

## IMPROVING COMMUNICATION IN BUILDING SIMULATION SUPPORTED PROJECTS

Prazeres L<sup>1</sup>, Kim J and Hand J  
Energy Systems Research Unit, University of Strathclyde  
(<sup>1</sup>corresponding author)

### ABSTRACT

Building simulation supported projects are difficult to manage when there are many different participants involved (e.g. simulation specialists, project managers, design teams with engineers and/or architects and clients). These participants are often dispersed and have a diverse knowledge level.

In addition, the goal of understanding how the building works and the impact of design decisions is often hampered by limitations in the presentation of performance data. Contemporary results display is constrained to what was considered good practice some decades ago rather than in ways that preserve the richness of the underlying data.

This paper discusses in detail the system connectivity of a framework from previous works which improve collaborative simulation modelling. Widely available communication protocols were used to allow concurrent information sharing between all participants. A case study is also presented to reinforce the potential benefits of the framework.

### KEYWORDS

Collaborative simulation, Concurrent information sharing, System connectivity, Data management

### INTRODUCTION

Current simulation projects involve the effort of many people, each with a different skill-set, which tend to complement each other – however they also have different needs. For example, one member of the team might be responsible for generating the model geometry and setup the attributions (e.g. material, HVAC, usage pattern *etc*) within the building simulation software. Obviously, this is done with the input from the other members of the design team, which forces many technical exchanges and model reviews among the team and therefore it tends to be un-objective and inefficient. Apart from diverse and dispersed teams, the complications worsen with the fact that building simulation outputs are large data-sets, complex and inter-related.

Users are required to employ a spreadsheet to display simulation generated data in a meaningful way. Transport of model descriptions and simulation results files is a non-trivial task. Conventional work practices seem designed to exhaust the participants even as it constrains their ability to understand and choose between design options.

There were many attempts to tackle this problem. Papamichael *et al.* (1999) developed the building design advisor tool which enables users to easily compare different design options without the need for expert knowledge. Donn (1999) and Donn *et al.* (2001) developed the concept of an Internet database of building simulation outputs for quality control and analysis. Stravrovavdis and Marsh (2005) improved design decision making by developing scripts to automate the generation of building simulation outputs to be stored and managed in on-line databases.

A study that focused on building simulation data communication (Prazeres, 2006) enhanced the concept of Integrated Performance View (Hand, 2007) to develop an Internet-enabled tool (I<sup>3</sup>PV – Integrated, Interactive and Intelligent Performance View). The tool embeds techniques and rules proven to enhance efficiency, effectiveness and flexibility of information displays targeted to the different user types (e.g. simulation specialist, engineer, architect *etc*) and task types (e.g. exploration, analysis and presentation). The *Intelligent* dimension refers, for example, to the anticipation of user needs by identifying the user type and therefore offer appropriate data displays / default values.

### **User Survey**

Targeted displays that address the needs of the different user types are crucial. Based on field research, Prazeres (2006) identified the following user patterns:

- Inexperienced users preferred intuitive displays because it helped them to understand what was actually going on;
- Experienced users were more likely to trade-off intuitive displays for screen-space and computer power resource saving;

- Energy managers should have less display interactivity to avoid confusion and assessment errors;
- Experienced users preferred the flexibility of having both objective and subjective elements when comparing design options (e.g. costs versus benefits);
- Architects appreciated audio based feedback more than other user types. Examples included experiential appraisals for acoustics assessment and voice annotations for project briefings or to provide essential supplementary information;
- Engineers preferred overall values or pass/fail results rather than detailed breakdowns because they were more objective; and
- Engineers also appreciated one location to encompass all design option and project-related information with multimedia techniques.

Some features were appreciated by all user types:

- The display of information within a main window with scrolling instead of within separate pop-up windows. This avoids window overlap and saves screen space;
- The existence of toggles to allow the change to a more preferable information format (e.g. from a bar graph to a table) or the selection of a feature to unclutter the display (e.g. to turn off a graphical grid or to include values on a bar graph);
- The existence of suppression techniques to un-clutter displays (e.g. to minimise internal windows in an IPV display); and
- The combinations of audio and visual clues benefited users with disabilities.

In general, the consulted users were content with the ability to simultaneously display several performance metrics. To implement this concurrent and collaborative information system for building simulation supported projects, a software framework and its connectivity (one of the focuses of this paper) is described next.

## FRAMEWORK OVERVIEW AND CONNECTIVITY

The framework consists of ESP-r (Clarke, 2001) and Radiance (Larson and Shakespeare, 1998) as simulation engines. EnTrak (Kim, 2004) as an Internet-enabled data management system and I<sup>3</sup>PV (Prazeres, 2006) as an Internet-enabled results analysis, exploration and presentation tool. Figure 1 illustrates the connectivity within the framework.

The integration agent module does the data management and converts the data formats to be readily consumed by the other modules. It is implemented as software procedures.

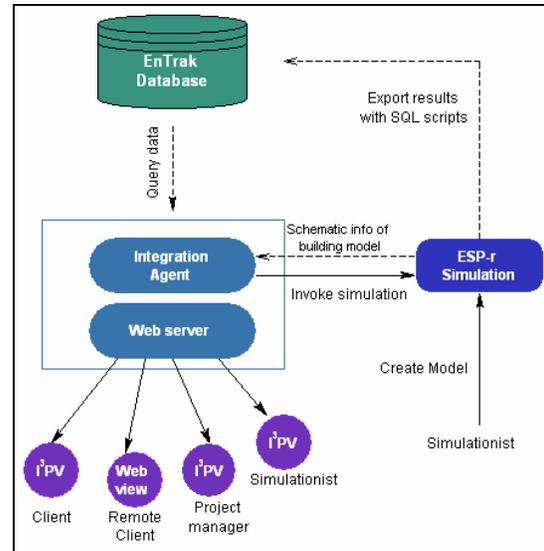


Figure 1: The on-line framework.

SQL (Structured Query Language) is the communication mechanism between the simulation software and the database (Kim, 2004). Because building simulation data is time-based it could be translated into SQL statements easily. While the simulation is in progress, the bridge with the relevant tables in EnTrak (e.g. building description, energy use, indoor environment, climate *etc*) could be initiated to store the data. The following SQL statements are embedded within the ESP-r program code:

```
REPLACE INTO indoor_climate (ref, ic_code, datetime,
ic_item, value) VALUES (zone_id, 'ESP', dt, db, tma);
```

```
REPLACE INTO energy (ref, meter_id, fuel_type, r_type,
to_datetime, dial_1, tot) VALUES (zone_id,
'HF', 'HF', 'ESP', dt, qm, qm);
```

Here, the values of 'zone\_id', 'dt', 'db', 'tma' and 'qm' are obtained from the ESP-r simulation program – 'zone\_id' is defined by a project name and zone id number.

The building information is stored in EnTrak tables, where basic information about zones is grabbed from the summary file available from ESP-r. A zone in a modelling project could be defined as an entity with a zone ID number and the simulation project name in the 'ref' field. The entire building model consisting of several zones is registered with the project name in the 'building\_ref' field. The notable characteristics of the modelling exercise (e.g. design options) may be coded and stored in the 'sort\_code' fields in the building table. The following SQL statements are examples of the registration of the entity in EnTrak database. Figure 2 shows the summary file of a simulation model of which part information is exported to the database using the following SQL statements.

```
INSERT INTO entity (ref, name, origin_data, entity_type)
VALUE ('FEDERICK_01', 'rest1_1', 'DV', 'BD');
```

```
INSERT INTO building (ref, building_ref, ht, volume,
ht_flr_area, transp_area, opaque_area) VALUE
('FEDRICK_01', 'FEDERICK', 99.9, 37.0, 35.2, 105.7);
```

Significantly, the simulation predictions could be transferred to EnTrak at each time step of the simulation through an SQL communication protocol. This feature allows various applications such as network-based modelling process or real-time based interactivity between real entity and virtual data (e.g. control algorithms based on the virtually predicted data). For example, the predictive control using a physically-based thermal simulation program (Clarke et al. 2002) requires real time monitored data to be used as input parameters for the simulation process. The simulation results (e.g. the optimum start time) must be informed to the control devices at a certain time step or every time step. The real-time input data from sensors and the simulation results could be transmitted between devices and simulation programs via a database server. As the simulation results data and entity data are sent to EnTrak database, the virtual data could be broadcasted immediately to other systems (e.g. I<sup>3</sup>PV) via EnTrak database server. Such a network-based building simulation environment would enhance the efficiency of the communication and cooperation between parties involved in a simulation project.

## COLLABORATIVE SIMULATION MODELLING

A detailed simulation modelling project is usually carried out as a collaboration between several individuals.

For instance, a building designer may commission a modelling team consisting of a project manager and a simulationist. The project manager verifies the model made by the simulationist. The designer is often asked to provide relevant data required by the model. A reliable and acceptable model is obtained as a consensus between the project manager, simulationist and designer. This requires a series of technical exchanges and model reviews. However, the designer often has difficulty reviewing the model due to a lack of knowledge about the operation of the modelling tool being used. Providing a user-friendly reviewing tool is, therefore, an important part of improving the efficiency of collaborative decision-making.

An on-line review system makes it possible to review schematic results in real-time. The data communication between ESP-r, EnTrak database, Web server and I<sup>3</sup>PV tool interface has been established, and a Web-based modelling reviewer designed. Once an initial simulation model is generated by the simulationist, the building's geometry, weather context and simulation results may be transferred to the Web server domain and EnTrak database. The model and the simulation results are eventually broadcasted by the Web server over the Internet using the HTTP protocol. This allows various types of content, including multi-media objects, to be delivered to Web clients. The purpose of the integration agent is to manage any data queries from the database and co-ordinate the data transaction between the Web server and the ESP-r system.

The building geometric model is a crucial target in simulation modelling. Enhancing user interactivity with the building model would improve the modelling process and help make a valid model. It is important to present the building model in a user-friendly manner to those who are not familiar with the modelling system (i.e. designers).

```
Synopsis

This is a synopsis of the model refurb, restaurant & kitchen, (24 & 30)
cooling Federick st. defined in FEDERICK_b_cool_2.cfg generated on Thu Feb 5
12:50:55 2009. Notes associated with the model are in FEDERICK.log

The model is located at latitude 56.50 with a longitude difference of -3.00
from the local time meridian. The year used in simulations is 1980 and
weekends occur on Saturday and Sunday.
The site exposure is typical city centre and the ground reflectance is 0.20.
.....
ID Zone          Volume |          Surface
Name           m^3   | No. Opaque Transp ~Floor
1 rest1_1       99.9  13  105.7  35.2  37.0 near the entrance in restaurant 1
2 rest1_2       75.6  12   85.9  27.4  28.0 down area of restaurant 1
3 bar           216.0 20  208.6  48.6  80.0 bar
4 rest2         86.4  13  101.3  27.5  32.0 rest2 describes restaurent 2 area
5 court        187.9 18  133.0  95.7  61.6 court describes a... court area
6 kitchen      104.5  8  140.9   7.2  38.7 kitchen describes a kitchen
.....
13 office      2247.7 7 1012.0  0.0 169.0 office describes a...office building
above the restaurant
all           4298. 142 2940.  250. 644.
```

Figure 2: ESP-r summary file.

As the ESP-r building model contains attribution data as well as geometric data, the capability of reviewing such information in an efficient way is also significant in terms of quality assurance. To this end, the Virtual Reality Modelling Language (VRML) has been chosen since it is a universally accepted 3D manipulation device as well as Internet-enabled (Web3D Consortium, 2009). By restructuring the data format of the building geometric model in VRML, the ESP-r building model could be presented in a Web-based, user-interactive form.

In order to transform the attribution and geometric data of the ESP-r building model to VRML format, the geometric data in the '.geo' files of an ESP-r building model are reformatted. A parsing program manages this transformation automatically. The geometric data from several '.geo' files in the ESP-r zones directory are combined into a single VRML file. Figure 3 (on the left) shows part of a '.geo' file of a zone, while Figure 3 (on the right) shows the equivalent VRML file. The VRML building model could be viewed with any 3D model viewer available from various vendors.

It is also necessary to view simulated data items easily to assess the simulation result before going for a more sophisticated analysis. In addition, the modelling analysis program may generate the visualised outcomes, for example, associated with lighting analysis. ESP-r has the option to invoke a RADIANCE analysis and orchestrate image outcomes. A series of image files presenting time-based results could then be used to provide animations. Although the analysis process requires expertise, the outcomes may be shared over the Internet between members of the design team.

Figure 4 shows an example of an ESP-r model in the Web-based model reviewer. As noticed, users could perceive the geometric model from different angles in the VRML model viewer (Cortona3D Viewer, 2009). Since the VRML model viewer provides URL links on the surfaces of the model, the basic information of the zone appears on the right pane by simply pointing to a zone on the screen. In addition, the specification of a construction is linked to the name of the surface so that it could be detailed in another window by clicking on the surface name.

Next, a case study is described in detail where this framework would have been hugely beneficial in the context of collaborative simulation modelling.

### Case Study

The case study is a refurbishment project of a restaurant and kitchen in the basement of an 1890's stone building in Edinburgh, Scotland along a busy pedestrian district. This street had recently become a trendy area for eating out and the client wished to

convert the lower level of the building into a restaurant even though it had relatively restricted views to the street. The property also had a courtyard in the back as well as an old stable block.

The change of use of the building as well as its layout and composition posed a number of questions for the design team:

- a) was there enough sunlight in the courtyard to offer an amenity to clients and were there any patterns in the sunlight into the courtyard that might be a feature in the design;
- b) was the solar access on the street side going to cause a problem with glare – awnings would tend to block the view of pedestrians;
- c) could the muse (stable block) at the rear of the property be converted into a kitchen and would kitchen equipment cause overheating of the kitchen and adjacent courtyard;
- d) how sensitive would the dining area be to changes in temperature and humidity as the number of clients varied; and
- e) would there be a rush of air from the street through the restaurant into the rear courtyard or localised discomfort on busy nights if openings to the street and courtyard were restricted (e.g. the courtyard was glassed over).

The design team had many ideas but a limited time frame, and indeed a limited attention span, for dealing with what-if questions. The mass of the structure was assumed to be important but the degree of importance was unknown.

The movement of air and the distribution of heat gains in the kitchen and seating areas were also flagged early in the study. Thus both teams began the process not knowing if the proposed use of the building was viable.

For the simulation team the combination of design questions and the composition of the spaces posed a number of issues which required a methodical approach to capture the essential characteristics of the building and yet allow for the model to adapt as the design evolved. There were multiple assessment domains - visual, thermal and air flow. And there was also the uncertainty of client reactions to new performance information - it might be a decision to proceed or a what-if question or a request for further explanations of yesterday's question or last week's debate.

Fast is not fast if you lose track of which design variant you are working on. A focused study could turn into a local black hole for staff resources if the level of detail in the model is not constrained and it would lose credibility if important-to-the-client details were not considered.

<pre> *Geometry 1.1,GEN,kitchen # tag version, format, zone name  *date Mon Jan 26 16:45:21 2009 # latest file modification kitchen describes a kitchen # tag, X co-ord, Y co-ord, Z co-ord *vertex,18.10120,-0.32618,0.00000 # 1 *vertex,19.26589,-4.67285,0.00000 # 2 *vertex,27.57285,-2.44701,0.00000 # 3 *vertex,26.40817,1.89965,0.00000 # 4 .....  *vertex,21.09559,0.47618,2.70000 # 14 # # tag, number of vertices followed by list of associated vert *edges,5,2,3,7,13,6 # 1 *edges,4,3,4,8,7 # 2 *edges,5,4,1,5,14,8 # 3 .....  *edges,4,14,13,7,8 # 8 # # surf attributes: # surf name, surf position .....  # boundary condition tag followed by two data items *surf,to_wc,VERT,-,-, ,kit_inwall,OPAQUE,ANOTHER,07,03 # 1   &lt; to_kitchen:wc .....  *surf,void_court,VERT,-,-, ,fict,SC_fictit,ANOTHER,05,18 # 7   &lt; void_court:court *surf,ceiling2,CEIL,-,-, ,ceiling,OPAQUE,ANOTHER,08,05 # 8   &lt; floor:first_1 # *insol,3,0,0,0 # default insolation distribution # shading directives *shad_calc,none # no temporal shading requested *insol_calc,none # no insolation requested *base_list,1,5, 38.70 0 # zone base list </pre>	<pre> #VRML V2.0 utf8  # VRML materials derived from ESP-r constructions... Anchor { parameter [ "target = description" ] children [ Shape { appearance DEF Glass_dbl_glz_nb Appearance { material Material { diffuseColor 1 1 1 ambientIntensity 1.0 specularColor 0 0 100 shininess 0.725 transparency 0.80 } } } ] } ..... # zone kitchen starts here.... Anchor { parameter [ "target = description" ] url [ "Federick.html#kitchen:to_wc" ] children [ Shape { appearance USE Solid_kit_inwall geometry DEF to_wc IndexedFaceSet { ccw TRUE solid FALSE coord DEF COORD_kitchen Coordinate { point [ 18.10120 0.00000 0.32618, 19.26589 0.00000 4.67285, 27.57285 0.00000 2.44701, 26.40817 0.00000 -1.89965, ..... 21.09559 2.70000 -0.47618 ] } coordIndex [ 1,2,6,12,5,-1, 5,12,6,2,1,-1 ] color Color { color [ 0.35 0.35 0.35, 0.35 0.35 0.35 ] } colorIndex [ 0, 1 ] colorPerVertex FALSE } } ] } </pre>
--	---

Figure 3: Example of an ESP-r .geo file and its VRML equivalent.

The first step for the simulation team was to understand the basic performance characteristics of the building and the likely interactions between different areas of the restaurant and the outside.

We had to decide if the initial virtual restaurant was suitable and what assessments were required to reach a level of confidence for the simulation team as well as deliver information which might be of interest to the design team.

One traditional approach is to impress the client with

numbers and the weight of the report. But the truth is, design teams often do not digest information and soon tire of being forced to work hard to find a pattern in the phone book sized appendix that landed on their desk. They long for someone to tell them a good clear story.

Storytelling is a rare and valuable skill in the simulation community. We dress it up in terminology about connectivity and standard query language syntax but what we are looking for is a clear understanding of what is happening in the virtual representation. It

requires intuition as well as a strategy for locating patterns and opportunities. Implementing strategies for collecting data that design teams might recognize as patterns is the core goal of integrated performance views.

Firstly, different practitioners recognise patterns in different forms of reporting - some prefer statistics, some are quicker to identify frequency bins and some like graphs. Redundant forms of reporting are part of the IPV report.

Secondly, if one metric of performance is recognised, it is likely that someone would want to drill-down and find out more. For example if the room overheats:

- a) when did it overheat?;
- b) how often did it overheat?;
- c) what happened just before the overheating?;
- d) was the mean radiant temperature also notable?; and
- e) is there a design change which could reduce the radiant temperature in the space.

A seasoned practitioner could often guess at the classes of information that may be relevant and work interactively with the client to explore them singularly and in combination. These same guesses, if they could be recorded as directives within the model, might prove valuable for the regular communications in a rapidly evolving project.

Another idea of the IPV is that simulation teams who are overloaded often have short memories, they forget the data types that were an issue last week or which were discussed at the start of the project and thus do not notice that their work to make one aspect of the design work better has had an unintended consequence.

For this project, there was no budget for frequent face-to-face meetings and the client was in no mood to be buried by weighty tomes. So, Integrated Performance Views were used to encode specific performance metrics (what/where/when) into the model so that multi-format reports would be automatically produced as and when new assessments were run. The simulation staff looked for differences with prior reports as well as for new patterns in preparation for generating the executive summary as well as using the graphics generated.

Information about the performance of the restaurant and potential areas of concern needed to be passed to the client on a regular basis and if this had to be done via face-to-face meetings it would have had serious repercussions on the project budget. This project was thus a useful test of the IPV approach. Over time it was possible to identify which reporting formats were clearer for the client and fine tune the report. The variety of what-if questions also was a good test of

whether these issues could be supported by the IPV.

Initial assessments indicated that the Kitchen would have considerable overheating problems in the summer. This led to a search for alternative approaches, starting with a quantification of the consequences of incorporating HVAC in the Kitchen. The model was adapted and the demand over time for cooling as well as the peak demands and the changes in adjacent spaces was forwarded to the client. They judged the HVAC to be a costly option so the design team asked if increasing the ventilation rate for particular ranges of outside temperature would work. Again the model was adapted and the simulation team needed to find if there were unintended consequences to this less costly option.

At a later point, the design team became concerned about conditions within the dining room during peak demands such as during the Edinburgh Festival. One of the options tested was to use mechanical ventilation rather than full HVAC. This stage of the project involved an extended feedback cycle between the simulation team and the design team.

The authors noted that working practices were critical to maintaining sanity as well as model quality. Simulation tools may support rapid evolution of model details but they do not necessarily create a robust and clear audit trail. Saving a few seconds, for example, by using default names for entities rather than taking a moment to clearly name entities could easily result in models which are opaque to the design team as well as the simulation team. An IPV could be compromised if the titles of the subsections are not updated to reflect the designation of the current model variant.

As a hard copy report the IPV generally worked. What was not available at the time was to send across the IPV interface preloaded with a rich set of data so that the design team could drill down where they wanted.

In terms of re-constructing the chain of events for this paper the limitations of the tools and the completeness of model documentation are particularly apparent. Our failure to record the obvious at the time of the assessment is a risk that would be applicable to all simulation tools and all evolving design projects.

Time constraints and budgetary constraints were pushed in this project. It demonstrates both the benefits that might accrue from clarity in virtual communications of what-if questions and sets of predictions and the pitfalls.

Although few discuss it, the ad-hoc nature of design team exchanges brings with it the risk of confusion between the various design options investigated as

well as the risk that opportunities would be missed along with un-intended consequences. The enhanced communication forms discussed in this paper were able to support some of the needs of the design project. The authors also found that simulations tools generate an audit trail in order to take advantage of concepts such as Integrated Performance Views. The IPV design enforces a multi-criteria view that could reduce risk when simulation staff and design teams are under time pressures.

Figure 4 shows some typical I<sup>3</sup>PV displays that could have been used during analysis, exploration and presentation of outputs. A brief description of each interface follows:

*Project manager:* users could view all design options linked to a particular project by loading file: "ProjLoader.loader". Their basic information is stored and retrievable on the right panel. Colour coding could be used to differentiate design options, for example, in terms of excessive energy consumption or CO<sub>2</sub> emissions (with detail feedback on the bottom panel).

*Matrix comparison:* users could compare design options side-by-side, which as been proven to be a very effective manner to analyse data (with design options in columns and QA/performance entities in rows). All individual windows are fully dynamic and interactive.

*Model viewer for QA:* users could interact with the model viewer freely and enquire about problematic areas, such as, construction materials, overheating zones etc.

*Shading Analysis:* users are allowed to dynamically visualize shading over a time period for a given design option. The change rate speed could be controlled by the user. A sound file, recorded, for example, by a lighting expert, could be displayed to complement to the visual information.

## CONCLUSION

This paper presents a framework to improve the communication of building simulation support projects. Focusing on system connectivity and targeted data displays.

Based on this case study but mainly on previous studies, it has been concluded that the framework needs (but not limited) to include:

- 1) easy and effective ways to compare design options;
- 2) targeted displays to the different members of the design team (through the mechanism of display adaptation and the use of visual/acoustic rules);

- 3) real-time data connectivity across platforms and networks;
- 4) simulation tools that are able to communicate with databases;
- 5) a repository of issues to be investigated by the design team; and
- 6) a way to quickly and interactively make the link between the performance information and model composition.

## REFERENCES

- Clarke J A (2001), *Energy Simulation in Building Design (Second Edition)*, Butterworth-Heinemann, Oxford.
- Clarke J, Cockroft J, Conner S, Hand J W, Kelly N J, Moore R., O'Brien T, Strachan P (2002), *Simulation-assisted Control in Building Energy Management Systems*, *Energy and Buildings*, V34, pp933-940.
- Cortona3D Viewer, 2009, <http://www.cortona3d.com/cortona>, viewed in February 2009.
- Donn M (1999), *Quality Assurance-Simulation and The Real World*, Proc. Building Simulation'99, Kyoto, pp1139-1146.
- Donn M, Amor R and Harrison D (2001), *A design proposal for an internet based Simulation Quality Control Tool*, Rio de Janeiro, Brasil, August 13-14.
- Hand J W (2007), *The ESP-r Cookbook*. University of Strathclyde, Glasgow.
- Kim J (2004), *Integrated Information System Supporting Energy Action Planning via the Internet*, PhD Thesis, Glasgow: University of Strathclyde.
- Larson G W, Shakespeare R (1998), *Rendering with Radiance: the art and science of lighting visualisation*, Morgan Kaufmann publishers, California, USA, ISBN-1-55860-499-5.
- Papamichael K (1999), *Application of Information Technologies in Building Design Decisions*, *Building Research & Information*, V27(1), pp20-34.
- Prazeres L (2006), *An Exploratory Study about the Benefits of Targeted Data Perceptualisation Techniques and Rules in Building Simulation*, University of Strathclyde in Glasgow ESRU, PhD Thesis.
- Stravoravdis S and Marsh A (2005), *A proposed method for generating, storing and managing large amounts of modelling data using scripts and on-line databases*, 9th International IBPSA Conference, pp. 1185-90, Montreal, Canada, 15-19th August.
- Web3D Consortium (2009), <http://www.web3d.org/>, viewed in February.

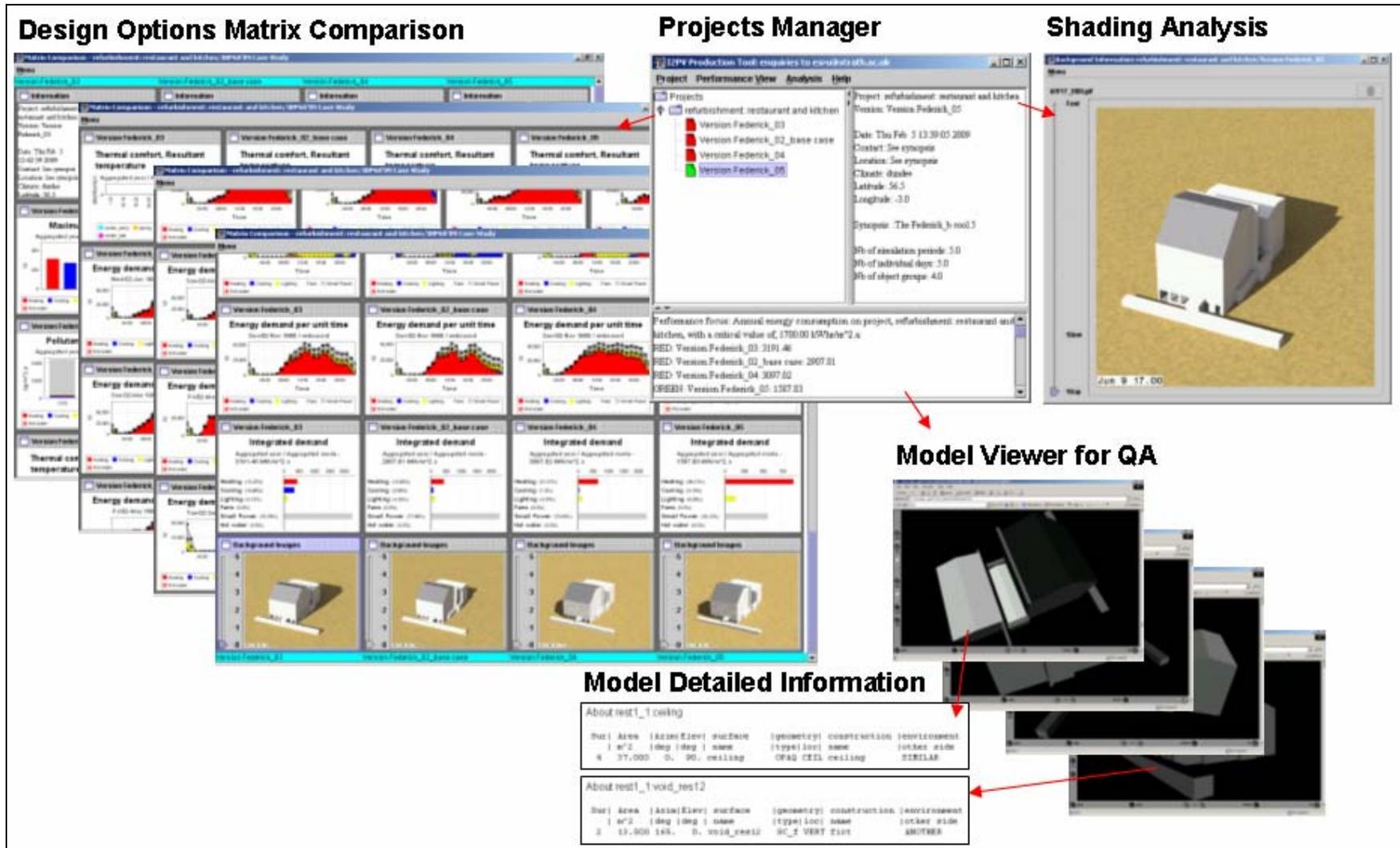


Figure 4: Typical I<sup>3</sup>PV displays (original in colour).