Building Simulation 2005

Ninth International IBPSA Conference
Montréal, Canada
August 15-18, 2005

QUALITATIVE ANALYSIS ON THE USEFULNESS OF PERCEPTUALIZATION TECHNIQUES IN COMMUNICATING BUILDING SIMULATION OUTPUTS

Prazeres L and Clarke J A
Energy Systems Research Unit, University of Strathclyde, Glasgow, Scotland
esru@strath.ac.uk

ABSTRACT

This paper complements a previous publication in the Building Simulation Conference series by identifying where perceptualization techniques can improve data presentation and assist with the interpretation of the underlying performance message. The paper describes hypotheses that were tested in practice via a performance display prototype. Intended future work is summarised.

INTRODUCTION

A copious amount of complex and time varying data are generated by contemporary building simulation programs and the translation of these data to information that may be acted upon is problematic. Although graphs are an effective way of displaying quantitative information, they are unable to support experiential appraisals whereby building performance can be fully comprehended.

This paper reports the interim findings of a PhD project (Prazeres 2005), which is addressing the interpretation of performance trends inherent in large data sets as produced by building simulation programs. In the initial stages of the project, a literature review on data perceptualization was undertaken. Based on the outcome, a Web-enabled results display and analysis tool was developed. This Interactive Integrated Performance View (I^2PV) tool supports the composition and display of multi-variate performance 'pictures' using devices that aid interpretation.

Recent work has undertaken an evaluation of this prototype in the context of actual design projects. This involved the formal observation and analysis of practitioners' interaction with the prototype using a qualitative approach based on structured interviews whereby users expressed their opinion and offered suggestions for further improvements. The evaluation involved two companies, who have recently integrated building simulation within their business – Hulley and Kirkwood Consulting Engineers and HLM Architects – and students/staff within the Energy Systems Research Unit, who have been involved in the use/development of building simulation tools.

Although the perceptualization techniques used in this study have been successfully applied in other areas, it is recognised that their effectiveness will depend on the application domain, the user types involved and the tasks being performed (Spencer 2001). This is the issue that gave rise to the present research to investigate performance in the building simulation domain.

Table 1 summarises the activities of the three organisations involved in the study, while Table 2 lists the characteristics of each focus group and the building simulation issues addressed.

METHODOLOGY

Each focus group received an introduction to the I^2PV tool's functionality prior to the interview and a real consultancy project was selected to ensure that the material used was relevant. In some cases, sample data were used.

The focus group members were requested to perform certain tasks, which followed the flow of the tool's normal usage.

The evaluation was carried out against three criteria - effectiveness, efficiency and flexibility:

1. *Effectiveness* at communicating the messages inherent in the predicted data;
2. *Efficiency* in terms of how quickly the message is conveyed; and
3. *Flexibility* in dealing with the different requirements of the members of the design team and others.

Table 1: Organisations consulted.

Hulley and Kirkwood Consulting Engineers	Established in 1953, the firm deals exclusively with the design of mechanical and electrical services in buildings. With a current staff complement of over 130 personnel, the company is one of the larger specialist M&E practices in the UK. http://www.hulley.co.uk
HLM Architects	Established in 1964, the firm cultivates a blend of commercial, technical and design expertise and applies these skills to a range of sectors such as Education, Health, Defence, Justice, Civic, Commercial and Residential. The company is much engaged in PPP/PFI contracts aiming to achieve optimally designed solutions to minimise the building's life cycle cost and impact. http://www.hlm.co.uk
Energy Systems Research Unit	Established in 1987, this university research group is concerned with new approaches to built environment energy demand reduction and the introduction of sustainable means of energy supply. The work of the team is divided between research, consultancy services, education & training, and software distribution. http://www.esru.strath.ac.uk

Table 2: Focus groups and related issues.

Focus Group A: - 3 users, advanced skills - Consultants with 10-20 years experience	- compare design options - produce quality report - present results quickly and intuitively
Focus Group B: - 3 users, medium-to-advanced skills - Consultants with 2.5-6 years of experience	- present results intuitively - provide a concise summary of results
Focus Group C: - 4 users, medium-to-advanced skills - academic researchers with 3-6 years of experience	- have flexible outputs - compare design options - have visual feedback of results - interrogate behaviour - search for patterns
Focus Group D: - 4 users, basic skills - academic researchers with 1 year of experience	- have visual feedback of results

An evaluation sheet was used to record a user's level of satisfaction for each task against a five-point scale (very dissatisfied, dissatisfied, neutral, satisfied, very satisfied).

In order to exemplify the potential benefits, each task was accompanied by mock-ups. Further, each interview was recorded to allow later analysis. Where appropriate, user recommendations were incorporated into the tool prior to subsequent interviews. Each interview took on average 2.5 hours (35 hours in total).

I^{2}PV FUNCTIONALITY

As depicted in Figure 1, data can be delivered in many formats - alphanumeric, graphic-based, sound-assisted *etc*.

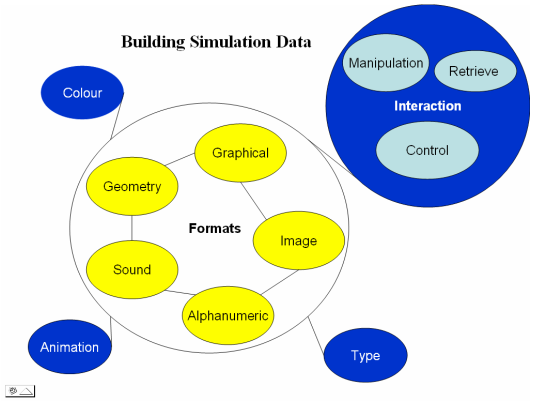

Figure 1: Data formats and attributes.

Further, each format may have assigned attributes (Prazeres 2003) such as (in order of importance) interactivity, dynamicity, colour and type. A brief description of these attributes follows.

Interactivity: this plays a crucial role in data exploration and needs-related presentation (i.e. data rearrangement). It can be divided into 3 components: data manipulation (e.g. of 3D geometry using a mouse), data retrieval (e.g. tool tips) and data control (e.g. animation speed rate).

Dynamicity: this is a crucial attribute because building simulation is inherently dynamic in nature and so special techniques are required in order to convey the temporal dimension of performance.

Colour: this attribute support analysis at a glance and the grouping of performance elements that naturally belong together. However, the attribute has accessibility implications for those with impaired vision although, according to Tufte (1990), the use of the primary colours (yellow, red and blue) and black provides maximum differentiation, which may help the colour blind. Figure 2 illustrates the use of colour to indicate which design options are passing (green), failing (red) or borderline (yellow) relative to some accepted standard.

Type: this defines the nature of the display such as a pie, bar or line chart, or an audio segment conveying speech, music, alerts *etc*.

The I^{2}PV tool derives from the Integrated Performance View (IPV) concept as embodied within the ESP-r system (Clarke 2001) whereby a standard set of performance metrics are used to represent the multi-variant behaviour of a building. IPVs corresponding to different design options may then be compared to determine in which respect one design option gives rise to performance advantages over another. An IPV might typically encapsulate disparate performance metrics:

- General information – such as project descriptors, images and contact details.
- Maximum capacity – diversified totals for heating, cooling and lighting to represent critical equipment sizes and hence capital costs.
- Thermal comfort – temporal distribution of some thermal comfort index to indicate the severity of any departure from an acceptable comfort zone.
- Visual comfort – temporal distribution of some visual comfort index to relate visual discomfort to any excess/lack of light or problematic contrasts in the field of view.
- Environmental emissions – seasonal primary energy demands converted to equivalent gaseous emissions to define environmental impact.
- Daylight availability – distribution of daylight levels to give an indication of the potential for daylight utilisation.
- Glare sources – potential glare sources are highlighted and quantified within a synthetic colour picture.
- Primary energy consumption – patterns of primary energy demand, by fuel type, expressed as cumulative profiles for typical seasons.
- Energy performance indicators – these comprise the building’s annual energy consumption per unit of floor area for each of the fuel use categories.

The I^{2}PV tool takes the above entities as the starting point and applies perceptualization techniques to improve communication of the inherent message. The tool works with any building simulation program because it employs a neutral file format. In use, it offers the following functionality.

A user may load an unlimited number of projects and design options (Figure 2), with information on each option retrievable as shown in Figure 3. Colour is used at this stage to differentiate design options in terms of principal performance parameters such as discomfort risk or excessive energy consumption. At any stage, the user may select a specific design option in order to view all available metrics grouped within a standard or user-defined IPV (Figure 4).

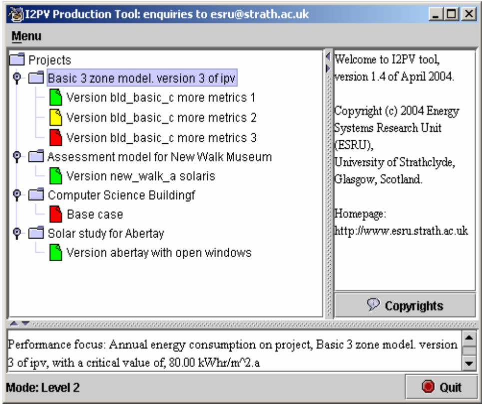

Figure 2: Colour used to indicate performance at a glance (original in colour).

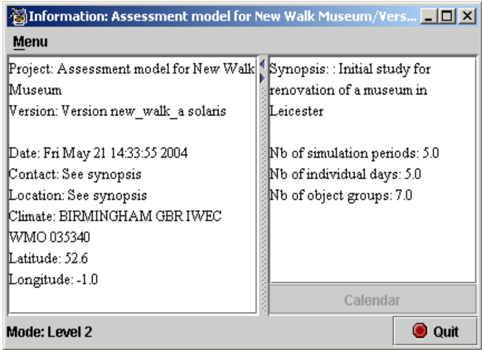

Figure 3: Design option information.

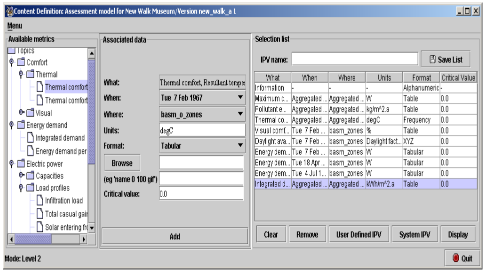
Figure 4: IPV content definition.

A user may also compare design options in one of several ways as follows.

- By simultaneously displaying: all design option corresponding to a given focus.
- By displaying an IPV for each option in different tabs. The user may then switch between tabs to identify the principal performance differences.
- By displaying a scatter diagram of energy cost versus a nominated performance parameter. Alternatively, a bubble chart can be used to include another parameter such as capital cost. In this way the overall benefit of a given approach may be assessed.

The geometry of a given design option may also be verified by direct enquiry as shown in Figures 5 and 6.

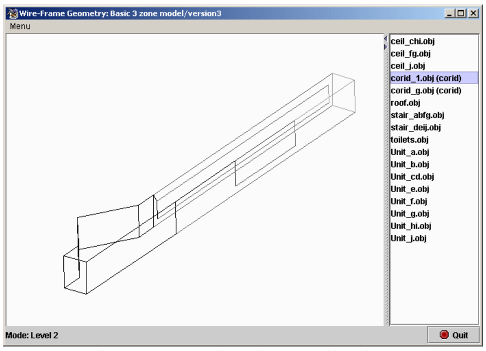

Figure 5: Wire-frame display.

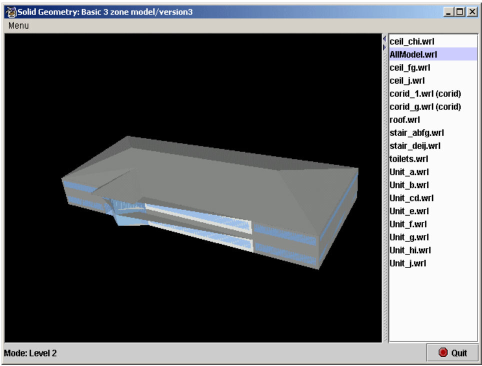

Figure 6: Solid display (original in colour).

Save As and *Print features* are available at the main and sub-display levels (e.g. whole IPVs, individual performance entities and geometry).

Figure 7 shows an output example produced by the I^{2}PV prototype. This includes interactive charts, editable alphanumeric data, looping images (movies), glare sources and CFD data. Each window is resizable, movable and iconizable, with save/print functionality available at the individual and all-window levels.

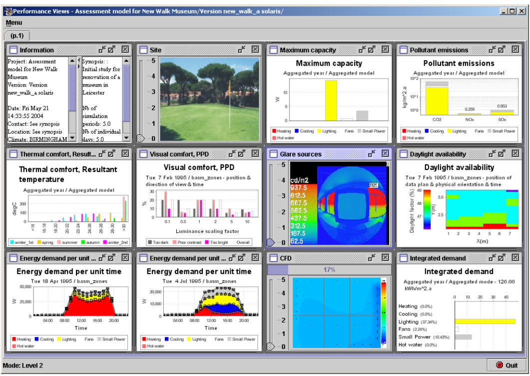

Figure 7: An IPV produced automatically by the I^{2}PV tool (original in colour).

HYPOTHESES TESTING

This section summarises the results of the focus group interviews in terms of the principal format types employed within building simulation.

In general, the consulted users were content with the ability to simultaneously display several performance metrics. For presentation purposes, the default window sizes were in some cases too small and the user was required to manually resize. To address this issue, a layout manager was proposed by 21% of users. This has now been implemented.

Tables 3, 4 and 5 detail the findings from the focus group interviews for three principal data types, alphanumeric, image and sound respectively: what follows here is a summary for all data types considered.

Graphical data

This format type is used extensively within building simulation. In summary, the findings from the focus group activities were as follows.

- Effectiveness increased when bar charts were used to compare data, line charts were used to show how two continuous variables are related, and counter plots were superimposed on a 3D representation to display spatial data.
- Effectiveness and efficiency increased when the following features were applied: clear labels, chart focus information, grid lines and element differentiation with hatching/colour.
- Flexibility was greatly improved where chart interactivity and feature toggles were supported.

Geometry data

This format type is at the core of building simulation, so delivering this data effectively, efficiently and flexibly will be highly beneficial. In summary:

- Colour used to distinguish different parts of the model increased concept appreciation.
- Flexibility increased when geometry was available in wire-frame and solid formats.
- Direct geometry manipulation was considered an essential feature by all users, as was the flexible display of zone combinations, including viewpoint accelerators.
- The ability to retrieve compositional data directly from a model was regarded by all as an important aid.

Alphanumeric data

This format type is used in a variety of situations such as within tables or to provide user help. Table 3 details the study findings related to this type. In summary:

- Text should be non-capitalised, Arial font with no underlining for ease of reading (except for hyper-links).
- 79% of users preferred time definition via a calendar.
- Data should be grouped, structured, spaced and aligned to decrease search times.
- A word search feature should be included to reduce search times.
- Hyper-links should be provided to facilitate 'drill-downs' with tool-tips activated as required to aid information retrieval.

Image data

This format type is used to convey motion and change. Table 4 details the study findings related to this type. In summary:

- Images embedded within project information and help messages are an effective guiding mechanism.
- The integration of third party software results within IPVs (e.g. the CFD data of Figure 8 as encapsulated within Figure 7) helps to place such results in context.

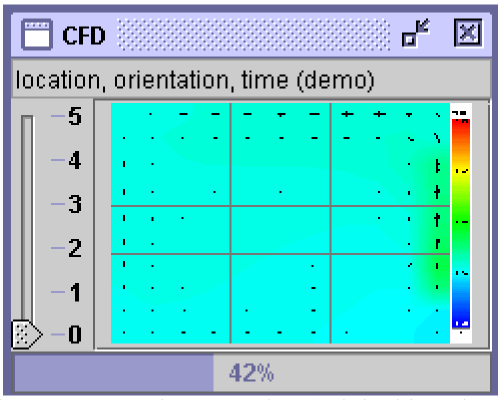

Figure 8: Importing CFD data (original in colour).

Sound data

This format type may be used to provide alarms and alerts or to reinforce issues using voice annotation. Table 5 details the study findings related to this type. In summary:

- Experiential appraisal in, for example, acoustics assessments were considered to have great potential.
- Only 57% of users were enthusiastic about sound alerts when a chart has a value above critical. A text-based warning message was the preferred way for the remaining users.
- 86% of users were happy with voice-based annotations to deliver general information.

Design option comparisons

The ability to compare design options is a crucial feature of building simulation. Where performance must be expressed in terms of several parameters, the comparison is non-trivial. The I^2PV tool supports multi-variate comparisons by automatically rating each metric against a default critical value using a three-point scale: falls below the target (0), meets the target (1) or exceeds the target (2). The overall benefit, B_d, for a given design option is then calculated from

$$B_d = \sum M_i * (I_i/100)$$

where M_i is the rating of metric i (range 0-2) and I_i the importance of metric I as assigned by the user (0-100%).

79% of users reported satisfaction with this comparison technique, with the most enthusiastic response coming from Focus Group A. The remaining users were all from Focus Group B, who claimed that the approach was too subjective to be useful. This result probably corresponds to the practical nature of novice practitioners, who require objective evidence for presentation to clients. More experience users of simulation tend to appreciate a flexible approach that combines objective (e.g. annual energy consumption per design option) and subjective (e.g. comfort levels) issues in a single rating.

43% of users stressed that the three-point rating should be applied to all design options for consistency, with the rating level values automatically suggested by the I^2PV tool in the light of building regulations and good practice values. 14% of users requested that the calculation of the overall benefit be made explicit, with the contribution of the contributing parts listed.

CONCLUSIONS AND FUTURE WORK

The study results indicate that the perceptualization needs of building simulation users can be met by superimposing results on 3D objects, allowing users to interact with the data, providing customised multi-criteria reports, and offering comparison techniques that blend objective and subjective aspects of overall performance.

Users require intuitive means to explore data, flexible means to change performance views, the ability to retrieve multi-variate performance information 'on the click of a button', and the ability to readily compare design options. The focus group users, in general, demonstrated receptiveness to future display techniques such as experiential appraisals through the use of immersive, haptic and/or acoustic techniques.

Different focus groups made different responses to the techniques. For example, the most experienced group was open to subjective analysis but less receptive to intuitive techniques, while the less experienced group preferred intuitive techniques because they imparted a better understanding of what was actually happening. Also, consultants preferred functionality that permitted rapid reporting of result summaries, while the academic user types preferred flexibility in display composition.

Future work will refine the I^2PV tool's functionality and continue to monitor its impact in practice. One intention is to support users with different technical outlooks in order to allow users to compose integrated performance views that are matched to their knowledge level. Other functionality suggested by users includes: IPV layout management; performance information retrieval associated with the direct interaction with solid geometry models; and automatic client report generation.

REFERENCES

Bertin J, 1981, *Graphics and Graphics Information Processing*, Walter de Gruyter, Berlin.

Clarke J A, 2001, *Energy Simulation in Building Design*, Butterworth-Heinemann, Oxford.

Prazeres L, 2005, *Perceptualization Techniques Applied to Building Simulation Software*, PhD Thesis, Energy Systems Research Unit, University of Strathclyde, Glasgow (to be published).

Prazeres L and Clarke J, 2003, 'Communicating building simulation outputs to users', *Proc. Building Simulation '03*, IPBSA.

Spencer R, 2001, *Information Visualization*, Addison-Wesley.

Tufte E R, 1990, *Envisioning Information*, Graphic Press, Cheshire, Connecticut.

Table 3: Focus Group results for alphanumeric format types.

Dimensions	Hypotheses	Results and Analysis
Effectiveness	The treatment of time should be via a calendar.	Users were asked questions such as: How many days has a given simulation period? Is day X inside period Y a weekend? Which week number are we simulating? 79% of users were satisfied or very satisfied with the treatment of time. The remainder were neutral claming that alphanumeric data is more concise so that a calendar is not an essential input aid.
Efficiency	Text should be in non-capital letters, Serif font and not underlined for ease of reading (except hyper-link).	The users were generally satisfied or very satisfied with the prototype although most were dissatisfied with the font, preferring an Arial font, claming that each letter seemed bigger and therefore easier to read.
	Alphanumeric data should be grouped, structured, spaced and aligned to decrease search times.	The *Content Definition* of a design option should be organised by data trees (available metrics), aligned dropped-down menus (associated data) and lists (IPV selection) – all in one window to reduce the process time. Users were asked to evaluate the window after using it to select metrics from different topics, change the analysis focus or adding to the selection list. They were also requested to explore the available functionality, such as: saving a selection list for future recovery; selecting a standard IPV; removing individual metrics *etc*. Some users commented that the data was well organised and easy to select. All users were very satisfied.
	A word search facility should be provided to decrease search times.	All users were very satisfied with this functionality since it would operate like the *Find* feature in a Text Editor. The feature was deemed relevant to a help facility and also for performance-related searches where a limited set of keywords is available.
Flexibility	Hyper-link text should be used to 'drill-down' to more detail information.	All users were very satisfied with this functionality. One user recommended that Web links to related sites would be helpful.
	Tool-tips should be provided to help information retrieval.	All users were very satisfied with this functionality. Several users mentioned that this feature could be used to provide definitions for certain technical terms (Focus Group D considered this an extremely important issue).

Table 4: Focus Group result for image format types.

Dimensions	Hypotheses	Results and Analysis
Effectiveness	Help systems should have images to guide users.	All users were very satisfied. Suggestions for improvement were: images should be area-specific and linked by arrows to associated text; image animations are required to guide the user's actions to accomplish specific tasks; and images should be linked to audio files, which further explain the functionality.
	General information delivery should be aided by images (e.g. for site and preliminary results).	All users were satisfied or very satisfied. Most users were enthusiastic about the display of animated GIFs for shading visualisations. Some improvements were recommended: thumbnail displays; synchronisation between delivery mediums e.g. text and audio); user control similar to Quick Time; image print functionality for discussions; ability to add notes related to individual images; and embedding of general information within a separate window to save space.
Flexibility	IPV integration of third party software results should be supported.	All users were satisfied or very satisfied. Users were asked to evaluate the possibility of integrating images (e.g. CFD data) from third party software. 64% of users (including all users in Focus Group B) rated integration highly, while the remainder stressed animation and display control. Users were enthusiastic about time/location looping and dynamic window resizing. Other issues raised included: interactive 3D geometry to visualise locations, and display control similar to Quick Time (given on a pop-up window or hidden away to give more room for the image).

Table 5: Focus Group results for sound format types.

Dimensions	Hypotheses	Results and Analysis
Effectiveness	Experiential appraisal for acoustics assessment should be supported.	All users were satisfied or very satisfied. Users rated highly the use of a sound file to assess the acoustic performance of a room. However, users in Focus Group B (inexperienced simulators) were concerned about the practicality of this approach because it requires a high fidelity audio system to deliver useful results. Some users noted that the feature would have different target users (e.g. numerical data for acoustic engineer and audio data for clients).
	Sound alerts should be provided to flag performance metrics above a critical value.	Users were requested to set critical values before the display of the IPV report so that predictions above this value would initiate an acoustic alert in combination with other alerts such as a background colour change or the display of a critical value line on a chart. 57% of users were satisfied with this approach. The sound provided information about the number of metrics above the critical value, while the background colour located problematic areas on the pages of the IPV report and the line gave information on the extent of the departure from the critical condition. One user commented that the use of sound is good only as a Boolean rule (YES or NO) that informs the user that at least one metric had failed (perhaps accompanied by a change in colour of the tabs containing at least one failed metric). The remaining users were dissatisfied and recommended that a message indicating the number of failed metrics should be given instead of a sound. Some users were unhappy with the need to set critical values in the content definition stage believing that they should be defined at the project level so that they may be applied to all design options. Alternatively, critical values may be derived automatically from regulations or best practice recommendations.
Efficiency	Voice annotation should be provided to aid the delivery of general information.	The users were asked to evaluate the added value of delivering general information about a project through the audio format in combination with other formats such as images or alphanumeric data. 86% of users were satisfied or very satisfied. However, 58% of these users reported that the text transcript should be available also for future reference.