throughout the paper.

- □ Lack of scope in training
  Just as users are inclined to think that the raw power of a workstation will result in increased productivity, simulation teams often underestimate the resources required for training and support of large simulation exercises.
- □ Not stressing methodology
  The tendency of many users to put the numbers in and crank the handle - without a serious effort to define the purpose of the exercise, the questions to be answered and which simulation and reporting facilities were actually required - leads inevitably to ill-suited descriptions, increased resource demands, and a poor impression of the applicability of the simulation tool.
- □ Not stressing descriptive abstraction
  Capturing the essence of an artifact such as a building, plant system or automobile within the descriptive syntax of a given simulation program, especially one which is very general and allows several approaches to descriptive tasks is, to understate the problem, a non-trivial task.
- □ Power <> Productivity
  The *essence* of a workstation, as a platform for performance appraisal and design studies, has been observed to have little to do with raw power and everything to do with enabling a flexible use of tools and applications.
- □ Application inflexibility
  Applications, despite their other advances, have yet to evolve to the point where they can recognise the novice from the seasoned user, or adapt, in other than a very coarse way, to different user classes, or professions.

THE PASSIVE SOLAR PROGRAMME

The Energy Technology Support Unit (ETSU) of the Department of Energy is involved in promoting more appropriate use of energy in the UK including energy efficient design and the inclusion of passive solar design features in buildings. Their Passive Solar Programme (PSP) makes use of:

- ☐ *field studies* measuring the energy and financial benefits of passive solar design features in existing buildings,
- ☐ *design studies* which provide an opportunity for design practices to explore passive solar techniques in a wide range of building types and which result in exemplar designs,
- ☐ *generic studies* which focus on particular design features.

The PSP has been operational for over two years and involves, among others, architects in the Building Design Partnership (BDP), engineers at Oscar Faber and Halcrow Gilbert Associates, physicists at the Building Research Establishment and the Environmental Design Unit of Leicester Polytechnic. The *design studies* have made use of several building thermal simulation models, including the ESP thermal simulation system, which has been the subject of continuing development at the University of Strathclyde over the last 15 years (Clarke 1985).

Anticipating a number of difficult simulation tasks, ETSU have contracted with ESRU to support the use of ESP as a building performance assessment tool. This support service was established in December 1988 and consists of one full time staff member, with part time support from other staff. The first year's activities included installing ESP at several sites, providing training in the use of the system and its workstation environment, providing a software support/enhancement resource and producing a newsletter. During the second year, support evolved towards questions of descriptive abstraction, methodology and management of assessment tasks.

THE PSP MEMBERS

Each of the organisations have a different focus related to the *design studies* and this diversity has influenced both the evolution of the simulation tool and provided an excellent test bed for this study as it allowed the observation of simulation work covering most of the descriptive and simulation domains within the scope of the simulation tool.

- ☐ **ETSU**, as the controlling organisation, defines the goals for the PSP participants, focuses support service activities and clarifies the technical issues to be addressed.
- ☐ **The Building Design Partnership** coordinates a series of design studies wherein existing office blocks and hotels are redesigned with passive solar features such as atria, and the energy and cost implications of lighting control regimes, natural ventilation and air movement within the atria are investigated by Oscar Faber and other sub-contractors. The performance assessments have been based on annual simulations with results distilled into a simplified performance index.
- ☐ **Oscar Faber** undertakes energy performance assessments for buildings as supplied by BDP. Faber's approach to data abstraction is that the whole building must be included in a simulation with simplification of internal details, and fenestration as necessary to fit within the descriptive limits of the assessment tool. This approach, which tends to require major resources for the setting up and running of simulations, has been the subject of much debate and has highlighted issues related to the management of large simulation exercises. Figure 1 shows one of the buildings under assessment.
- ☐ **Leicester Polytechnic** is involved in a series of applicability studies which compare the sensitivity of ESP, HTB2 and SERI-RES to design parameters such as the area and type of glazing, wall construction, the use of blinds, and different ratios of convective and radiant heating. This required custom data extraction code and highlighted the need to evolve from support of customised versions to the provision of user-configurable facilities.
- ☐ **The Building Research Establishment** has focused their efforts on validation of ESP via the investigation of algorithms, comparison with empirical experiments and the effect of variations in input files generated by different users. This has required the ability to investigate particular types of heat transfer phenomena in great detail and has resulted in the evolution of facilities related to the extraction, recovery and reporting of energy flow paths.

ESRU has also been active in the CEC PASSYS programme which uses ESP in conjunction with test cells in several European sites. The nine institutions involved have provided a rich source of feedback focused on research aspects and artifacts with a physical scale altogether different from that of the PSP. Despite this, the training and methodology issues which were identified as critical factors for the PSP were also found in PASSYS.

TRAINING

The learning curve for a general purpose simulation tool such as ESP, which is used for a wide range of thermal assessment tasks and applied to such diverse artifacts as automobiles and office blocks, is not trivial. As with other general simulation tools there is a syntax and menu structure to become acquainted with and a mental model of the tool and its associated files which

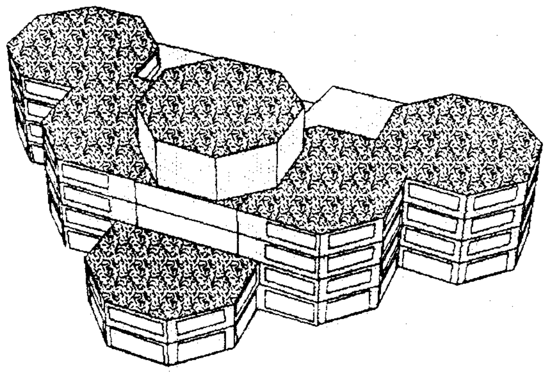

Figure 1: Typical office block under study.

needs to be developed. Despite the fact that such issues are covered in the ESP user manual (Clarke et al 1990), experience has pointed to the need for a combination of expert tuition and working experience to bring the user to an intermediate level of proficiency. At the same time written documentation has proved to be a difficult medium with which to demonstrate the facilities offered on a workstation. Thus, a virtually guaranteed source of user frustration and low productivity is to assume that a person can become a seasoned user by giving them access to a workstation, a users manual and a few days to sort it out by trial and error.

This is not to say that a self-taught user cannot become technically proficient, however, it has been observed that many such users become fixated with the simulation tool rather than the essence of their study. This typically manifests itself in a tendency to make use of every available simulation option and geometric contortion within the limits of the program at every opportunity. This, understandably, results in a massive descriptive and simulation results recovery task which is altogether more unpleasant that it might otherwise be.

The following training schedule is the current minimal recommendation:

Day	Activities
1	Introduction to energy modelling and the ESP/Unix environment: ☐ the evolution of simulation ☐ hardware, essential tools ☐ overview of ESP, file structure ☐ climatic data ☐ demonstration of system in use ☐ exercises to build proficiency
2	Becoming familiar with ESP: ☐ exercises highlighting file and module structure ☐ discussion of data abstraction and methodology ☐ exercises to build a set of descriptive files ☐ taking advantage of the workstation environment
3	Use of ESP facilities: ☐ exploring the simulation cycle ☐ report generation, more methodology ☐ automation via UNIX shell scripts
4	Advanced concepts: ☐ proficiency building exercises ☐ integration of 3rd party software ☐ the future

One important aspect of training is showing the user that many aspects of simulation can be investigated simultaneously via a collection of tools and applications. For example, a shading analysis could include viewing the object from the sun in one window while running a shading analysis in another, editing the description of the obstructions in another and capturing the images and output text for a final report in yet another window as illustrated in Figure 2.

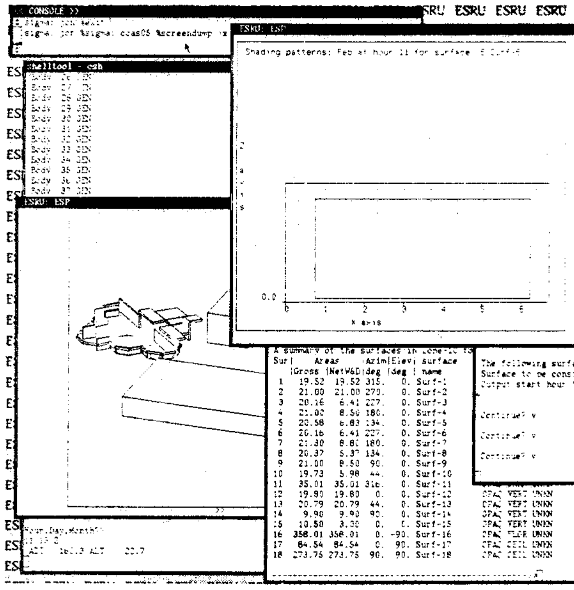

Figure 2: Analysis via multiple applications.

METHODOLOGY

One of the first and most crucial phases in any simulation exercise involves the specification of a methodology for the performance assessment, design study or investigative research project as the case may be. Such a methodology usually includes most of the steps in Table I, each of which involve the user making a number of decisions.

The reader should note that this process is largely applicable to any simulation tool. Furthermore, it is quite possible, and some would argue quite appropriate, to define a simulation methodology and arrive at the nature of abstract descriptions without touching a workstation.

TABLE I

Step	Typical decisions
a: Identify the issues to be addressed, the simulation and reporting facilities required, and what indices will be used to judge performance.	☐ Is the project a one-off assessment? Is it better described as a parametric study or an iterative design exploration? ☐ Are patterns of external shading and internal shortwave radiation distribution sufficiently described by approximations or should they be dynamically analysed?
b: Abstract the essence of the artifact into a format and syntax which is understandable by the simulation tool and appropriate to the focus of the study.	☐ Is it really necessary to describe a remote zone in order to assess the contribution of an atria to a building's energy demand? ☐ How much geometric detail is required in order to capture variations in daylighting which may influence artificial lighting demand?
c: Organise descriptive files, databases, and directory structures and proceed with the simulations.	☐ Which materials databases are most appropriate for the project? ☐ Are there regular patterns of occupancy and equipment use? ☐ What file naming convention is appropriate if there are three design variations to one portion of the artifact?
d: After the simulation the results must be interpreted, the energy performance categorised and reports generated.	☐ There is an unexpected late afternoon energy pulse in one zone - how may this be traced? ☐ Can the existing tabular reports be incorporated or should they be passed into a statistics program?

For example, as the support service has matured and taken an active involvement in methodology and abstraction issues it has become increasingly possible to find innovative ways of using the existing facilities to achieve simulation goals rather than resorting to code intervention.

There still remains the problem of how to implement methodologies which are dependent on assumptions which are built into the code or implicit in its structure, but which are not well documented, except perhaps within the source code. The expert is still positioned to make the most of the tool and to produce exemplars so that a wider audience can make use of such techniques.

DESCRIPTIVE ABSTRACTION

Step "b" in Table I is often known as the *problem definition* phase and it has been observed that the user's approach to this can influence their ability to efficiently carry out performance assessments and design studies. The user is constantly presented with questions of data abstraction, for example, how to adequately represent a building or plant system in order to answer specific questions. In many ways this is still more of an art than a science and involves an understanding of building and plant physics and its treatment in the simulation model.

As with most simulation tools, ESP defines general limitations on the number of zones, surfaces and materials with which the user can describe an object. Although such limitations are an occasional irritant, it is the alternative ways of abstracting a particular phenomenon which is most troublesome to the novice.

One way of dealing with abstraction is to allow it to be dictated by the focus defined by the methodology. There is little point in capturing any more than the *essence* of a phenomenon or portions of an artifact which contribute only second order effects to the focus. Abstraction should however seek to preserve surface areas, volumes, mass and contiguity.

The following discussion will take as an example, the office block shown in Figure 1 which is so large that it could not be fully described, (for example, each office, passage, computer and window crack) within the physical limits of the simulation program and the time-frames available to most users. What then is the appropriate level of data abstraction? If the project goal is to determine which of three lighting control regimes reduce energy demand in the office block, two extreme approaches can be evaluated.

The first, which is favoured by Oscar Faber, would be to describe the whole building with lumped internal details with some simplification of fenestration to fit within the descriptive limits of the tool but still retain the essence of daylighting in the various parts of the building. Thus, no scaling will be required to arrive at an aggregate lighting performance. The penalty is the substantial resource required to set up and debug the description. In addition, the complexity of the description will tend to act against iterative optimisation, the volume of the results against detailed exploration and the lack of detail against exploring other performance issues.

The other approach might be to construct a matrix of rooms (Figure 3) which are typical of portions of the building. This requires the user to select what he/she believes are typical office layouts and exposures. Since the scale of the exercise is reduced there is the opportunity to include shading devices, more accurate glazing placement and details. The example shown uses replication of one base case with each room possessing a different sensor layout and/or control (Hand 1990). Being simulated at the same time it is relatively easy to do cross comparisons between the predictions and determine which of the regimes is optimal. Alternately this simulation could include each of the typical rooms with one sensor layout and /control. The knowledge gained for the various parts can then be scaled to derive an aggregate for the building or the selected regime applied to the building as a whole.

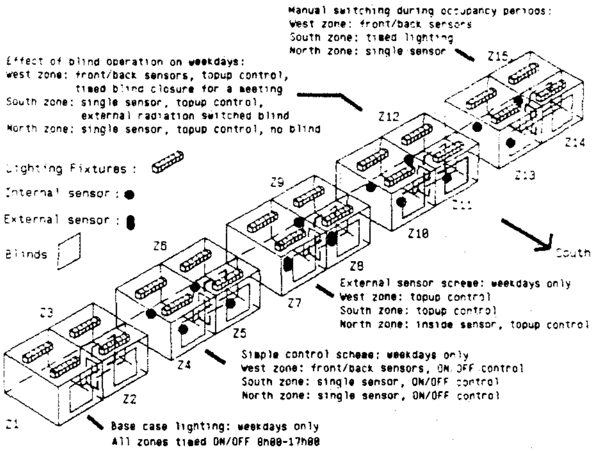

Figure 3: Test matrix for the evaluation of design parameters

Abstraction issues also occur at a detailed level, for example, what are the available means to characterise the convective and radiant nature of a heating device to be inserted into a zone? How is it controlled, can it be modelled as an ideal injection of energy with an On/Off response to a thermostat or is it necessary to evolve a more complex plant representation? Is its impact on the occupant such that its geometry should be described and its directional properties taken into account. Additional documentation, exemplars and interface enhancements will eventually reduce the descriptive burden for the user, but currently users are best served by consultation with experts.

EVOLUTION TO MEET USER EXPECTATIONS

As users gain proficiency and begin to explore more esoteric thermal simulation issues, they often find a mismatch between their expectations and the facilities offered. The first year's activities of the support service therefore included a significant effort to evolve the simulation and reporting facilities to better fit the range of simulations and analyses undertaken.

For example, ESP includes an extensive results reporting and analysis facility which provides interrogation, graphing, tabular reporting and statistical analysis for most of the temperatures, fluxes, air movements, convection, conduction, casual gains, radiation and climatic data associated with a simulation. Even with this wealth of options, PSP members have requested specialised reporting facilities for their work. In response ESRU has introduced generic facilities which allow the user to choose data types from menus and produce multi-column tabular listings in whatever order or number of columns as well as exporting this information to third party graphing utilities.

Extension of Technical Facilities As the PSP progressed in its work, several users gained sufficient proficiency to attempt simulations which were at the edge of ESP's capabilities. In their efforts to more closely model reality they made use of many of the more obscure facilities of the system, and, in exercising this code in an assessment context, identified areas requiring attention. For example:

- Oscar Faber's desire to model air flow in atria pushed the existing air flow network solution technique to its limits and a different solution technique and descriptive syntax were put in place which reduced simulation time by several orders of magnitude and allows for flows in branches of a network to be controlled in a similar way to that of casual gains and plant injection.
- Leicester's desire to move from a simplified treatment of windows to ESP's most rigorous level of analysis, exposed the fact that the latter facility did not yet have the ability to model movable devices such as blinds and thermal shutters. Restructuring of the solar radiation book-keeping code allowed blinds to be modelled and their thermal properties to change as a function of time.
- The Building Research Establishment's interest in detailed energy flows resulted in the enhancement of an existing facility which reported energy balance at air nodes by including a more verbose breakdown of energy flux paths and the introduction of a similar balance at the inside and outside faces of surfaces as shown in Figure 4. Such facilities are unglamorous yet vital for users who are concerned with tracing energy flows through a building or those who are interested in the dynamic performance of a particular construction type.
- BDP's interest in quantifying savings attributable to various lighting control regimes resulted in a decision to rewrite much of the existing facility to allow multiple illumination sensors and lighting systems within a thermal zone, to take into account illuminance from adjacent rooms (including blind operation) as well as accepting externally derived daylight factors. The matrix in Figure 3 is a subset of the available combinations.
- The interdisciplinary nature of the PSP and the need for better documentation of the abstract description lead to facilities to annotate descriptive files as well

as allow them to be automatically decoded into a less ESP specific context.

```
Which one ? 5
Zone to be considered ? 2
Surface to be considered ? 1
Causal energy breakdown (Watts) for surface 1 in zone 2: standard
Surface is opaque MLC, area=  8.00m2 & connects to the outside
Period from  1 Feb @  0h30 to  2 Feb @ 23h30
Tsteps: sim@ 60m, output@ 60m (not averaged)

                      Facing Zone  2          Facing Zone  0
                      Gain       Loss         Gain       Loss
Conductive flux      650.50   -1764.36      1983.98   -2169.01
Convective flux     2182.60    -209.48      3932.75   -1014.91
Longwave rad int       0.00    -999.88          --         --
LW rad ext >bldg        --         --         4.66     -90.28
LW rad ext >sky         --         --         0.00   -7295.42
LW rad ext >grnd        --         --        74.73   -1428.67
Shortwave rad.       150.23       0.00      6265.59       0.00
Unctrl cas typ 1       0.00       0.00          --         --
       cas typ 2       0.00       0.00          --         --
       cas typ 3       0.00       0.00          --         --
Cntrld cas typ 1       0.00       0.00          --         --
       cas typ 2       0.00       0.00          --         --
       cas typ 3       0.00       0.00          --         --
Heat stored           53.10     -62.71       719.49    -982.91
Plant                  0.00       0.00         0.00       0.00
Totals              3036.43   -3036.43     12981.19  -12981.19

/bin /usr/bin /etc /usr/etc /usr/ucb /usr/local/bin /usr/esr
esp/bin /usr/local/bin/sun3bin /usr/local/bin /usr/sccs /usr/
```

Figure 4: Causal energy breakdown at both sides of a wall

In allowing the user to more closely track a portion of reality there is a danger in bloating an already large system or allowing an uneven robustness of treatment to creep in. This is especially true when a simulation tool is evolving to meet the needs of single issue fanatics. Thus, a rather baroque set of control facilities was built on top of an engineering approximation of lighting distribution. At least the code is modular and extensible so that a first principles approach can be substituted at a later date without upsetting the control logic.

Software support has also involved bug fixes, of which the following are typical:

- Several shortcomings were found when users' descriptions were at the edge of the resolution of the underlying methods, such as surfaces with near perfect reflectance, heat injection devices with very high radiant components, minute windows in a wall or conversely walls composed mostly of windows.
- Incompatibility of supplied data is occasionally a problem, for example using a weather file which is somewhat remote from the site may give rise to a mismatch in the time of sunrise/sunset and the radiation data which caused ESP some distress in its daylighting calculations. Now the system can intelligently recover.

Interface Issues

Addressing simulation issues as broad as those within the PSP demands general purpose simulation tools. One of the drawbacks of such tools is, of course, the combinatorial explosion of options and alternative ways of abstracting reality into a model of the buildings and plant systems to be simulated. Users are then beset with a cornucopia of information which can be displayed, analysed and reported. Throughout this there are randomly placed user-hostile sections that never seem to be so critical as to rise to the top of the revision list.

Observations of seasoned ESP users have shown that the form of the interface, once its syntax has been mastered, has only a minimal impact on their ability to apply the tool to the problems at hand. Indeed, one unexpected discovery was that such users viewed methodology issues as being substantially independent of the form of the interface. The same can not be said for novice users who are often frustrated and confused to the point that they are distracted from abstraction and methodology issues which are of paramount importance.

To ease such burdens, a number of software support tools to aid in geometry checking, graphics display, file management and links to report generation tools have been introduced. It has also been possible to evolve the interface in several modules so that they are less cryptic, the program structure easier to follow, and the editing and reporting environments less diverse. It would appear that these have been successful in increasing the utility of ESP, but a significant effort such as the introduction of knowledge based interfaces would be required to really improve the ease of use.

TOWARDS THE FUTURE

Many users of simulation tools embark on very focused exercises which require the recovery of selective data such as illumination levels within rooms, the status of sensors or data on occupant activity levels which are not catered for in the standard results recovery and analysis facilities of the tool they are using. This holds true for programs such as DEROB which require the user to define the data to be saved, as well as for ESP which has several predefined sets of data capture and recovery. ESP's existing results archiving facility, which has been flexible and extensible enough to meet most users needs, could be further enhanced to allow additional information to be selected by the user and incorporated into the results database obviating the need for code interventions which some users were forced to undertake (Hand 1990b).

In the next phase of the service a modest effort will be expended in an attempt to make use of emerging knowledge based tools such as the Intelligent Front End (IFE) project (Clarke et al 1989). In effect, the IFE coordinates the gathering of a user's instructions and building/plant system descriptions and drives the required application programs in a form which is more sympathetic to the user. Figure 5 shows a typical session of an expert user defining the geometry of a thermal zone via a form-fill facility. For such a user, the data fields on the geometry form map directly to the ESP file structure and the text and field labels are terse. This information will be extracted by the IFE, and, by making use of its knowledge of the application, will compile a set of commands which will drive a standard geometry file creation facility.

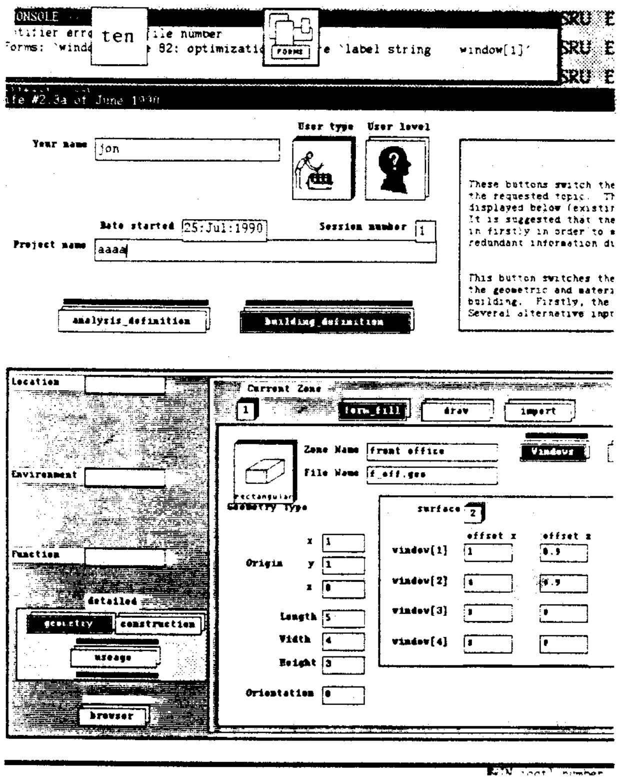

Figure 5: Typical geometric proforma

Even though the evolution of an interface or the incorporation of IFE facilities are useful and enhance productivity, when viewed in the context of enabling the use of simulation tools in professional practice, they only address one facet of the problem. An IFE does not necessarily alter the difficult decisions involving the abstraction of building descriptions, the development of simulation methodologies, the interpretation of simulation results or remove operational deficiencies in the applications with which it is associated. Nonetheless, observing the use of such tools by a diverse set of users will be essential in order to evolve more appropriate interfaces and knowledge bases for the next generation of simulation tools.

CONCLUSIONS

The Energy Simulation Research Unit of the University of Strathclyde has recently undertaken a major effort in support of the application of building performance assessment tools within A/E practices, universities and research groups around the UK via a Department of Energy funded support service. It has been found that simulation tools which are integrated into a workstation environment require a substantial investment in staff training, not only for the proficient use of the simulation tool, but to harness the rich operating environment and software tools which are available on workstations. Furthermore, it has been observed that care and attention to descriptive abstraction and methodology is needed early in the learning process to shape and focus the use of tools - otherwise a substantial waste of computing and staff resources is likely.

Anyone contemplating a serious thermal simulation project should not underestimate the need for training and software support or the resources required to become au fait with performance assessment tools. In the groups observed, a moderate level of proficiency required both formal training as well as hands on experience in the order of weeks to months depending on the individual. Groups which were not exposed to expert tuition tended to have difficulty with descriptive abstraction and were more inclined to "stuff in the dimensions and crank the handle".

Upwards of a year was required for most to achieve true expertise and even for these the use of advanced engineering software in practice can be problematic: what is needed is a greater degree of consensus on building description and performance assessment methodology and a move to knowledge based systems which incorporate a degree of user, domain and application knowledge.

ACKNOWLEDGEMENTS

I would like to thank Joe Clarke for helping me find paths into the core of ESP and my other ESRU colleagues who gave valuable ideas for this paper. I would also like to thank Adrian Cole of ETSU for his support and encouragement, the staff of BDP, Oscar Faber, Leicester Polytechnic and the BRE for their contributions and for allowing me to observe their evolving use of ESP.

REFERENCES

Clarke, J.A. 1985. *Energy Simulation in Building Design*, Adam Hilger Ltd, Bristol and Boston.

Clarke, J.A. and D. Mac Randal. 1989. "An Intelligent Front-End for Computer-Aided Building Design", *Proc. 3rd European Simulation Congress*, (Edinburgh Scotland, Sept.5-8).

Clarke, J.A, J. Hand and P. Strachan. 1990. *ESP A Building and Plant Energy Simulation System, Version 6 Series*, ESRU Manual U90/1, Glasgow.

Hand, J.W. 1990. "Parametric Matrix for Lighting Studies". ESRU Technical Note T90/7, University of Strathclyde, Glasgow. (Jun).

Hand, J.W. 1990. "Proposal for Restructuring the ESP Results Library", ESRU Technical Note T90/5, University of Strathclyde, Glasgow. (May).