

**University of Strathclyde
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Department of Mechanical Engineering**

**An Exploratory Study about the
Benefits of Targeted Data
Perceptualisation Techniques and Rules
in Building Simulation**

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**A Thesis submitted in fulfilment of the requirement
for the degree of Doctor of Philosophy**

**GLASGOW
2006**

Para Penny, Mãe e Pai, Francisco e Avó

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Abstract

A copious amount of complex and time varying data are generated by contemporary building simulation (BS) 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 PhD project addressed the interpretation of the performance trends inherent in large data sets as produced from BS.

In the initial stages of the project, a literature review of information perceptualisation techniques was undertaken. Although the perceptualisation 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. This is the issue that gave rise to the present research to investigate performance in the BS domain.

Based on the outcome, the requirements for a Web-enabled results display and analysis tool were identified. This *Interactive Integrated Performance View* (I²PV) tool supports the composition and display of multi-variate performance pictures using devices that aid interpretation.

An evaluation of the I²PV prototype in the context of actual design projects was then undertaken. This involved the formal observation and analysis of practitioners' interactions with the tool using a qualitative approach based on structured interviews following training sessions whereby users expressed their opinion and offered suggestions for tool improvements. The evaluation involved two companies who have recently incorporated BS 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 development and application of BS over an extended period.

The high level outcomes of the research can be summarised as follows.

- Effective techniques for the four stages of the BS process (i.e. exploration, analysis, presentation and reporting) were identified;
- Targeted displays that are tailored to user preferences are most effective;
- Virtual Reality displays and the use of sound have great potential in the communication of the message inherent in BS displays;
- Alternative formats (e.g. alphanumeric, images and sound) can be utilised in complementary mode; and
- The attributes interactivity, dynamicity and colour are needed for an effective display of results and the efficient support of design tasks.

The I²PV tool is discussed in the future work section where future refinements are considered, most notably the prospects for the introduction of a degree of intelligence.

Acronyms

API:	Application Program Interface
AIFF:	Audio Interchange File Format
BS:	Building Simulation
CFD:	Computational Fluid Dynamics
CSS:	Cascading Style Sheets
DTD:	Document Type Definition
ESRU:	Energy Systems Research Unit
GIF:	Graphics Interchange Format
HTML:	HyperText Markup Language
HVAC:	Heating, Ventilation and Air Conditioning
IPV:	Integrated Performance View
I ² PV:	Integrated and Interactive Performance View
I ³ PV:	Integrated, Interactive and Intelligent Performance View
JPEG/JPG:	Joint Photographic Experts Group
JRE:	Java Runtime Environment
NFRF:	Neutral File Results Format
OS:	Operative System
PDA:	Personal Digital Assistant
PNG:	Portable Network Graphics
RDB:	Relational Database
VR:	Virtual Reality
VRML:	Virtual Reality Modeling Language
XHTML:	Extensible HyperText Markup Language
XML:	Extensible Markup Language
XPath:	XML Path Language
XSL:	Extensible Stylesheet Language
XSL-FO:	XSL Formatting Objects
XSLT:	XSL Transformations
WAV:	A format for storing sound in files developed jointly by Microsoft and IBM
WF:	Wire Frame
3D:	Three Dimensional

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Chapter 1: *Introduction to Building Simulation*

Building performance became more prominent in the 70's due to the 'oil shock', which forced governments and the academic community to examine ways to reduce the energy consumption of buildings. This provided the impetus to evolve the then hand calculation techniques into powerful computer-based tools that are able to handle complex building performance assessments.

In order to provide results that are close to reality such tools are integrated and endowed with dynamic data exchange capabilities. This allows the simultaneous modelling of the heating, lighting, ventilation and acoustic domains, which are highly interrelated and interacting. By using such tools, designers are able to obtain a complete picture of the building's behaviour.

When effectively used, integrated tools can give rise to large energy savings in both new designs and refurbishments Clarke (2001):

“It is not hyperbole to suggest that the better design of new buildings would result in a 50-75% reduction in their energy consumption relative to 2000 levels, and that appropriate intervention in the existing stock would readily yield a 30% reduction.”

On top of that, improvements in indoor air quality, thermal/visual/acoustics comfort levels and environmental impacts can also be identified through the use of integrated building simulation tools.

Now, with the latest increase in computer processing power, it is possible to add new techniques — e.g. VR (Virtual Reality) — to further support the notion of emulating future reality at the design stage.

The researcher intends to address the needs of building simulation users, which require the introduction of building simulation tools in the design stage of new buildings and existing stock. This is due to the current political pressures in Europe (i.e. Energy Performance of Buildings Directive).

This chapter provides a brief description of the history of BS, the methods that allow multi-view (criteria) assessments, the present approach to the difficult task of exploring/analysing/presenting BS data, and the shortcomings in such an approach. The chapter concludes by summarising an alternative approach to data interrogation that is more effective, efficient and flexible.

1.1 Evolution of BS

According to Clarke (2001), BS has evolved through four generations to reach their present state:

- The first generation was based on simplified (often steady-state) calculation techniques with only weak coupling evident between the calculation steps. The intention was not to obtain results that were close to reality but to provide a crude performance indicator. Therefore, the first generation techniques were easy to use, they were difficult to apply due to their inaccuracy and weak match with reality.
- Second generation tools were developed in the mid-70's with the emphasis on dynamic fabric response. However, many of the underlying methods for modelling air flow, radiation exchange, *etc.* remained the same as in the first generation.
- Due to the advent of more powerful workstations, third generation tools began to emerge in the mid-80's. Now space and time were made discrete and formal conservation methods applied and implemented using numerical

techniques. This marked the beginning of the integrated modelling era where thermal, visual and acoustics performance could be considered together.

- The fourth generation emerged around mid-90's whereby the integrated domain approach continued to evolve while attention was focus on user interfaces.

The characteristics and consequences of each design tool generation are summarised in Table 1.1.

Table 1.1: Evolution of design tools (from Clarke, 2001).

Generation	Characteristics	Consequences
1	<ul style="list-style-type: none"> ▪ handbook oriented ▪ simplified and piecemeal ▪ familiar to practitioners 	Easy to use, difficult to translate to real world, non-integrative, application limited, deficiencies hidden
2	<ul style="list-style-type: none"> ▪ building dynamics stressed ▪ less simplified, still piecemeal ▪ based on standard theories 	↓ ↓ ↓
3	<ul style="list-style-type: none"> ▪ field problem approach ▪ shift to numerical methods ▪ integrated modelling stressed ▪ graphical user interface ▪ partial interoperability enabled 	Increase integrity vis-à-vis the real world ↓ ↓ ↓
4 and beyond	<ul style="list-style-type: none"> ▪ good match with reality ▪ intelligent knowledge-based ▪ fully integrated ▪ network compatible / interoperable 	Deficiencies overt, easy to use and interpret, predictive and multi-variate, ubiquitous and accessible

Up to this point, users had effectively adhered to a *tool-box* metaphor (Figure 1.1) whereby the user had to recognise a particular task, identify a matched tool, apply this tool, and translate outputs to appropriate design hypothesis modifications. This is now considered an inadequate approach because the tool is effectively decoupled from the process and requires the designer to translate between different data models.

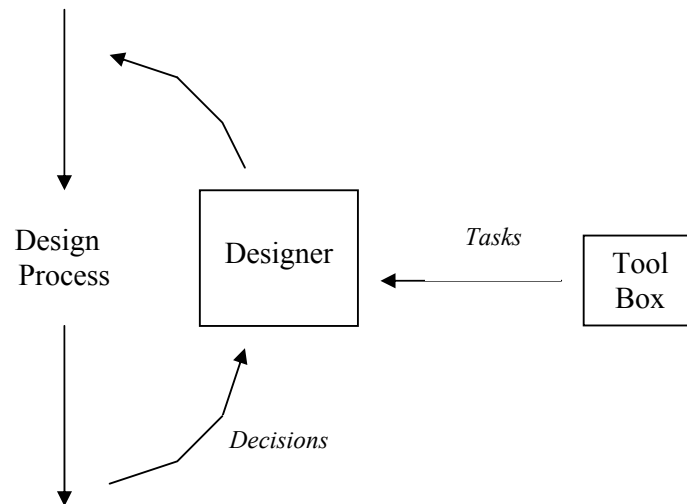


Figure 1.1: Tool-box approach.
(from MacCallum, 1993 as referenced in Clarke, 2001)

A better approach is shown in Figure 1.2, which depicts a computer-supported design environment (CSDE). Here, the designer evolves the design hypothesis in such a way that the computer applications are able to automatically access the data describing the design and give feedback on all aspects of performance and cost in terms meaningful to the designer.

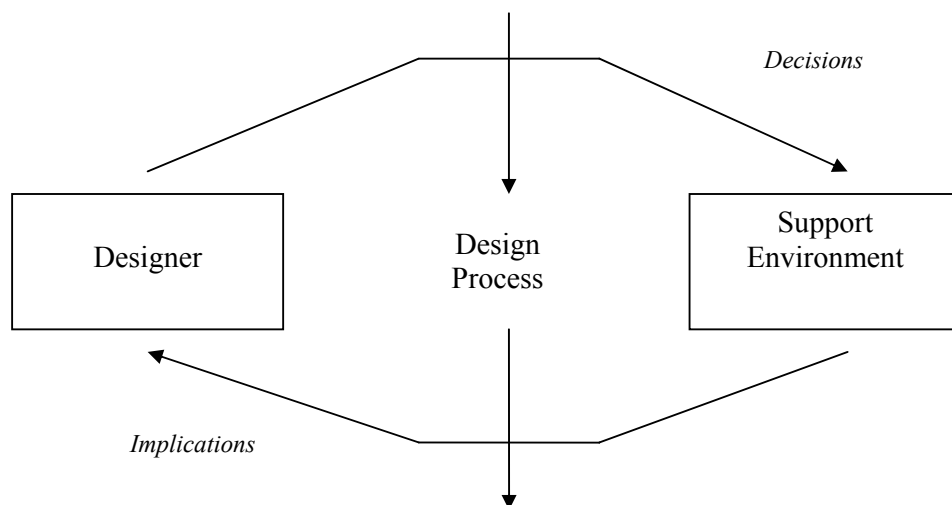


Figure 1.2: CSDE approach.
(from Clarke, 2001)

The attainment of such a CSDE is a non-trivial task requiring the development of a computational process in which the role of each participant, human and otherwise, is clearly defined.

Attaining a multi-view building performance assessment by applying different simulation programs will result in increased complexity in terms of simulation times, results complexity and the requirement that users have knowledge of the different possible domains. This issue is addressed in the next section.

1.2 BS Methods

Simulations to produce multi-view assessments may be achieved by the application of different methods: stand-alone, interoperable, run-time coupling and integrated. A brief description of each method, as reported by Citherlet (2001), is provided in the following sub-sections.

1.2.1 Stand-alone

This is the most basic approach to produce an integrated performance view. The applications used are entirely unrelated and therefore different input models must be created for each one. The schema of Figure 1.3 describes what happens during the simulation process.

This method is time consuming because of the decoupling, for example geometry changes in one application must be reimplemented in the others to maintain consistency and compatibility. Such repeated modifications also increase the probability of user error because of the inevitable differences between data models and user interfaces.

With regards to the exploration, analysis and presentation of simulation data, this method renders the process unwieldy and complicated because there are multiple result sets to be processed, analysed and integrated.

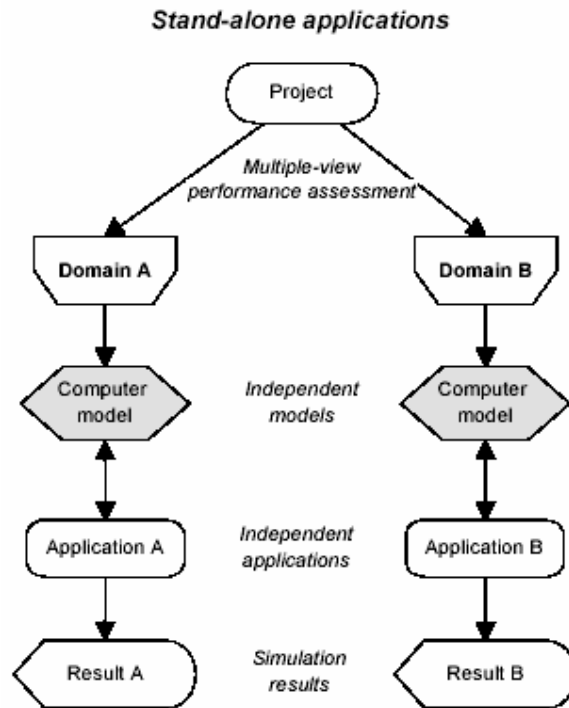


Figure 1.3: Stand-alone method.
(from Citherlet, 2001)

1.2.2 Interoperable

In this approach, the building model is shared between applications although different interfaces are still used for each application. The main problem with this method is that dynamic data exchange during simulation is not possible; the user must invoke other applications in order to exchange the data model between applications. The method may be further sub-divided as follows.

1.2.2.1 Exchange of Building Model

Here, two or more stand-alone applications may exchange the building model using a neutral file format. The schema in Figure 1.4 describes the process.

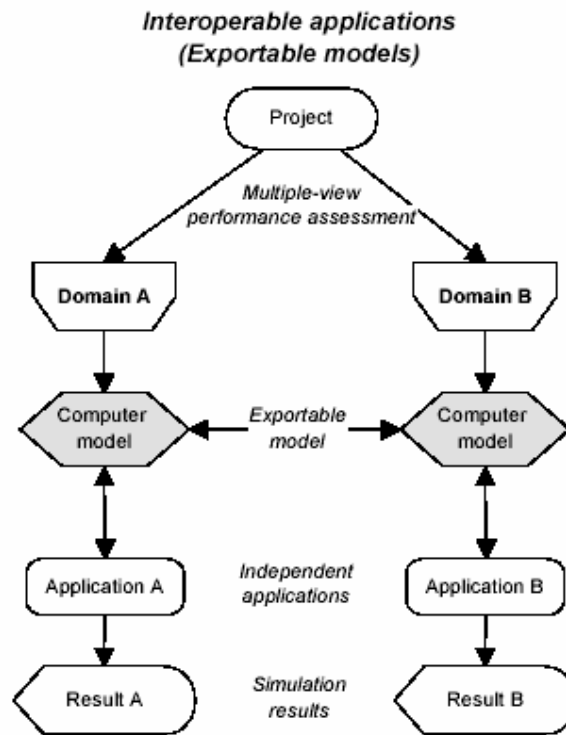


Figure 1.4: Interoperable method with exportable model.
(from Citherlet, 2001)

The main advantage of this sub-method is its greater efficiency and lesser required information to create the building model. However, because each application has a unique building model, multiple and separate models must be updated when the project changes.

1.2.2.2 Sharing of Building Model

Here, a single building model exists, which is shared by all applications and managed centrally by a data management system. The schema in Figure 1.5 describes the process.

This approach draws its advantage from the existence of a central information coordination and maintenance point for all applications data. However, to manage concurrent access to the same data source is a non-trivial task.

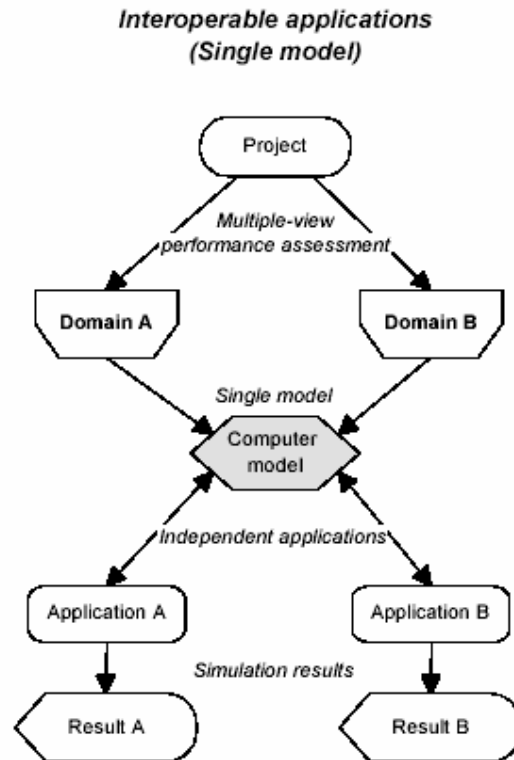


Figure 1.5: Interoperable method with model sharing.
(from Citherlet, 2001)

According to Bazjanak *et al* (1997), data sharing is crucial within a multi-view building performance assessment platform and will account for up to 80% of the required resource. Bazjanak also states that the cost of an interoperable method is six times less than the stand-alone method. The main advantage of the interoperable method is time saving due to the sharing of data across applications. Some of the well known simulators based on the interoperable method are BDA (Papamichael *et al*, 1997), COMBINE (Augenbroe, 1994) and IES-VE (IES, 2005).

While the interoperable method avoids data redundancy, it does not entirely prevent inconsistency and still requires a complex data management system. Further, and as with the stand-alone method, the user must master multiple user interfaces. The approach does not usually support the dynamic exchange of data between applications during a simulation. However, this weakness could be overcome by a sequential data exchange where the output of one application is the input of another

— an example is the lighting simulator ADELIN (Erhorn *et al*, 1998), which generates an illuminance output file for use by energy simulators such as DOE-2 (Winkelmann *et al*, 1993) or TRNSYS (Beckman *et al*, 1994). When close-to-reality results are required, or where performance views are closely linked, the sequential data exchange approach might be difficult to implement and therefore more powerful methods are required.

In regards to the exploration, analysis and presentation of simulation data, and when compared to the stand-alone method, this method makes the process less complicated, because the computer model is held in a central location. However, the user is still required to gather results from the different applications and then integrate these in order to obtain a multi-view performance assessment.

The following two methods provide a solution by which the required user interaction is held to a minimum.

1.2.3 Run-time coupling

This method allows automatic data exchange during run-time. The schema of Figure 1.6 describes the process.

Usually, there is a dominant application, which drives the simulation. When this application requires information from another application, it issues a request and the second application is automatically started. Janak (1998) has presented an example of this method in which an energy program, ESP-r (Clarke, 1997), operates co-operatively with a lighting program, Radiance (Larson, 1993).

The advantage of this method is the automatic exchange of data during the simulation process. However, a drawback still persists: the maintenance of data consistency in the context of the separate evolution of applications.

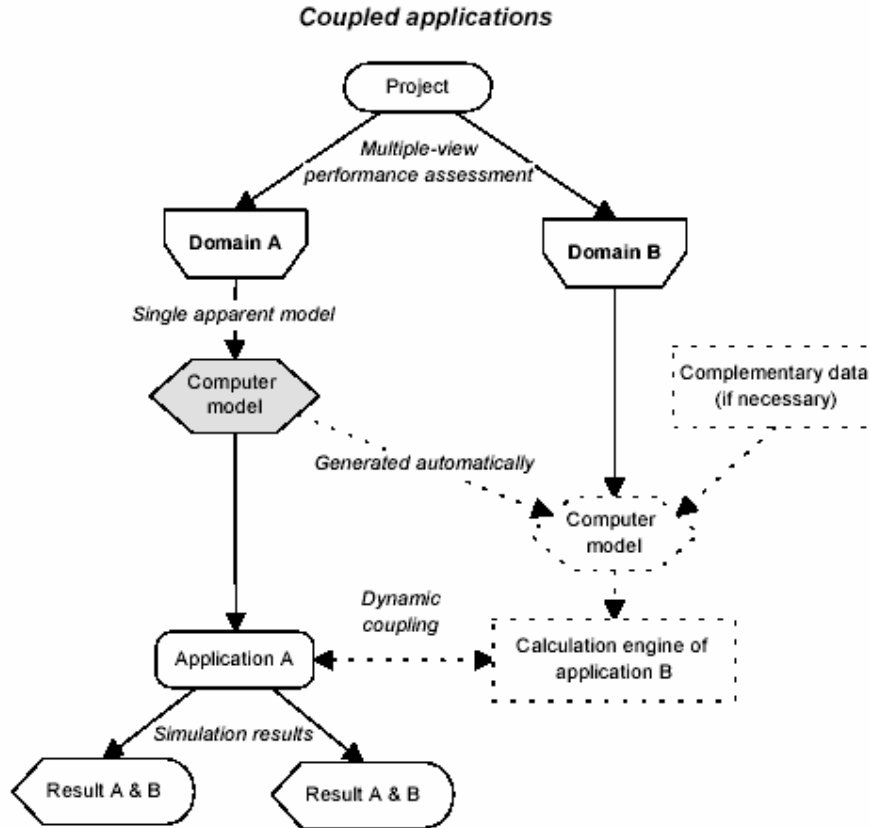


Figure 1.6: Run-time coupling method.
(from Citherlet, 2001)

In regards to the exploration, analysis and presentation of simulation data, this method is attractive because the data model is held in a central location while the output data comes solely from the main application. This avoids the user from having to manually integrate results in order to obtain a multi-view performance assessment.

1.2.4 Integrated method

As the phrase indicates, the integrated method brings together the different applications as shown in the schema of Figure 1.7.

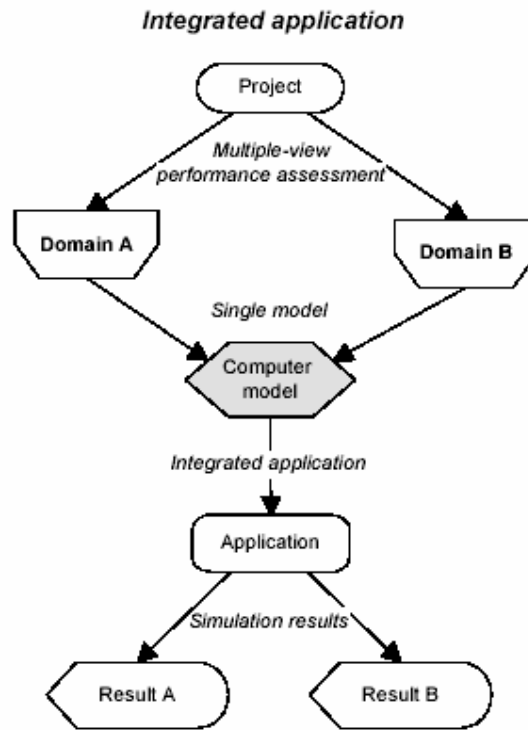


Figure 1.7: Integrated method.
(from Citherlet, 2001)

The integrated method, like its run-time coupling counterpart, benefits from automatic data exchange during the simulation process with the purpose of solving a set of combined equations that represent the simultaneously occurring physical phenomena. Clarke (1999) has provided a description of the integrated method:

“The aim of an integrated approach is to preserve the integrity of the entire building system by simultaneously processing all energy transport paths to a level of detail commensurate with the objectives of the problem to hand”.

In order to achieve the integrated approach, the distinct applications are merged at the algorithm level, thus creating a single, integrated application. An example is EnergyPlus (Crawley *et al*, 1999), where the energy calculations come from DOE-2 (Winkelmann *et al*, 1993) and the ventilation calculation from BLAST (Bauman *et al*, 1983).

The main advantage of this method is that the building model data is better managed because the evolution of the application does not depend on external simulation engines. The remaining drawback is that the user still needs to understand the different technical domains.

In regards to the exploration, analysis and presentation of simulation data, there is no additional improvement because the data model is also held in one central location and the output data comes solely from one application.

1.2.5 Summary

Table 1.2 summarises the simulation approached as described above.

Table 1.2: Comparison of approaches to multi-view performance assessment (from Citherlet, 2001).

Approach	Advantages	Disadvantages
Stand-alone	<ul style="list-style-type: none"> ▪ problem specific application 	<ul style="list-style-type: none"> ▪ several data models ▪ several user interfaces ▪ no dynamic data exchange
Interoperable	<ul style="list-style-type: none"> ▪ single data model ▪ model consistency 	<ul style="list-style-type: none"> ▪ several user interfaces ▪ no dynamic data exchange ▪ transaction management ▪ complete model if missing data
Run-time coupling	<ul style="list-style-type: none"> ▪ single data model ▪ model consistency ▪ single user interface ▪ dynamic data exchange ▪ physical model 	<ul style="list-style-type: none"> ▪ maintenance of link consistency
Integrated	<ul style="list-style-type: none"> ▪ single data model ▪ single user interface ▪ dynamic data exchange ▪ model consistency ▪ application maintenance 	<ul style="list-style-type: none"> ▪ require knowledge of various domains

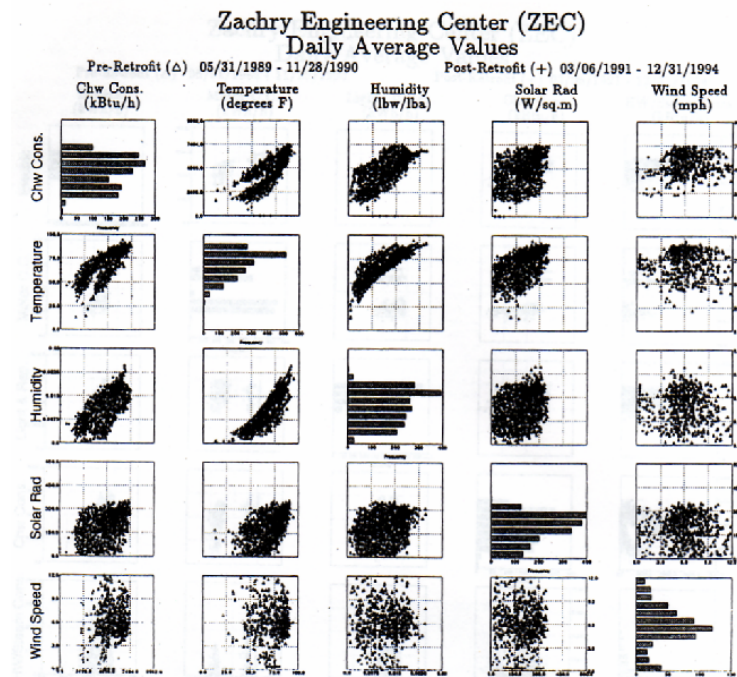
Both the run-time coupled and integrated methods support the dynamic exchange of data in support of a multi-view building performance assessment. However, neither guarantee an effective, efficient and flexible exploration, analysis and presentation of BS data. The next section elaborates this issue.

1.3 Current Applications / Studies

Few studies have examined the problematic issue of communicating integrated BS results effectively, efficiently and flexibly to users with different conceptual backgrounds such as designers, energy managers and policy makers. The predicament such users find themselves in is that while simulation can generate vast quantities of highly useful performance information, these data are time varying and inter-related in a complex way making interpretation problematic. Some approaches to the resolution of this dilemma are considered in the following sections.

1.3.1 Graphical indices

A study by Haberl *et al* (1998) demonstrated that graphical displays can help a user to efficiently analyse hourly performance data, check for errors and establish trends over an extended time period (Figure 1.8).



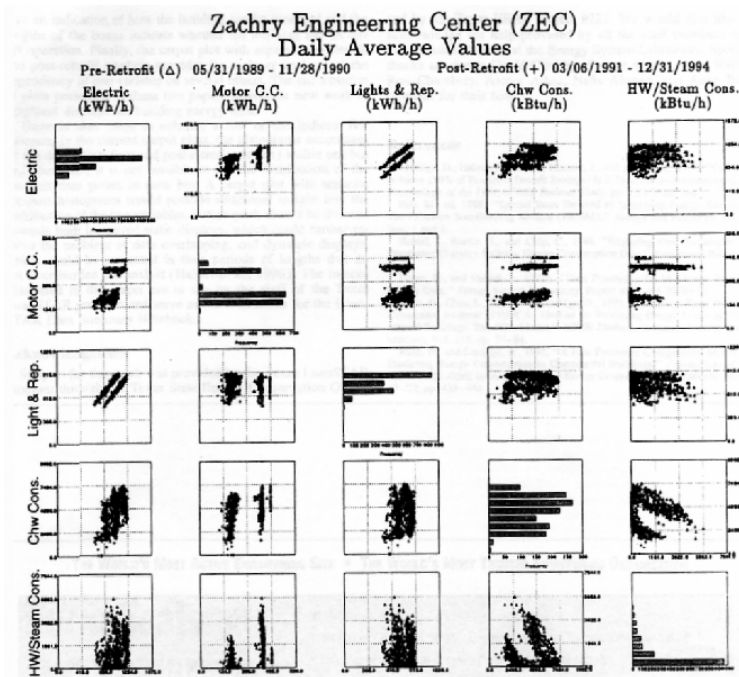


Figure 1.8: Carpet plot matrix for chilled water consumption, weather variables and energy consumption.
 (from Haberl, 1998)

The approach is informative, visually efficient and easy to comprehend: the matrices of Figure 1.8 support the display of approximately 25,000 data points, which corresponds to several years of hourly data.

The key lesson to be taken from Haberl's research is the way that the data is delivered. Essentially, the matrix, form of presentation is:

- an effective way to organise data (rows and columns);
- can accommodate large data volumes; and
- supports ready data comparison.

However, effective exploration, analysis and presentation of BS data can be further improved as discussed in the next section.

1.3.2 The Building Design Adviser application

Within the BDA system, Papamichael *et al* (1997) have created a Building Browser concept to allow designers to navigate through the multitude of descriptive and performance parameters addressed by the analysis and visualisation tools linked to BDA (Figure 1.9).

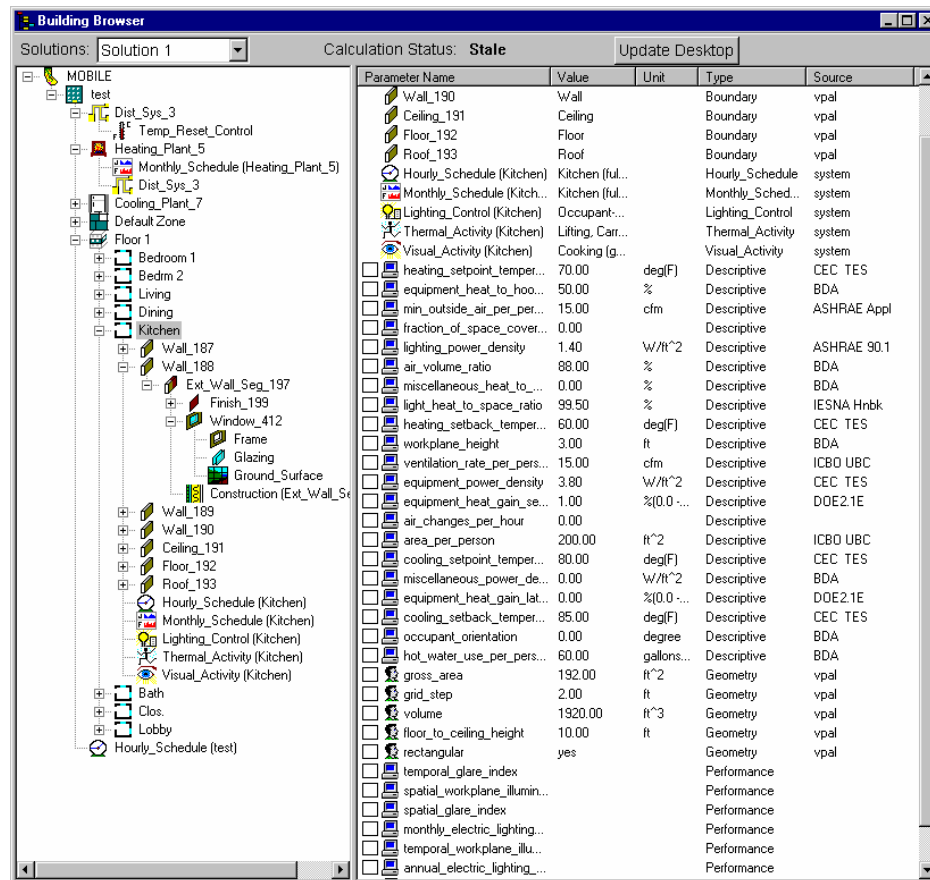


Figure 1.9: BDA's Building Browser.
(from BDA, 2004)

In addition, BDA has a Decision Desktop concept, which allows the user to compare multiple alternative design solutions with respect to multiple criteria considerations, as addressed by the analysis and visualisation tools and databases linked to the BDA (Figure 1.10).

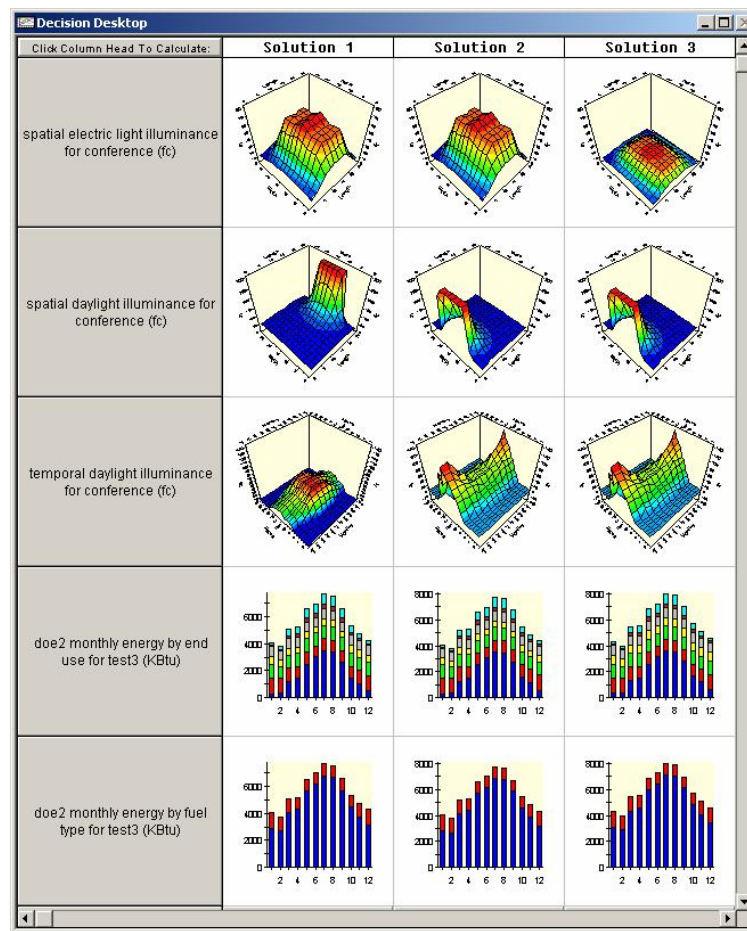


Figure 1.10: BDA - Decision Desktop.
(from BDA, 2004)

The Decision Desktop supports a large variety of data types, including 2D and 3D distributions, images, sound and video, each of which may be displayed and edited in a separate windows.

Once again the matrix approach is used, but here in a more advanced manner with the use of multimedia and user interactivity. In addition, a data-tree is employed, which is able to organise group-related data (e.g. surfaces that belong to a zone or properties that belong to a surface).

However, effective exploration, analysis and presentation of BS data can be further improved as discussed in the next section.

1.3.3 ECOTECH application

ECOTECH (Marsh, 2005) has a unique approach to conceptual building design. It couples an intuitive 3D interface with a comprehensive set of performance analysis functions and interactive information displays. Wherever possible, calculations are performed instantaneously and are therefore fully interactive.

For example, shadow analysis within ECOTECH is both quick and easy to use. As well as external shadows, internal sun patches may be generated within any space throughout the year (Figure 1.11).

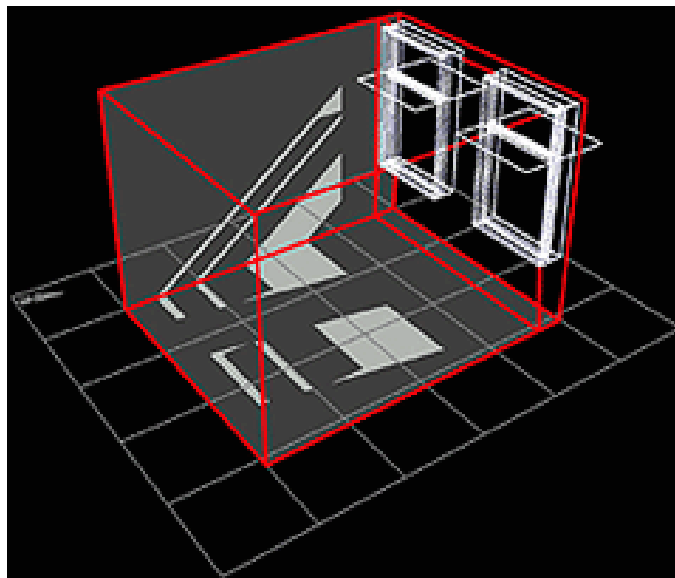


Figure 1.11: An ECOTECH sun penetration.
(from Marsh, 2005)

ECOTECH allows the user to analyse both natural and artificial lighting levels in any space within the building. Results may be visualised on a flat plane (Figure 1.12) or relative to a 3D grid (Figure 1.13).

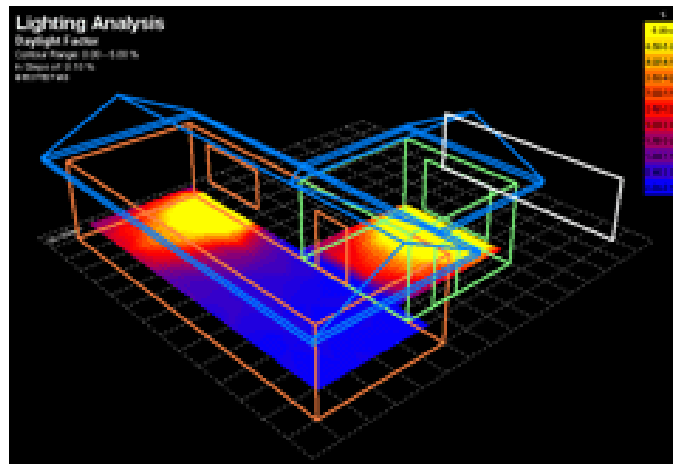


Figure 1.12: ECOTECH daylight factors.
(from Marsh, 2005)

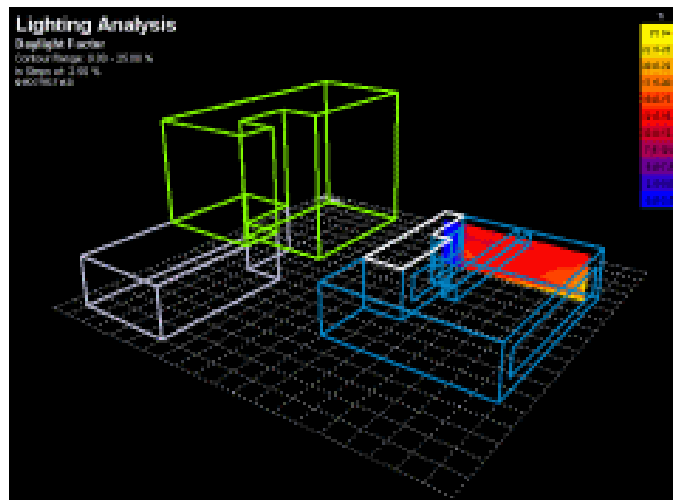


Figure 1.13: ECOTECH spatial animation.
(from Marsh, 2005)

ECOTECH uses both ray spraying (Figure 1.14) and ‘sound particle’ animation (Figure 1.15) techniques with colour and transparency to demonstrate how sound moves and decays within a space.

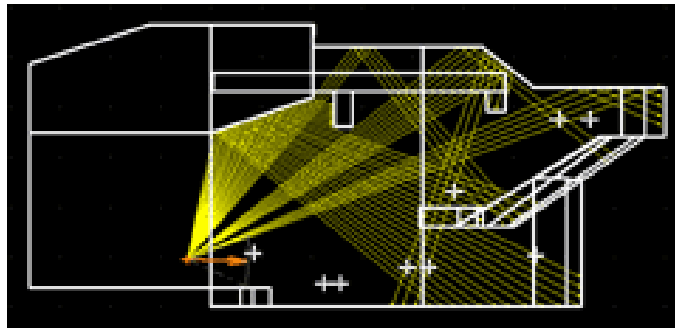


Figure 1.14: ECOTECT sprayed acoustic rays.
(from Marsh, 2005)

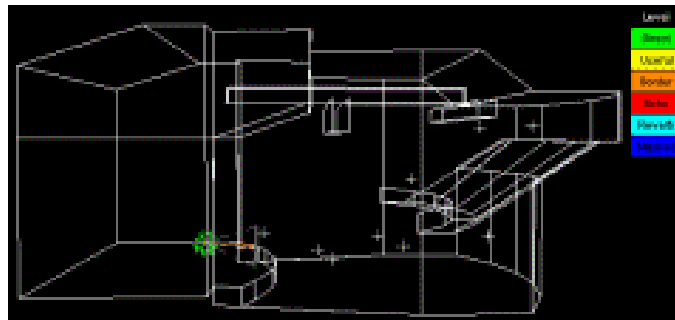


Figure 1.15: ECOTECT animated sound particles.
(from Marsh, 2005)

In the researcher's view, the main lessons from ECOTECT are the intuitive interactivity in the displays, which enhances user ability to understand the message inherent in the performance data.

1.4 Current application shortcomings

While the applications described above are a step in the right direction, they share common deficiencies in that they lack one or more of the following attributes.

- Support for exploration of performance data in a fully intuitive and interactive manner — this includes the linkage of the building model to the performance data.
- Support for analysis of performance data through techniques that allow comparison of all design options at a glance.
- Support for the digital and hardcopy presentation of performance data in an organised, structured and grouped manner.

- Support for targeted displays that depend on the user's technical/experience level (or background) and are, therefore, independent of the developer's perception of what is required.

The next section describes a proposed solution to these shortcomings.

1.5 Proposed Solution

A study by Clarke *et al* (1996, 1997) proposed the concept of an Integrated Performance View (IPV), whereby, a range of relevant performance indicators may be collated to represent the multi-variant performance of a building (Figure 1.16).

A standard IPV will typically cover several performance indicators: maximum power capacity, annual energy consumption, predicted percentage of dissatisfied (thermal comfort), daylight factor profile, visual comfort index and emission of pollutants (related to energy consumption). Citherlet (2001) extended the above performance metrics with acoustic reverberation time and emission of pollutants (related to construction material manufacture). A further development of the IPV concept is represented by the HLM-ESP system (Morbiter, 2003), which customised the IPV to the specific needs of a particular architecture firm and automated the IPV generation.

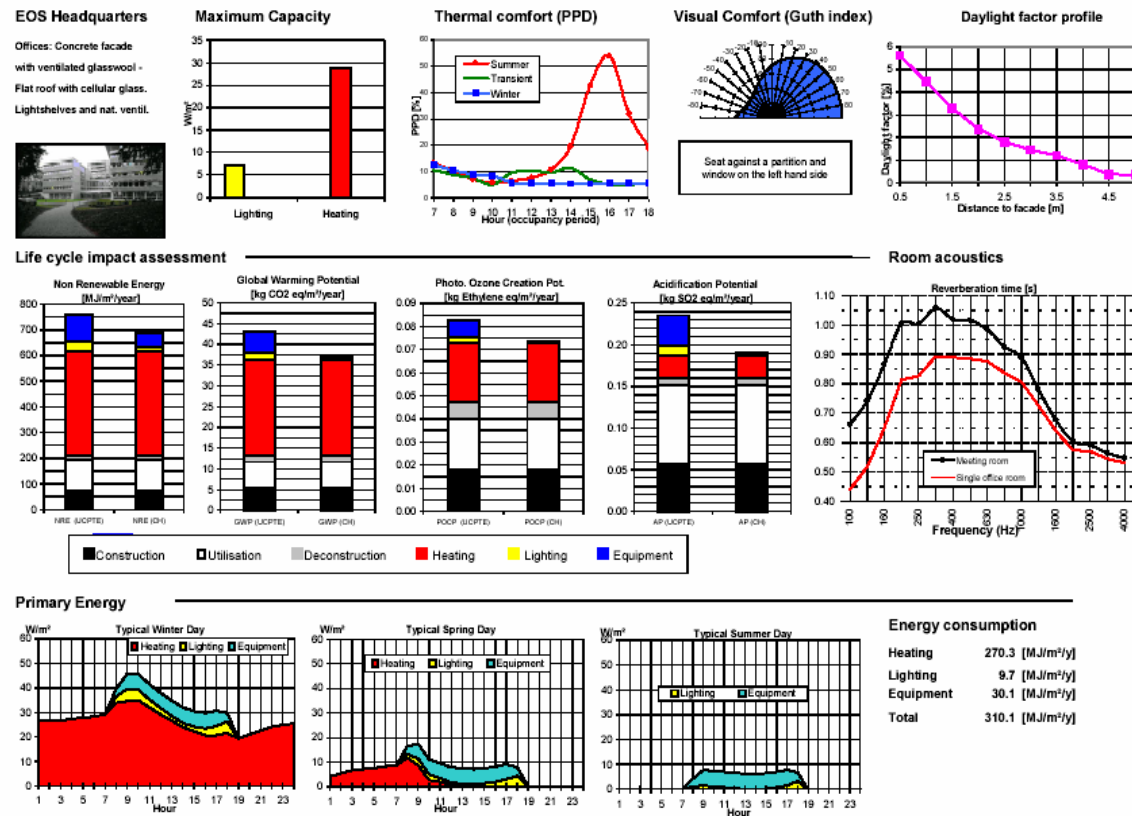


Figure 1.16: An integrated performance view.
(from Citherlet, 2001)

The concept of presenting BS data in a compact way is effective because it provides a clear picture of the building's behaviour at a glance. An IPV can also be included in a client report or used as a platform for client/design team discussions.

This PhD project accepted the IPV concept as its starting point and then deepened the approach by adding perceptualisation techniques and cognition rules. The work required research into:

- the effect of interactive techniques when exploring BS information;
- techniques for the analysis of BS information;
- techniques to organise, structure and group BS information (i.e. support internal presentation and external reporting); and
- the benefits of targeted displays in addressing the needs of the different user types.

1.6 Summary

This chapter described the evolution of BS, the methods used to produce multi-view performance assessments, some current studies that are attempting to solve the problem of dealing with large amounts of complex BS information, and proposed the solution that underpins the present work. This solution suggested is based upon the IPV concept with the addition of perceptualisation techniques to increase the effectiveness and flexibility of results interrogation while also decreasing the time and effort required to undertake the task.

The next chapter covers the results from a literature review of cognition and data perceptualisation techniques that could be applied to the BS field.

Chapter 2: *Information Perceptualisation Techniques and Rules*

Raw data is meaningless and therefore useless. The problem is compounded with building simulation which produces large output datasets in most applications. The analysis of such data, in order to comprehend the inherent behaviour and thereby make informed design decisions, is entirely non-trivial. Users typically approach the task by displaying the data in a way that supports message perception – in effect transforming data into information.

Data may be displayed in a variety of ways, for example, by the use of visual, audio, haptic or smell techniques. Various devices may then be adopted within each technique, for example:

- Vision: via a photorealistic image, a line or bar chart or even a paragraph of text;
- Audio: via the selection of a pre-recorded human voice, the raising of an audible alarm or alert or by the generation of an experiential fragment that embodies the virtual reality;
- Haptic: via a virtual reality environment that mimics a predicted level of thermal comfort or air movement; and
- Smell: via a standalone device that mimics the odour/smoke level in a space.

Furthermore, colour may be introduced to aid perception by differentiating alternative solutions or highlighting problematic results. Multimedia techniques may also be used to this end by, for example, combining animation, graphics, text and so on and presenting the user with a fully interactive interface that supports model manipulation and interrogation. By applying different attribute combinations (colour, animation, interactivity, *etc.*), the effectiveness of the display can be maintained across the different user types (i.e. users with different technical capabilities and level of domain knowledge).

In summary, there are no exact rules or guidelines for information display. The only way to establish a best practice is to test perceptualisation technique combinations as applied in other fields (medical, financial, *etc.*) in order to verify their effectiveness in the building simulation domain. Also, because effectiveness varies with user preference, a qualitative analysis is carried out to allow insight into the underlying reasons.

This chapter reports on a literature review into information perceptualisation techniques and rules as developed in the cognition sciences. It begins with an overview of the human senses – with the emphasis on primary senses – followed by a review of techniques for information visualisation, sonification, haptisation, odourisation and VR where all senses can be combined effectively (immersed mode).

2.1 Human Senses

Vision is the dominant sense modality of human perception. There are three senses that respond to stimuli at a distance: vision, hearing and smell (Gleitman *et al.*, 2000).

2.1.1 Vision

The stimulus is light of different intensities and wavelengths. The amount of light entering the eye is controlled by the iris and lens, which provide a proper proximal stimulus resulting in the retinal image. The visual receptors, the rods and cones, then create a neural impulse, the impulse being greatest in the fovea where the conal density is highest.

The duplex theory of vision states that the different receptors have different functions. The rods are active at low light intensities (colourless sensations) while the cones are active at high illumination levels (colour sensations).

Visual sensations vary with colour, which may be divided into three dimensions: hue, brightness and saturation. Harris (1999) defines these as follow:

- *Hue*: name of the colour, such as, red, yellow, blue, green, violet, *etc.*;
- *Brightness*: describes how light or dark a colour is (sometimes separated into shade (or darkness), which is the result of adding black to the basic colour, and tint, which is the result of adding white to the basic colour); and
- *Saturation (or Chroma)*: the vividness (or intensity) of the colour (higher saturation indicates a brighter or more vivid colour, and lower saturation indicates a duller colour).

In humans, movements of the eyes provide the major means of orientating. Peripheral vision informs that something is going on, say, in the upper-left section of our field of vision. But, our peripheral acuity is not enough to determine what it is precisely. To find out, the eyes move so that the region in which the activity is taking place falls into the fovea. In fact, motion in the visual periphery tends to trigger a reflex eye movement, making it difficult not to look towards a moving object.

Other factors influence eye movement. One of them is of interest here. In general, the eyes are directed towards regions that are visually informative, although the gaze pattern is different for different observers. This is not surprising, since what interests one person may not interest another. Even for a single individual, interests change from occasion to occasion.

Research has shown that the act of looking is purposeful. People do not scan the world in the hope that their foveas will hit on some interesting bit of visual news. They pick up some information from what they have vaguely seen in the periphery and also from their notions of what the scene is all about. They then move their eyes to check what they have seen and refine their visual knowledge (Yarbus, 1967; Rayner, 1978; Stark and Ellis, 1981).

In the context of BS data display, colour is a key parameter. The three dimensions (hue, brightness and saturation) can be applied to increase effectiveness. For example:

- in Visual Comfort by matching the colour of a bar graph element to its label (*Too dark*, *Poor contrast* and *Too bright*); and
- in a wire-frame 3D model by assisting depth perception by changing the colour from black to grey on the lines that are further away.

Within the IPV concept, because huge amounts of performance information might be simultaneously displayed, important information should take advantage of the automatic human eye trigger with motion. For example:

- by playing site / background results images in a loop;
- by displaying dynamically a time based performance metric; and
- by simply flashing a metric or element.

The idea that too much information could be confusing has its obvious base of truth. The remedy is to support cognition by facilitating the rapid scanning of multi-variate performance data and the ready redefinition of the focus of enquiry. By simply limiting the displayed information to what the user thinks is needed will only limit the delivery of an accurate performance picture.

2.1.2 Hearing

The sense of hearing, or audition, is a response to pressure variations in the air, from the source outwards. When the sound waves reach the ear, they trigger auditory receptors.

Sound waves have physical dimensions of amplitude and frequency, which correspond to the psychological dimensions of loudness and pitch. Therefore, a sound is louder if the amplitude increases and has higher pitch if the frequency increases.

Intensity is usually measured in decibels on a logarithmic scale to avoid the huge range. Psychologically, perceived loudness doubles when the intensity increases by 10 decibels (Stevens, 1955). Table 2.1 gives examples of common sounds at different intensity levels.

Table 2.1: Intensity levels of common sounds (from Gleitman *et al.*, 2000).

Sound	Intensity level (decibels)
Manned spacecraft launching (from 150 feet)	180
Loudest rock band on record	160
Pain threshold (approximate)	140
Loud thunder; average rock band	120
Shouting	100
Noisy automobile	80
Normal conversation	60
Quite office	40
Whisper	20
Rustling of leaves	10
Threshold of hearing	0

The frequency of a sound wave is measured in cycles per second, or hertz. Humans can hear tones as low as 20 hertz and as high as 20,000 hertz, with maximum sensitivity in between. Table 2.2 gives examples of musical tones of different intensity levels.

Table 2.2: Sound frequencies of some musical tones (from Gleitman *et al.*, 2000).

Sound	Frequency (hertz)
Top note of grand piano	4214
Top note of piccolo	3951
Top range of soprano voice	1152
Top range of alto voice	640
Middle C	256
Bottom range of baritone voice	96
Bottom range of bass voice	80
Bottom note of contra bassoon	29
Bottom note of grand piano	27
Bottom note of organ*	16
*Can be felt but not heard	

As people age, their sound sensitivity declines, especially at higher frequencies.

In the context of BS displays, loudness and pitch can be used to cause different alerts. For example:

- values above a critical value set by the user could have different amplitudes depending on the severity of departure; and
- dangerous levels could be assigned different frequencies depending on to the level of criticality.

Different types of sound could also be selected to indicate the nature of the alert or the advisable action that might be taken.

Experiential acoustic assessments may also involve the playing of real sound excerpts corresponding to actual indoor environments when subjected to different noise sources. While such an approach may seem like science fiction due to the requirement for powerful sound equipment, the potential is growing with the advent of mobile, portable digital technology (i.e. MP3 players, iPod players, mobiles or PDAs).

2.1.3 Haptic

Haptic relates to the sense of touch caused by force on the body. The combination of tactile and kinesthesia is the haptic perception (e.g. perception of object solidity, texture, vibration, inertia, weight, elasticity, viscosity, *etc.*).

The term comes from the Greek and means to grasp. Real world tasks performed by the hands usually involve exploring and manipulating objects. Haptics differs from other sensory modalities in that it intrinsically requires both input and output (Salsibury and Srinivasan, 1997).

According to Durlach and Mavor (1995), haptic tasks can be divided into two main groups, exploration tasks, which are primarily sensory oriented (output), and manipulation tasks, which are primarily motor driven (input). To investigate an object's properties typically requires a combination of exploration and manipulation skills (Nesbitt, 2003). The individual perceptions – skin and kinesthesia – are described below:

Skin Senses: In humans, skin sense is more acute in the exploratory parts of the body, such as hands, fingers, lips and tongue. There are at least four different skin sensations: pressure, warmth, cold and pain. However, some researchers extend that list to include other sensation, among them: vibration, tickle and itch.

Kinesthesia Sense: The sense of movement and orientation in space, which is basically skeletal movement that includes the limbs, neck, *etc.* The information comes from the receptors in the muscles, tendons and joints.

In the context of BS displays, haptic perception could be useful in several ways, for example:

- the use of an external device that can recreate temperature or other surface properties such as roughness; and
- the use of an immersive virtual reality building model that allows the user to touch surfaces through data gloves in order to acquire information such as the temperature, roughness and heat flux. Or a data suit to acquire information about air movement and sound vibrations. This would bring BS data analysis to a new level whereby users may control simulations through virtual menus, buttons and the like.

2.1.4 Smell

Humans, compared to other mammals, are olfactory incompetents. However, it does help spotting danger (e.g. gas leakage), supports the taste sense when consuming food and is the basis of the perfume/deodorant industries.

In the context of BS displays, this sense could be useful to check the level of odour or smoke in a space. This may be achieved with a stand alone device or through immersed virtual reality.

The next section explores the concept of information perceptualisation, which is acquired by humans through the above senses.

2.2 Information Perceptualisation

Taken together, human senses give rise to perceptualisation, including visualisation, sonification, *etc.* (Card *et al.*, 1999).

The founder of psychophysics, Gustav Fechner, investigated sensory intensities by measuring the ability of humans to differentiate between stimulus intensities. The smallest increment of intensity that produces a stimulus that is just large enough to be detected is called a just-noticeable-difference, or jnd. According to Weber's law, the jnd is a constant fraction of the intensity of the standard stimulus (Gleitman *et al.*, 2000).

The kinesthesia sense is the best way to detect a difference, followed by touch and then the auditory sense. Surprisingly, the least effective senses are vision and taste. Dix *et al.* (1998) compared the reaction times of the auditory, visual and pain senses and demonstrated that the fastest reaction was associated with the auditory sense, followed by vision. He also demonstrated that combined signals result in more rapid response times.

In the context of BS displays, there are clear advantages in designing multiple sensory systems because they increase the effectiveness and flexibility of displays and the efficiency of carrying out simulation tasks.

The next section introduces visualisation, sonification, haptisation, odourisation (which are the useful information display modalities in the context of BS) and VR.

2.2.1 Visualisation

The following concepts and definitions were mainly derived from the work of Spence (2001), Gleitman *et al.* (2000) and Card *et al.* (1999).

Visualisation is an activity that a human being engages in (a cognitive activity) (Ware, 2000; MacEachren, 1995). In other words, it goes on in the mind and the result is internal to the individual. The potential value of visualisation (that of gaining insight and understanding) follows from its definition, but due to its cognitive nature, the topic is difficult to study.

According to Spence (2001), the definition of visualisation is independent of computers although computers are excellent facilitators of the visualisation process. Several activities are concerned with the creation of visual artefacts, and the interrelationships need to be disentangled in order to set information visualisation in context. The definition of visualisation used here is:

“The use of computer-supported, interactive, visual representations of data to amplify cognition.”

Cognition is the acquisition or use of knowledge. This definition has the virtue of focusing as much on the purpose of visualisation as the means. Hamming (1973) stated that:

“The purpose of computation is insight, not numbers.”

Likewise for visualisation:

“The purpose of visualisation is insight, not pictures.”

The main goals of such insight are discovery, explanation and decision making. Information visualisation is useful to the extent that it increases the ability to perform these and other cognitive activities.

Normally, the concern is with situations in which a body of data is available and the requirement is to gain insight into that data. It is important to make a clear distinction between data and information. The ‘information explosion’ so widely discussed is actually a data explosion: it is the derivation of information from the data that is difficult, and which is facilitated by means of visualisation tools.

Data is not always numerical. It may be ordinal (sequential), as with items that are naturally ordered such as the days of the week, or categorical, such as the names of entities where there is no order.

2.2.1.1 Scientific and Abstract Information

Visualisation dates, as an organised topic, from the NSF report, ‘Visualisation in Scientific Computing’ (McCormick and DeFanti, 1987). This identified visualisation as a tool to facilitate the handling of large sets of scientific data in order to enhance scientists’ ability to identify patterns. The formal definition of scientific visualisation is:

“Use of interactive visual representations of scientific data, typically physically based, to amplify cognition.”

Scientific visualisations tend to be based on physical data – a building, human body, the earth, molecules and the like. The computer is then used to render visible some properties. While visualisations may derive from abstractions in physical space, the information is nevertheless inherently geometrical. Scientific visualisation primarily relates to a physical object where the data is best displayed in the immediate context of the object.

Non-physical information – such as financial data, business information, collections of documents and abstract concepts – may also benefit from being presented in visual form although it is information that does not have any obvious spatial mapping. Thus, in addition to the problem of how to render visible properties of the objects of interest, there is the more fundamental problem of mapping non-spatial abstractions into effective visual forms. There is a great deal of such abstract information in the contemporary world, and its mass and complexity are a problem, motivating attempts to extend visualisation into the realm of the abstract (Card *et al.*, 1999). The formal definition of abstract visualisation is:

“The use of computer-supported, interactive, visual representations of abstract data to amplify cognition.”

Scientific and abstract visualisations are sub-fields of visualisation and therefore have overlapping display techniques.

In the context of BS displays, the data is usually physically related, for example: geometry and air flow data (among others) are interconnected. Therefore, where possible the results should be superimposed on the related geometric representation to facilitate understanding.

Data mining, also called Knowledge-Discovery, is the process of automatically searching large volumes of data for patterns such as associated rules. It is a fairly recent topic in computer science but applies many older computational techniques from statistics, information retrieval, machine learning and patterns recognition. Data mining techniques have traditionally been employed in the financial and marketing sectors to elicit patterns within the data. However, Morbitzer *et al* (2003 and 2004) work showed that data mining techniques (in particular, clustering) can help the understand the underlying reasons why a building performance is a certain way. This is especially true in climate responsive building which involve complex interactions of, for example, ventilation, solar gains, internal gains and thermal mass.

However, information exploration, analysis and presentation are complex matters as discussed in the next sections.

2.2.1.2 Exploration, Analysis and Presentation of Information

The opportunity to explore the underlying data of a non-computer display is either non-existent or limited, often due to the relatively small amount of data involved but mostly because there is no means of rearranging the data to provide a new, more valuable depiction. The ability to explore data by rearranging it interactively is so valuable that a great deal of effort has been invested in the invention and implementation of interactive visualisation tools that harness this potential.

Existing, highly responsive, interactive visualisation tools have given rise to two principal observations:

- a rearrangement of how the data is displayed often leads to a surprising degree of additional insight; and

- the property of interactivity can considerably enhance a tool's effectiveness, especially where the response is immediate – say within a fraction of a second.

A most useful and perceptive comment was made by Bertin (1981):

“A graphic is no longer ‘drawn’ once and for all: it is ‘constructed’ and reconstructed (manipulated) until all the relationships which lie within it have been perceived ... a graphic is never an end in itself: it is a moment in the process of decision making.”

This is confirmed by Cleveland (1985) who commented that:

“Graphical data needs to be interactive because we often do not know what to expect of the data; a graph could help discover unknown aspects of the data, and once the unknown is known, we frequently find ourselves formulating new questions about the data.”

A user (and especially a user in possession of domain knowledge) may decide upon further rearrangement or the addition of other relevant data. This is the essence of interactive visualisation: a lively, interactive examination and interpretation of graphically presented data, in which rearrangement is an important part and the outcome is usually not predictable. However, rearrangement is not always beneficial, as when a well-intentioned cleaner ‘tidies up’ one’s desk (Malone, 1983).

Rearrangement may occur in different ways. In some, a new presentation appears following a discrete user command. In others the data is dynamically rearranged. Two modes are of interest here. First, a smooth, manually controlled rearrangement enables cause and effect to be displayed simultaneously, often to good effect.

Second, rearrangement is automated, leaving the user free to concentrate upon interpretation. A brief description of each mode follows.

Dynamic manual rearrangement: Insight into the relation between two or more quantities is often sought by the variation of one variable and concurrent observation of the consequent variation of one or more of the remaining variables. No new data is being generated or acquired: the user is simply exercising a design freedom by selecting, for view, a different subset of the data.

Dynamic automated rearrangement: The scanning rate – that is, the speed of animation – requires careful choice: if changes are too rapidly the user may fail to comprehend the meaning of the changes; and if changes are too slow the user will have difficulty in integrating what is observed into a useful mental model.

Each program author has to arrange and display their data in some useful way. Often, they find they have more data than they can easily display within the limited area of the screen.

In many realistic situations in commerce and industry the volume of data to be processed is huge. It is important in such situations to consider the way in which scale influences the way in a visualisation tool is designed. What the user actually sees is termed the ‘externalisation of data’. Clearly, the way in which data are externalised – usually by visual presentation (Tufte, 1983) – is crucial to the success of the adopted method.

In the pre-computer age, the authors of images had to perform selection, representation and presentation according to their understanding of the task to be performed or the message to be conveyed: author and viewer were two different people. Now, with the availability of powerful computers, interactive control by a user – now the author of the externalisation - can influence all display aspects within the freedom limits set by the author of the visualisation tool. Thus, to be effective, the tool must handle the range of interests that user may have.

In the context of BS, user interaction is crucial to the exploration, analysis and presentation of results – to allow, for example:

- the superimposition of results on geometrical representations in order to highlight the context of a technical performance metric;
- controlled animation of results to assist an appreciation of dynamic effects and to allow the focus of enquiry to change in both the space and time dimension; and
- support for model quality assurance by allowing users to explore all model information interactively.

The next section discusses exploration, analysis and presentation techniques, including their usefulness and shortcomings within the BS context.

2.2.1.3 Information Exploration, Analysis and Presentation Techniques

Visual aids to cognition benefit from good visual representation of a problem and from interactive manipulation of those representations. Card *et al.* (1999) have provided the following summary of how information visualisation can amplify cognition.

Increases Resources

- High bandwidth hierarchical interaction: a human's moving gaze partitions channel capacity so that it combines high spatial resolution and wide aperture in sensing visual environments (Resnikoff, 1987).
- Parallel perceptual processing: some attributes of visualisations could be processed in parallel compared to text, which is serial.
- Offload work from cognitive to perceptual system: some cognitive inferences done symbolically may be recorded into inferences and performed by simple perceptual operations (Larkin and Simon, 1987).
- Expanded working memory: visualisations could expand the working memory available for solving a problem (Norman, 1993).
- Expanded storage of information: visualisations could be used to store massive amounts of information in a quickly accessible form (e.g., maps).

Reduced Search

- Locality of processing: visualisation group information brought together thus reducing search times (Larkin and Simon, 1987).
- High data density: visualisations can represent a large volume of data in a small space (Tufte, 1983).
- Spatially indexed addressing: by grouping data about an object, visualisations avoid symbolic labels (Larkin and Simon, 1987).

Enhancing Recognition of Patterns

- Recognition instead of recall: recognising information generated by visualisation is easier than recalling that information.
- Abstraction and aggregation: visualisations simplify and organise information, supplying higher centres with aggregated forms of information through abstraction and selective omission (Card *et al.*, 1991; Resnikoff, 1987).
- Visual schemata for organisation: visually organising data by structural relationships (e.g., by time) enhances patterns.
- Value, relationship, trend: visualisations may be constructed to enhance patterns at all three levels (Bertin, 1977/1981).

Perceptual Inference

- Visual representations highlight some problems: visualisations can support a large number of perceptual inferences that are extremely easy for humans (Larkin and Simon, 1987).
- Graphic computations: visualisations can enable complex specialised graphical computations (Hutchins, 1996).

Perceptual Monitoring

- Visualisations can allow for the monitoring of a large number of potential events if the display is organised so that these stand out by their appearance or motion.

Manipulation Medium

- Unlike static diagrams, visualisations can allow exploration of a space of parameter values and can amplify user operations.

There are many techniques that improve the effectiveness of information exploration, analysis and presentation, such as, viewpoint controls, overview + focus, scroll, location probe, suppression, RSVP, animation and tree structures: these techniques are now described.

Viewpoint Controls

Viewpoint control is a transformation of view that uses affine transformations¹ to zoom, pan and clip the viewpoint. These transformations are common, because they magnify the visual structure or change the point of view to make details more visible.

Panning is the smooth movement of a viewing frame over a two-dimensional image of greater size, while zooming is the increasing of magnification of a decreasing fraction (or vice versa) of a two-dimensional image under the constraint of a viewing frame of constant size. The choice of viewing location afforded by panning, and the ability offered by zooming to choose between local detail and global overview, will be readily appreciated.

Zoom factors of between 5 and 30 have been observed to work best, with larger zoom factors requiring an intermediate view (Shneiderman, 1998 and Plaisant *et al.*, 1995).

The problem with zooming is that the surrounding area (the context) disappears as the details are magnified. One strategy, explored by the Pad and Pad++ systems (Perlin and Fox, 1993), is to make the zoom rapid and easy to invoke, for example by assigning control of the operation to the mouse buttons (Bederson and Hollan, 1994). However, this requires the user to remember information that is at times not visible.

¹ An affine transformation or affine map is one in which between two vectors spaces consist of a linear transformation followed by a translation: $x \rightarrow Ax + b$.

In the context of BS displays, this technique is useful when:

- zooming into a performance graph to obtain a snap-shot of a result of interest or to occult an unwanted part; and
- applying zoom, pan, rotate and viewpoint-acceleration to a geometry model to check for errors, to locate critical issues when performance data is also displayed, or to prepare the geometry for the *Save As* function.

‘Overview + Focus’ and Scroll

In the ‘Overview + Detail’ technique (Shneiderman, 1996), two windows are used together with an overview of the visual structure in one window and a detailed, magnified view in the other. The overview then defines the context of the detail view and acts as a control widget to make selections.

The overview + details technique has both strengths and weaknesses. A strength is that it is simple to implement and understand. It can also provide rapid access to the details of a visualisation that are otherwise too large to fit within the display. Its primary weakness is that comparison may require the movement of the detail window, including disrupting attention directed at the overview window. Further, an overview analysis may require a visual structure that does not fit within the overview window, which is typically much smaller than the detail window.

Figure 2.1 shows an example of a map with the focus + context technique applied. The right-bottom corner shows the context with focus indicator (blue rectangle) – which is interactive, dynamic and can be suppressed with a toggle. Other features include: map scales, zooming with scale, panning directly or through buttons and three view modes (map, satellite and hybrid).

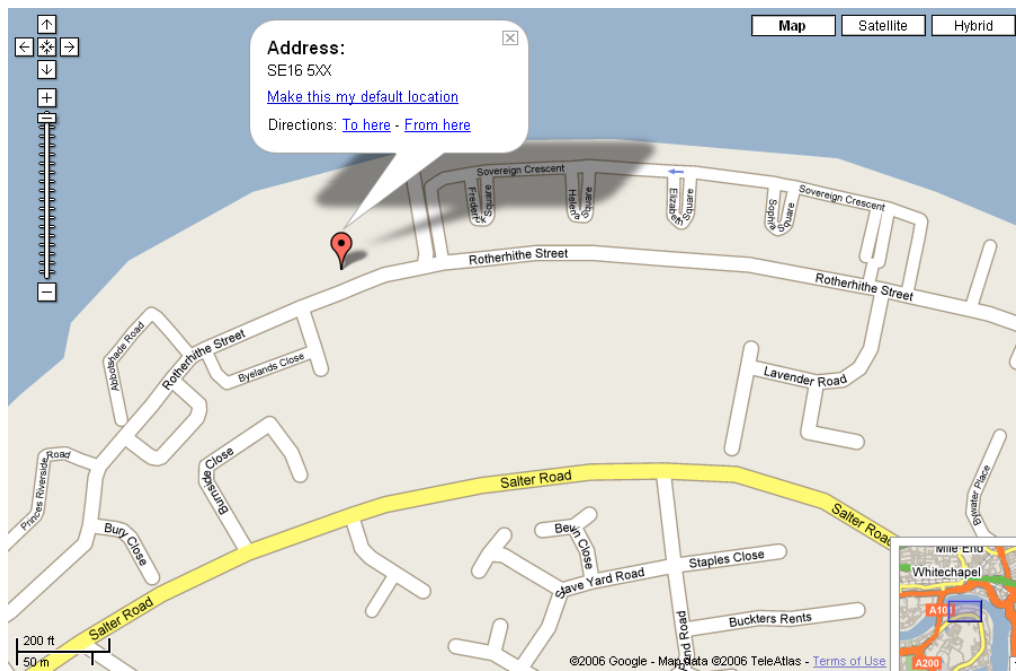


Figure 2.1: Focus + context technique applied to a map
(Google, 2006 – <http://maps.google.co.uk/>)

In view of the importance of context, a great deal of attention has been directed over the last two decades to the problem created by the need to have context information beneficially co-existing with the detail of the focus of attention. One of the most successful concepts, and one which has led to numerous derivative techniques, is the Bifocal Display (Imperial College Television Studio, 1980; Spence and Apperley, 1982). The solution is simple: imagine a strip of paper to be pulled back across two posts, but in such a way that all of it is still in view. One or two items would appear in the centre and, if they are documents, would be readable, but the viewer is still aware of the (albeit distortion) presence of all other items. This is where the skill of the interaction designer is evident: if the encoding of the distorted items is carefully handled, then an informative overview of the information space is immediately available. Other terms associated with the concept are the *Fisheye Lens* and the *Distortion Technique*.

Distortion is a visual transformation that modifies a visual structure to create focus + context views. Overview and detail are combined into a single visual structure. Examples include: *Hyperbolic Tree* (Lamping and Rao, 1996), *Perspective Wall*

(Mackinlay *et al.*, 1991), *Bifocal Lens* (Spence and Apperley, 1982) and *Table Lens* (Rao and Card, 1994).

An obvious solution is to scroll the data in and out of the visible area. In other words, provide a means whereby a long document may be moved past a window until the required part is reached. This mechanism is widely used but carries with it many penalties. One relates to the ‘where am I?’ problem. With a scrolling mechanism, most of a document is hidden from view. A similar difficulty relates to the use of the famous London ‘A to Z’ street directory. These and other similar problems may be ameliorated by the provision of context – for example, via the provision of a map with the location of the focus of interest indicated. Thus, a detailed display of part of a map could be placed near a global, less detailed map, with the location of the detailed map indicated.

Another solution borrows from a most obvious metaphor – that of bringing a magnifying glass to something in order to discern more detail. Furthermore, limiting the display of detail to a small region removes the danger of clutter over the whole display, and is less expensive computationally than if the function of the lens were to be applied globally. Indeed, maintaining the area outside the lens in its unmodified state provides useful context.

Further improvements of this technique were developed by Ware and Lewis (1995) and Lieberman (1994, 1997) – addressing the issue of occlusion by a magnifying glass to the immediate context of the detailed region.

In the context of BS displays, these techniques would be useful when:

- part of the building is required to be prominent to indicate that it is associated with an accompanying performance metric that has been brought to the user’s attention;
- an IPV presentation has too many entities so that the user’s focus cell may shown in detail while the remainder of the document is distorted;

- displaying general information or offering help – text can be displayed using a miniature font size (i.e. the context) with an associated indicator (circle or rectangle) pointing to the portion currently being viewed;
- displaying a complex IPV, a miniature version of the complete IPV can be shown in a corner of the main window with an indicator pointing to the portions that the user is presently viewing; and
- navigating inside a building geometry model (solid format) where the complete building could be displayed in a corner of the main window in miniature size with an indicator of the zone(s) presently being considered.

Figure 2.2 shows the focus + context technique applied to the geometry building model, where the all model is the context, the group of zones selected by the user is the first level of the focus, a zone within the group is the second level of focus and finally a surface within that zone represents the third level of focus.

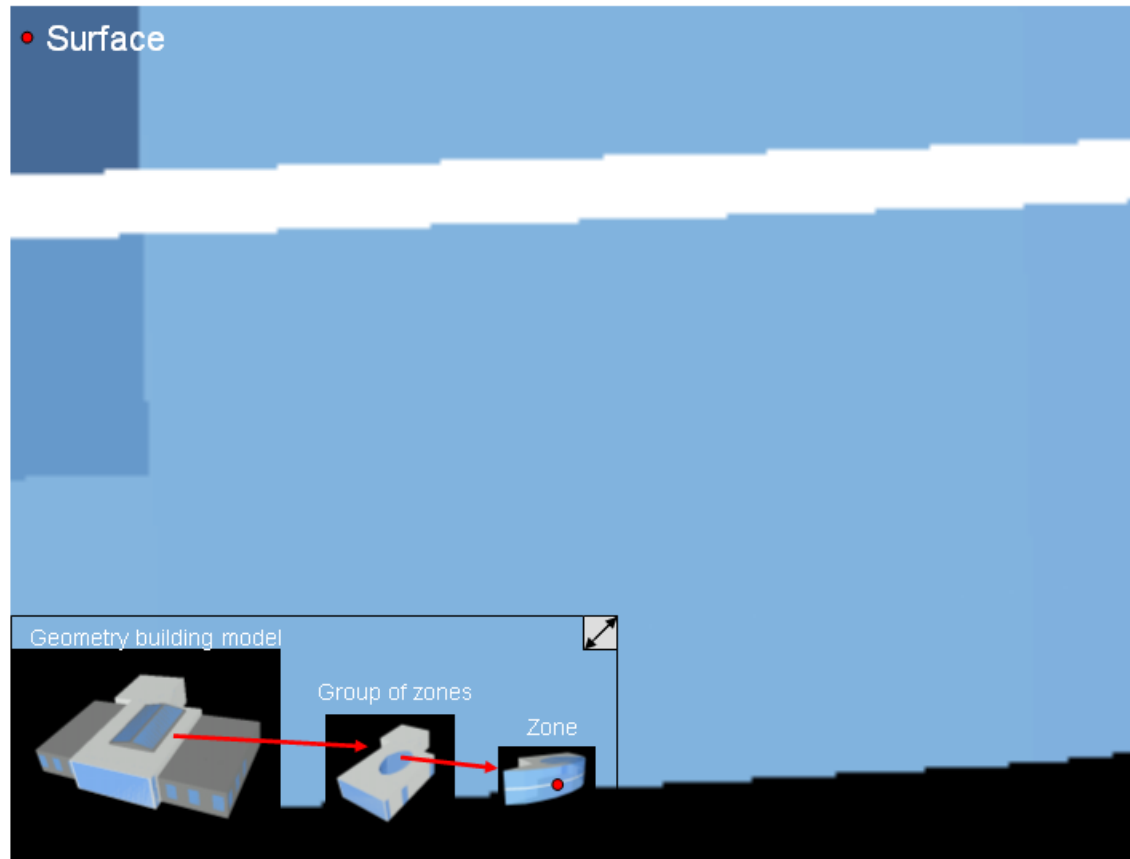


Figure 2.2: Focus + context technique applied to a geometry building model.

Location Probe

Location probes are view transformations that use location in a visual structure to reveal additional data table information. Brushing is a form of probing where the cursor passing over one location creates a visual effect at another location (McDonald, 1990).

Probes may also augment the visual structure. Scientific visualisations use slicing plane probes to access the interior of 3D solid objects (DeFanti *et al.*, 1989). Streamlines are a probe that renders vector fields visible. *Magic Lenses* – the magnifying glass metaphor – (Fishkin and Stone, 1995) are probes that give an alternative view of a region in the visual structure. Objects in the region reveal additional properties of the data table.

According to Glaser and Ubbelohde (2001), these techniques support the reviewing of time dependent data (common to building simulation). They enabled rapid inspection of trends and singularities in the data (for example in daylight analysis), that are difficult to ascertain from conventional methods.

In the context of BS displays, this technique would be useful when:

- interrogating a performance metric graph in order to find additional underlying information (e.g. percentage of energy consumed up to that point in time) through sensitive data points;
- displaying a building geometry model in order to locate information about surfaces, zones, plant, control systems and so on through sensors that are activated only when such additional data exists; and
- providing help via a pop-up box, the availability of which is indicated by the text being in a different colour (or otherwise differentiated).

Suppression

Where less important data can be omitted from the display, this should be done to reduce clutter and facilitate decision making by showing only essential information.

Techniques in this category include *Furnas Fisheye Concept* (Mitta, 1990) and *Z-thru Mapping* (Colby and Scholl, 1991).

In the context of BS displays, this technique would be useful where:

- some graphical elements (scale lines, hatching, *etc.*) could usefully be occulted in order to de-clutter the view;
- target zones in a building geometry model are changed from solid to wire-frame format so that the view becomes clearer;
- parts of the display are no longer required, a suppression bar can occult it; and
- internal cells within an IPV-page are blocking/overcrowding the view, a minimizing toggle can reduce its size.

RSVP

Rapid serial visual presentation, or RSVP, is an application of the riffling technique (De Bruijn and Spence, 1999, 2000). A mouse-click triggers RSVP images of the content, where the trajectory suggests that the images emerge from one side of the folder and return to the other side. At a rate of around ten per second or more a user is able to gain an insight into content and often recognise a sought after image. A progression bar would be complete when all images have been displayed, thereby providing some idea of the time it would take to view the entire set of images (results). A second click would stop the riffling. Other controls (for example, increment/decrement by one) could be added according to the application.

Figure 2.3 shows the use of images in static and moving modes to present information to potential holiday makers. In comparison to plain text, images (particularly in moving mode) are far more effective in describing the hotel information because one can visualize the actual rooms, restaurants, bars, *etc.*



Figure 2.3: Static and moving images to present hotel information
(from Expedia Web-site, 2006).

In the context of BS displays, this technique would be useful when displaying images of the building site or complex time varying results, time-frame by time-frame. If the focus is within an IPV cell, the controls (stop, play, pause, *etc.*) and progression bar should be occulted when not in use, in order to retain the clarity of the overall IPV page. Images are an important mechanism to show BS information, in particular for distant project management.

Animation

Time-based animations can encode any type of data. However, while this is a natural manner it is not always the most effective encoding style. For example, mapping time data into a spatial framework allows comparisons between two points in time.

Tufte (1994) reported a more sophisticated variant in which miniature visualisations are arranged along an axis of time. This display then controls an animated sequence.

Another use of time animation is similar to the unstructured axes of space. Animations are used to enhance the ability of the user to keep track of changes of view or visualisation. If the user clicks on some structure causing it to enlarge then other structures become smaller. Such animation can convey change and, more significantly, the change that took place. Simply viewing the two end states may be confusing. Another use of animation is to enhance a visual effect. Rotating a complicated object, for example, can induce a 3D effect and support the interpretation of some visual mappings.

At the lower edge of the display, familiar video controls would facilitate automated animations and speed adjustment along the time line. The most obvious form of interaction is direct manipulation.

Some interaction devices are more efficient than others in the context of specific tasks. For example, it is more efficient to directly manipulate a geometry display using a mouse rather than to effect the same control through buttons. The reason is simple: during manipulation of an object, the focus is on that object and the link between action and result immediate. On the other hand, if attention is divided between the object and the means of control (e.g. a keyboard button) then the link is broken and the result delayed.

In the context of BS displays, this technique would, for example, be useful where:

- time is animated so that the data is presented step-by-step at the user's discretion through display controls such as play, still, stop and rate;
- the user controls the display of performance metrics superimposed on a 3D geometry representation; and
- the cells of an IPV page are used to display time stepping data (e.g. air flows over a specified time period), so that the user can appreciate the dynamic change by scanning the rows of the IPV from left to right.

Tree structures

Many relations are characterised by connectedness of a special sort such as represented by a graph that conforms to a tree structure. Nodes at the (conventional) extremities of the tree are often referred to as ‘target nodes’ in view of the fact that the function of non-target nodes is frequently to guide the user through a menu to a single source of information. Within such a tree structure nodes are typically referred to as parents, siblings and children.

A major problem with tree structures is that their conventional representation occupies a great deal of space, usually to the extent that for more than three levels and more than 50 nodes at the third level, the tree is too large for effective presentation on a display. The search for a better presentation of a tree, and ways in which interaction could be supportive, has resulted in some effective schemas such as: *Cone-Trees* (Robertson *et al.*, 1991), *Tree Maps* (Johnson and Shneiderman, 1991; Shneiderman, 1992) and *Hyperbolic Browser* (Lamping and Rao, 1994).

In the context of BS displays, this technique could be used to create a topic hierarchy that imparts organisation, structure and data grouping. This technique could therefore be used to display:

- the performance metrics available for a given design option in support of efficient selections;
- help system topics to allow ready access to assistive information; and
- building model data from an *All Model* level, through the *Groups of Zones* level, down to a single *Element level* including all associated properties.

2.2.1.4 Quantitative Information Display Guidelines

This section draws mainly on Tufte’s (2001) and Spence’s (2001) work, which has been collated and summarised by Prazeres and Clarke (2003).

In relation to graphical displays Tufte (1997) states:

“When we reason about quantitative evidence, certain methods for displaying and analyzing data are better than others; superior methods are more likely to produce truthful, credible, and precise findings. The difference between an excellent analysis and a faulty one could sometimes have momentous consequences.”

In other words, to be understood, graphics must first be accurately perceived (Cleveland 1985).

William Henry Playfair, 1757-1823, either developed or improved upon nearly all graphical design techniques, seeking to replace conventional tables of numbers (Playfair, 1786; Playfair, 2005; Spence and Howard, 2001). Often the most effective way to describe, explore and summarise a set of numbers is to look at picture representations of those same numbers.

Excellence in statistical graphics consists of complex ideas communicated with clarity, precision and efficiency. Graphical displays should adhere to the following guidelines:

- show the data;
- induce the viewer to think about the substance rather than about the display method, the graphic design, the technology used to produce the graphics, or something else;
- avoid distorting what the data have to say;
- present many numbers in a small space;
- make large data sets coherent;
- encourage the eye to compare different pieces of data;
- reveal the data at several levels of detail, from a broad view to the fine structure;
- serve a reasonably clear purpose in relation to issues such as description, exploration, tabulation or decoration; and
- be closely integrated with the statistical and verbal descriptions of a data set.

“Graphics do not become attractive and interesting through the addition of ornamental hatching and false perspective to a few bars. Chartjunk could turn bores into disaster, but it could never rescue a thin data set.”

(Tufte, 2001)

The history of devices for communicating information is written in terms of increases in efficiency of communication and production. It has been observed that interpretation efficiency has increased as the introduction of graphic display techniques evolved. Designing graphics displays is now recognised as a complex and multivariate task involving considerations not only of efficiency, but also of complexity, structure, density, and even beauty.

Venturi (1977) stated that where possible, ‘data-ink’ should have a multifunction use to display both complex and multivariate data. Graphics should be designed to have at least three viewing layers:

- overall/aggregated data (e.g. provided by the graph itself);
- detailed data (e.g. provided by the zoom functionality); and
- implicit meanings (e.g. provided by the location probe sensor).

These three layers justify the use of interactive graphics to display performance metrics as produced by BS.

Monty and Senders (1976) have stated that when designing graphics, it is essential to maximise data density and the size of the data matrix (within reason) because this invites comparison when more information is displayed on one page – reducing eye movement. This is in line with the proposed concept of an integrated performance view, where large amounts of data may be simultaneously displayed.

However, as the density increases, the data elements must shrink (smaller dots, thinner lines, smaller letter font, *etc.*). In this situation, clutter and redundant data ink is more costly than usual in data-rich designs.

There are two ways to increase data density: one is to increase the data matrix; the other is to decrease the graphic area. The latter is effective because data graphics can usually be reduced by half of their published size with little loss in legibility and information content. This is called small multiples:

“Small multiples resemble the frames of a movie: a series of graphics, showing the same combination of variables, indexed by changes in another variable. ... The design remains constant through all the frames, so that attention is devoted entirely to shifts in the data.”

(Tufte, 2001)

Graphical elegance is often found in simplicity of design and complexity of data.

Small explanations enrich the data and make the display more attractive to the viewer:

“Words and pictures belong together. Viewers need the help that words could provide. Words on graphics are data-ink, making effective use of the space freed up by erasing redundant and non-data-ink. It is nearly always helpful to write little messages on the plotting field to explain the data, to label outliers and interesting data points, to write equations and sometimes tables on the graphic itself, and to integrate the caption and legend into the design so that the eye is not required to dart back and forth between textual material and the graphic. (The size of type on and around graphics could be quite small, since the phrases and sentences are usually not too long – and therefore the small type would not fatigue viewers the way it does in lengthy texts.)”

(Tufte, 2001)

With BS graphs, small bits of text are very important, for example, to indicate the period and location to which the graph refers.

According to Monty and Senders (1976), the effectiveness of combining words and pictures depends on the purpose. When used to communicate data, words on and around graphics are effective in telling viewers how to allocate their attention to the various parts of the display. When used for data exploration, words tell the viewer how to read the design (if it is a technically complex arrangement) and not what to read in terms of content.

There are many specific differences between friendly and unfriendly graphics as described in Table 2.3.

Table 2.3: Differences between friendly and unfriendly graphics (from Tufte 2001).

Friendly	Unfriendly
Words are spelt out, mysterious and elaborate encoding avoided	Abbreviations abound, requiring the viewer to sort through text to decode abbreviations
Words run from left to right, the usual direction for reading occidental languages	Words run vertically, particularly along the Y-axis; words run in several different directions
Little messages help explain data	Graphic is cryptic, requires repeated references to scattered text
Elaborately encoded shadings, cross-hatching, and colours are avoided; instead, labels are placed on the graphics itself; no legend is required	Obscure codings require going back and forth between legend and graphic
Graphic attracts viewer, provokes curiosity	Graphic is repellent, filled with chartjunk
Colours, if used, are chosen so that the colour-deficient and colour-blind (5 to 10% of the viewers) could make sense of the graphics (blue could be distinguished from other colours by most colour-deficient people)	Design insensitivity to colour-deficient viewers; red and green used for essential contrasts
Type is clear, precise, modest; lettering may be done by hand	Type is clotted, overbearing
Type is upper-and-lower case, with serifs	Type is all capitals, sans serif

Albers (1975) stated:

“The more the letters are differentiated from each other, the easier is the reading ... words consisting of only capital letters present the most difficult reading – because of their equal height, equal volume, and, with most, their equal width. When comparing serif letters with sans-serif, the latter provides an uneasy reading...”

There are two main reasons why graphics should be longer on the horizontal than on the vertical:

- first, the eye is used to detecting deviations from the horizon; and
- second, labelling is more effective because it is easier to write and read words from left to right on the horizontal.

According to Zusne (1970), if the nature of the data suggests the shape of the graphic, then that suggestion should be followed. Otherwise, it is best to adopt towards horizontal graphics that are approximately 50% wider than tall.

In BS performance data should be superimposed, where possible, on a geometrical representation, because this defines a natural shape for the data. Examples include daylight availability, visual comfort and air movement.

The next section describes the most common graphs/charts types that may be used within the BS context.

2.2.1.5 Graphs and Other Chart Types

The following compilation of graphics techniques is mainly based on the work of Tullis (1988), Harris (1999) and Bounford (2000).

Column and Bar Graphs

It is important to adopt a consistent orientation (horizontal or vertical) for related graphs. The explanations provided below refer to column-wise graphs but the concepts apply equally to vertical types.

Column graphs are a family of graphs that display quantitative information by means of a series of vertical rectangles. Column graphs are frequently used to compare multiple entities or to show how one or more entities varies over time.

Each column represents a data element, and a complete set of columns represent a data series. The top of each column is located at the value it represents. The length and/or area of the columns may or may not be proportional to the values they represent. Because the tops of columns are so pronounced, this type of graph is one of the best for showing specific values. Because of the stand-alone nature of each column, it is also well suited for representing discrete data. Column graphs normally have one linear quantitative scale on the vertical axis and generally have a category or sequence scale (e.g. time series) on the horizontal axis. Spacing between adjacent columns should typically be less than the column width to facilitate comparisons between columns. A useful variation is the deviation column chart in which columns are constructed so that, under normal conditions, the bar ends lie in a straight line.

When two or more data series are plotted side-by-side on the same column graph, the result is referred to as a clustered, grouped, multiple, or side-by-side column graph. Grouped columns graphs enable the user to:

- compare multiple items at various points in time;
- show how relationships between multiple items change with time;
- look for correlations or meaningful relationships between multiple data series; and
- condense into one graph what otherwise would require multiple graphs.

With this type of graph, each data element of each data series is represented by a separate column. The data series are differentiated from one another by assigning a different colour, shade or pattern to each data series. The columns from each data series that correspond to the first interval on the horizontal axis are placed side-by-side to form a group or cluster in the centre of the first interval. The columns from each data series that correspond to the second interval on the horizontal axis are placed side-by-side in the centre of the second interval. This placement continues until all of the columns representing data elements are entered on the graph. A space is almost always provided between each group of columns so that the data associated with each interval can be easily distinguished. The spaces used in a given graph may be of any width. Although they are generally uniform throughout the graph.

Technically, there is no limit as to the number of data series that may be plotted on a single graph. Practically, if the number goes above three or four, the graph can become confusing. Group columns graphs can accommodate both positive and negative values on the vertical axis.

In the context of BS, this graph type may be used to display specific results while, at the same time, facilitating comparisons between different data sets – for example, maximum plant capacities for a simulated period / group of zones and for the different systems (e.g. heating, cooling lighting, etc. with legends in different colours). Figure 2.4 gives an example of this graph.

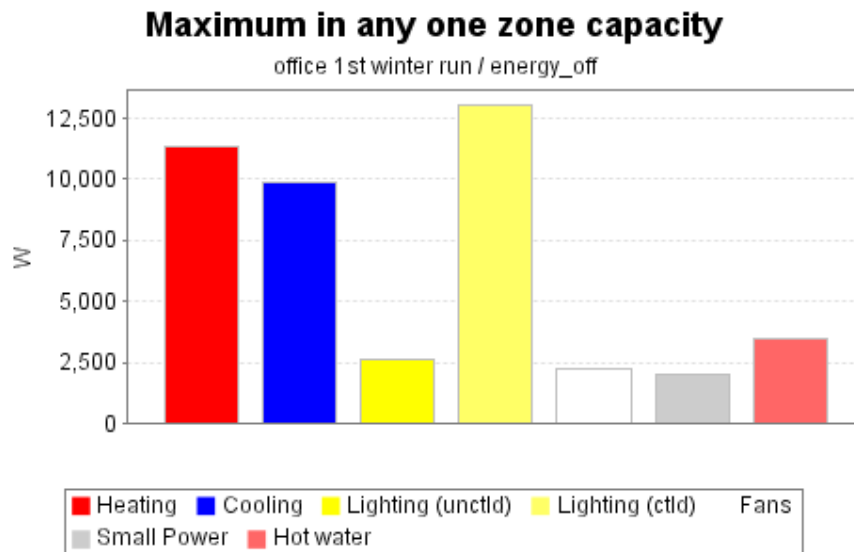


Figure 2.4: A column graph example.

Histograms

Sometimes referred to as the frequency diagram, the histogram is the best known member of the family of data distribution graphs. A frequency polygon is a segmented or smooth line version of a histogram. Histograms and frequency polygons show the frequency with which specific values (referred to as data elements), or value ranges (referred to as class intervals), occur in a set of data.

The set of numbers is typical of a group of values whose distribution requires evaluation. One method is to plot all the values along a single axis (often termed a one-axis data distribution graph). Based on this graph, an estimate can be made about where the values are concentrated, what are the extremities and whether there are any gaps or unusual values. Overlapping data points can become a problem with such a graph, even with a relatively small number of data elements. To address this problem and at the same time quantify the distribution, it is usual to divide the axis into five to ten equal intervals (called class intervals, classes, group intervals, bins or cells) and, using the actual data, count the number of data elements in each interval. A further step is to make a joined column graph of the counts or frequency in each interval (such a graph is called a histogram).

In addition to knowing how many data elements fall into each interval, it is desirable to know what percentage those quantities represent of the total number of elements in the data set. This information may be displayed on a histogram either by showing the percentage alongside each data graphic or by adding a percent scale to the graph. These percent figures are called percent frequency or relative frequency. When the percent is shown in its decimal equivalent format - 0 to 1 - it is referred to as a proportion.

In the context of BS, this graph type is used to set 'bins' (interval values) where the number of times it falls in them within a simulated period is displayed on the Y-axis (e.g. for a comfort index such as predicted mean vote to indicate the frequency of overheating). Obviously, the number of times they fall in the bins depends on the time-step of the simulation. Extra information may then be provided via the location probe technique. Figure 2.5 gives an example of this graph.

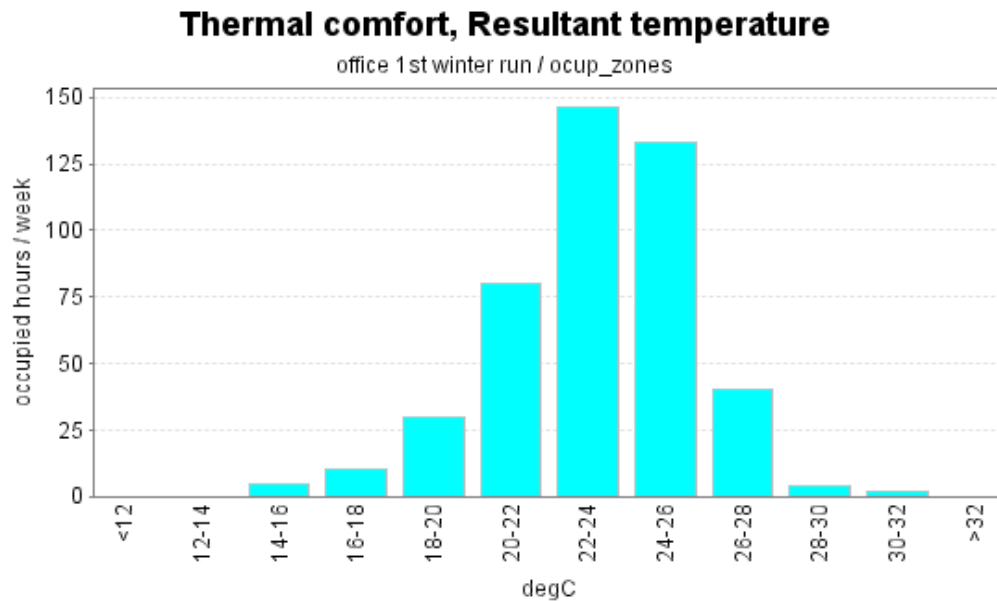


Figure 2.5: A histogram example.

Stacked Column or Bar Graphs

It is important to adopt a consistent orientation (horizontal or vertical) for related graphs. The information given below also applies to the bar graph.

This graph type is referred to as a segmented, extended, divided, composite or subdivided column graph. Stacked column graphs are generally used to show how a larger entity is divided into its various components, the relative effect that each component has on the total entity, and how the sizes of the components and the total change over time.

A stacked column has multiple data series stacked on top of one another instead of being placed side-by-side as in a grouped column graph. This means that the tops of the columns represent the totals of all the components (data series) for each interval along the horizontal axis. Each data series is identified by a different shade, colour, or pattern, explained in a legend. Depending on the nature of the data and individual preferences, the largest, most important, or least variable component might be placed on the bottom of the stack. The scale on the vertical axis is always quantitative,

linear, starts at zero, and has no breaks. Category or sequence scales are used on the horizontal axis.

When the changes from column to column are small, the space between columns can be eliminated to make the stacked graphs easier to read. Where the changes are significant this approach will be less effective.

Data series comprising all negative values can be plotted on stacked column graphs. On the other hand the use of a stacked column graph for data series comprising a combination of positive and negative values will result in a confused picture and is therefore rarely used.

A logarithmic scale (on the y-axis) should be avoided because it distorts the individual elements' amounts.

In the context of BS, this graph type would be useful when total values are of more interest than the relative size of the individual elements. It should be noted that some metrics can not be stacked because this would not make sense (e.g. maximum plant capacity), in contrast to other performance entities such as energy-related gaseous emissions, energy breakdowns, *etc.* Figure 2.6 gives an example of this graph.

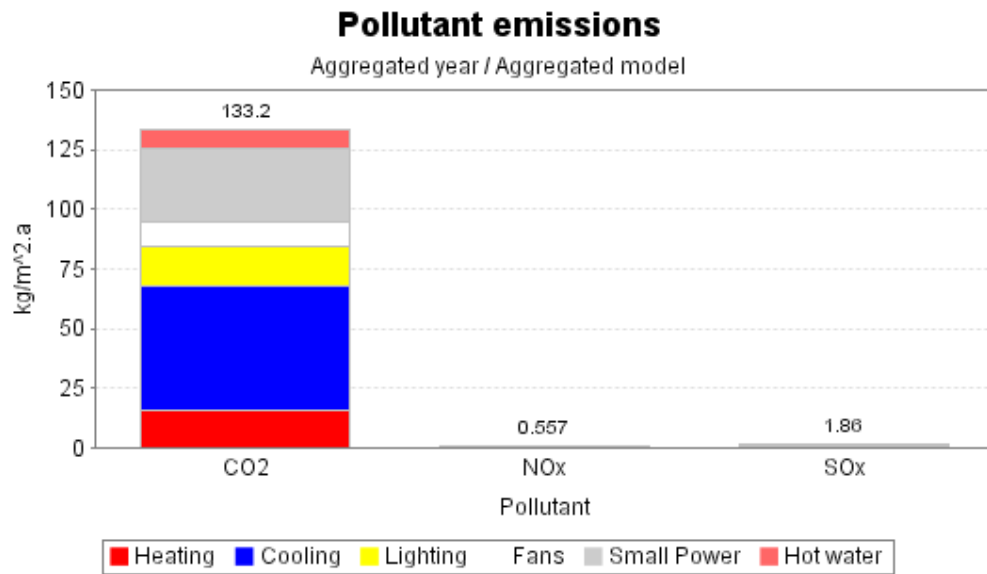


Figure 2.6: A stacked column graph example.

Figure 2.7 shows the same graph, but zoomed, so that the individual elements of NO_x and SO_x are visible.

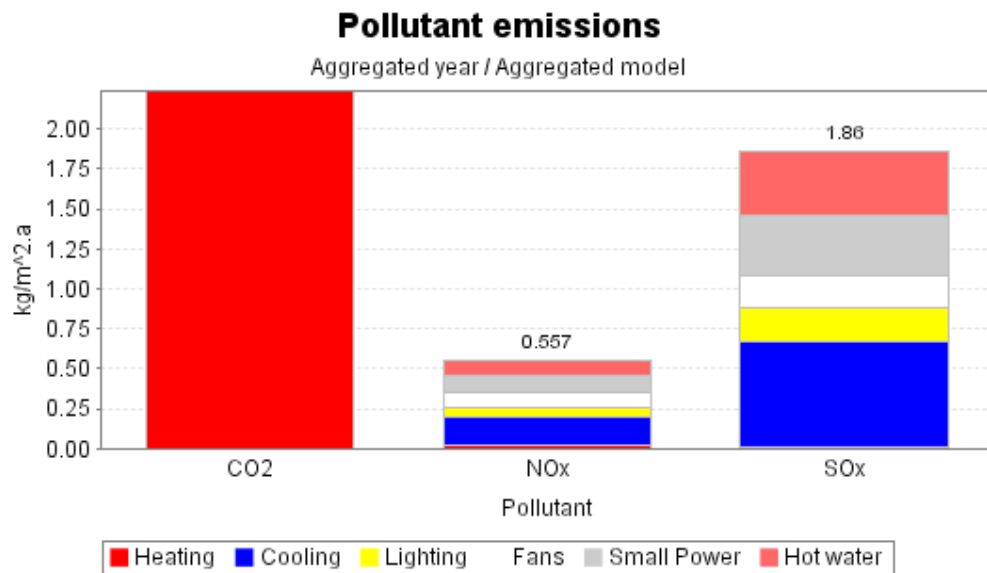


Figure 2.7: A stacked column graph example zoomed.

In addition, the problematic issue of displaying combinations of positive and negative values is a drawback in the BS context. Clearly, it would be advantageous

to display energy demand and renewable energy supply as entities of different sign. This could be done effectively with non-stacked bar or column graphs.

Line Graph

These are versatile and are therefore used extensively. The type may be used to show how multiple continuous variables are related or to highlight variable changes over time.

A simple line graph displays a single data series. It typically has a quantitative scale on the vertical axis and a category, quantitative or sequential scale on the horizontal axis. With a category scale, a data point is located directly above every label (category) on the horizontal scale. All categories must be shown on the scale in order for the viewer to interpret the graph. With a sequential and quantitative scale, data points are usually not located over labels and, in many cases, labels are not displayed for every value (where time is included, it is typically plotted on the horizontal axis). Linear or nonlinear scales may be used on quantitative scales. When all scales are quantitative, the two-axis graph is called a simple XY line graph. Positive and negative values may be plotted on quantitative scales on either axis.

Grouped line graphs (multiple data series all referenced from the zero-axis) generally have a quantitative scale on the vertical axis and either a category, quantitative or sequence scale on the horizontal axis. All values along the vertical axis are referenced/measured from a common zero base line axis, which typically is the horizontal axis. When a category scale is used, all data series use the same categories. When the horizontal axis has a quantitative or sequential scale, there are two potential variations:

- all data series use the same values along the horizontal axis but each data point has a unique value along the vertical axis; and
- all data points have a unique pair of values along both the horizontal and vertical axes.

Technically there is no limitation on the number of data series that may be shown on a grouped line graph. Practically, when there are more than four or five data series (with each line having an associated label), the graph becomes confusing. There are many ways to differentiate lines for identification and encoding purposes (a third, discrete variable could be included using line-type or colour coding). Segmented and smooth curves are more frequently used for graphs with multiple data series. Stepped lines are sometimes used but could be confusing if the lines intersect. With all quantitative scales, the two-axis graph is termed a grouped XY line graph. Positive and negative values may be plotted on axes with quantitative scales.

In the context of BS, this graph type is important because time is a crucial variable and underpins all performance metric variations. A typical example is thermal comfort (e.g. resultant temperature) for a specific period. Effectiveness can be improved if the data is displayed dynamically. In the case of multiple parameters (lines) being displayed (perhaps corresponding to a group of zones with many zones), the effectiveness decreases substantially, especially where the lines are close together. Figure 2.8 gives an example of this graph.

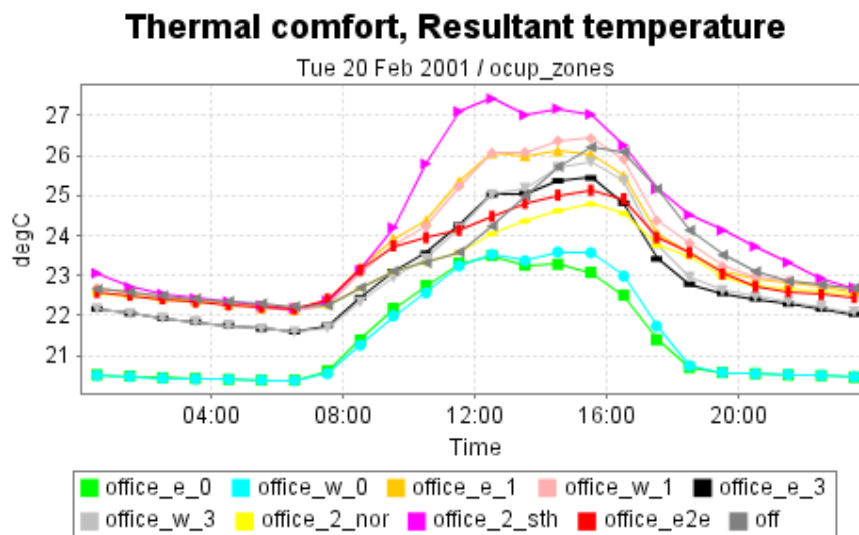


Figure 2.8: A line graph example.

Stacked Area Graph

A stacked area graph is the most widely used variation of an area graph. Each data series is added to the one below it with only the bottom series touching the horizontal axis. The top of the upper data series represents the total of all plotted data series. Stacked area graphs are referred to as stratum, strata, divided area, layer, subdivided area or subdivided surface graphs.

When approximations are all that are needed, stacked area graphs are usually adequate. When accuracy is desired, this type of graph is generally not used, particularly when the values fluctuate significantly and/or the slopes of the curves are steep. Sometimes the most important data series is placed on the bottom. Alternatively, the curve with the least variation is located at the bottom to prevent the propagation of irregularities throughout the stacked curves. Sometimes, reversing the relative positions of the components can significantly improve the readability of the information. Notwithstanding the above situations, there are no restrictions as to the relative positions of the data series on a stacked area graph.

The vertical scale of a stacked area graph is typically linear, starts at zero (no shortening of the scale), is continuous (no breaks), incorporates only positive values, and has an upper value equal to or greater than the largest value plotted on the graph. Each category (curve) should be labelled within its shaded area.

A logarithmic scale (on the y-axis) should be avoided because it distorts the individual elements' amounts.

In the context of BS, this graph type is used when the focus is mainly totals and not individual values. A typical example is energy consumption per unit time (W), which varies over time. Figure 2.9 gives an example of this graph.

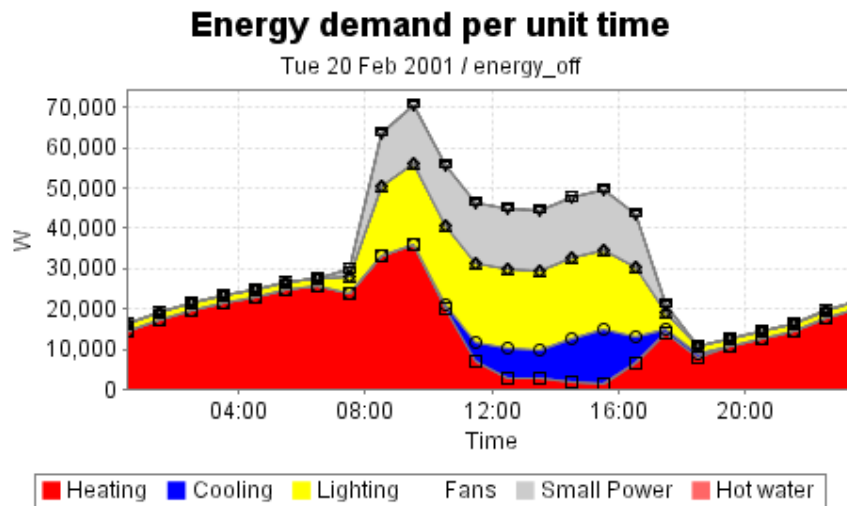


Figure 2.9: A stacked line graph example.

Scatter and Bubble Graph

These are probably the most widely used graph types. They generally have quantitative scales on both axes and can accommodate many data points. Scatter graphs are used extensively for exploring relationships between two or more sets of data. After the data are plotted, the pattern formed is used to make inferences about the inherent relationships.

Where the data points are tightly clustered around an imaginary line, the two variables are generally considered to have a strong correlation. Where loosely clustered, the relationship is considered weak. If the imaginary line slopes up, it is considered a direct or positive correlation; if down, an inverse or negative correlation.

A bubble graph is a variation of a scatter graph where the data points (dots) are replaced by circles (bubbles). The major advantage of a bubble graph is the ability to encode one or more additional variables by means of the bubble symbol. When bubbles represent quantitative variables, either the diameter or area of each bubble is made proportional to the value it represents (the two alternatives give somewhat different visual appearances). To enable the viewer to decode the inherent quantitative information, a legend is provided, the values shown on the bubbles, or

the circles are coded and cross-referenced. Both positive and negative values can be encoded by means of bubbles – but not a mixture of the two.

When opaque bubbles are used, there is the risk of some of the circles being hidden. One solution is to make the bubbles transparent. Transparent bubbles with dots at their centres are sometimes used in conjunction with grid lines to enable the viewer to determine the exact location of the data point.

In the context of BS, the bubble graph is useful to effect comparisons of design options – such as capital cost versus energy cost, with the radius of the bubble representing the benefit. Figure 2.10 gives an example of this graph.

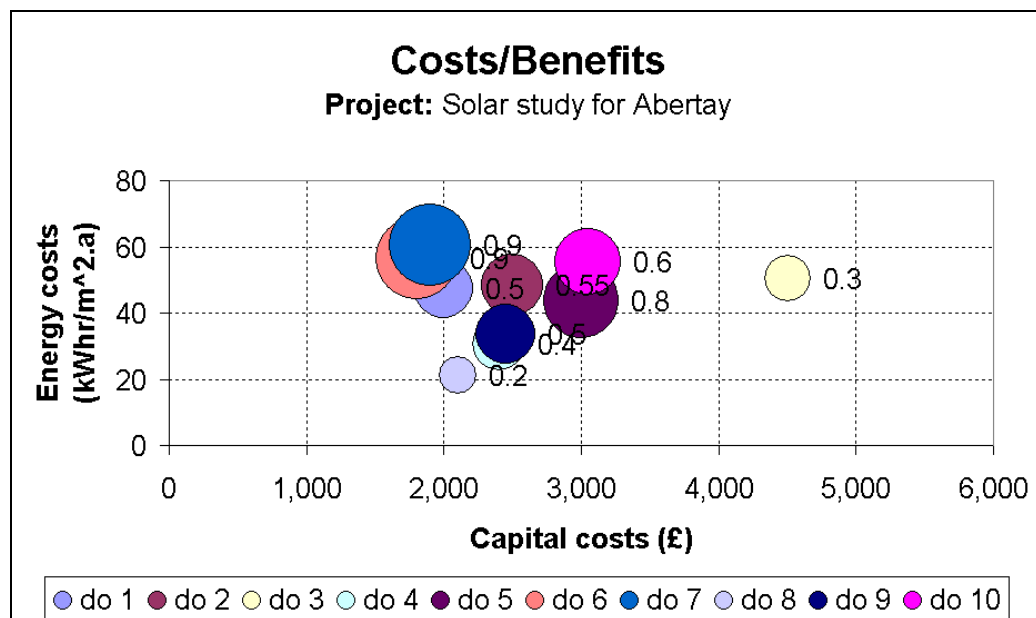


Figure 2.10: A bubble graph example.

Radar Graph

This is sometimes referred to as a star or spider graph. A radar graph is a circular graph used primarily as a comparative tool. The technique is useful for detecting patterns, but not for determining precise values or making accurate comparisons between variables.

Radar graphs can be interpreted by reading the actual values on the axes or by comparing the areas enclosed by the polygons formed by the data points. In general, whether a larger or smaller polygon is best depends on whether the more favourable values are nearer the centre or circumference. Whichever convention is selected, it must be used consistently throughout the graph. When one polygon is distinctly larger than the others, interpretation is straightforward. In other cases, for example where the curves intersect one another, interpretation is more problematic and often involves judgment.

In radar graphs, each category axis (radii) represents a different variable. Other than readability, there is no limitation as to the number of variables that may be included. Whatever the number of variables, they are distributed equally around the 360° of the circle.

Each axis typically has a scale along which one characteristic element is plotted for each data series involved in the comparison. After all data elements have been plotted, adjacent data points within the same data series are generally connected by straight lines forming closed polygons. The general characteristics of a radar graph are as follows.

- To avoid labels interfering with the information being presented, occasionally only the upper limit of a scale is shown. When the sole purpose of the graph is to compare two or more entities, it is not uncommon to omit the labels completely. Categories may progress clockwise or anti-clockwise;
- The general tendency is to keep the number of grid lines to a minimum and, frequently, circular grid lines are not used at all;
- The areas within the polygons may or may not be coloured or shaded. Such choices will greatly affect ease of reading.
- Radar graphs are well suited to comparing data series that have many variables. When more than two data series with large numbers of variables are to be compared, each series is generally plotted on a separate graph.

In the context of BS, this graph is an effective way to display, for example, visual comfort (e.g. Guth index) when superimposed on a geometry representation because it simultaneously provides information on viewpoint, direction of view and overall visual comfort. Figure 2.11 gives an example of this graph.

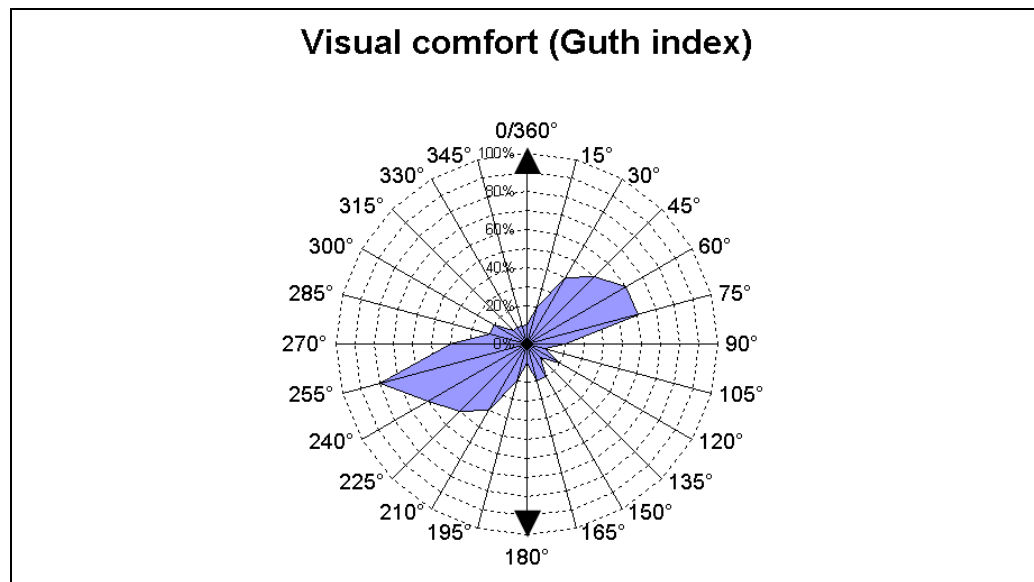


Figure 2.11: A radar graph example.

Filled Counter Graph

An alternative solution for identifying values on the z-axis is to fill the areas between the contour lines, thus forming what is called a filled contour graph. A legend is then provided to relate the fill colours, shades or patterns to z-axis values.

Advantages of a filled contour graph include:

- the ease of identifying areas of equal z-axis value (the boundaries between the different fills represent lines of equal value); and
- the uncluttered appearance resulting from the fact that z-axis values do not have to be shown in the plot area.

In the context of BS, this graph is effective when displaying daylight availability or air movement data superimposed on a geometrical representation. This is because users can clearly view the location of the high/low values on the data plan. The shape

of the data plan should match the area being analysed, which might not be a rectangle. Figure 2.12 gives an example of this graph.

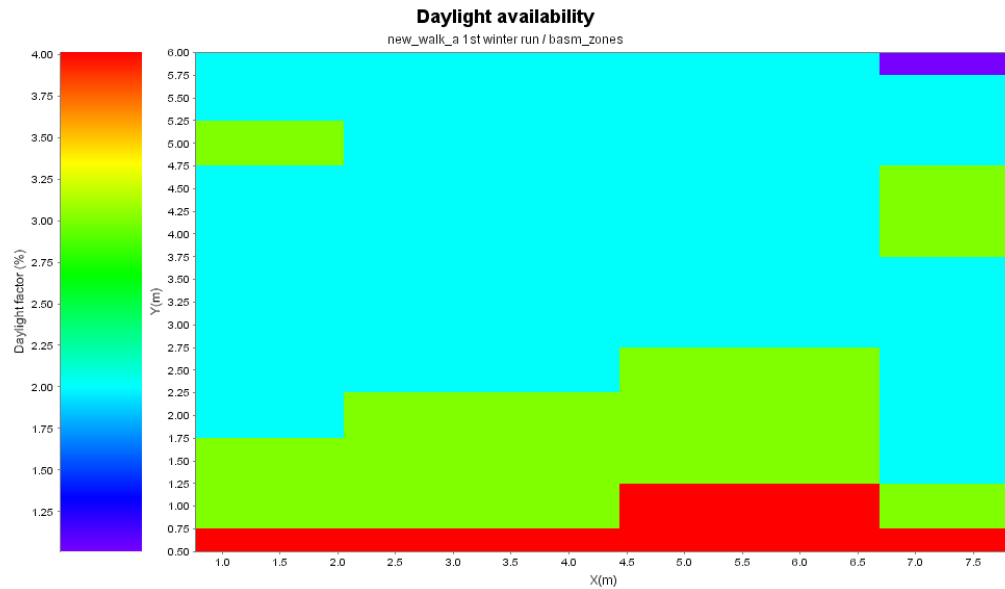


Figure 2.12: A filled counter graph example.

3D Graph

This graph type is useful when several variables are to be simultaneously displayed. In use, it is important to provide the user with an interactive rotation function. The augmentation of 2D data with 3D effects is not recommended (Tufte, 1990):

“... simple and clear is better, extra ink is bad, and extraneous information detracts from the impact of graphics. Rendering uninformative depth is a bad idea in principle because it could lead to misperception of the information of interest, and it could hide the real content from the viewer.”

The term 3-D graph is here used in two significantly different ways, which sometimes causes confusion. In one case, it is used to signify that a graph has the appearance of having depth, which makes it appear three-dimensional. This is frequently done for cosmetic purposes. In the other case, the term refers to a graph

that has three axes. This may be done for cosmetic purposes or to display data in a way that provides insights not possible using other formats.

3D graphs are seldom used for monitoring or controlling. They are almost never used where estimating relatively exact values from the graph is required, since it is difficult or impossible to determine exact values from such graphs. If it is necessary to extract exact values, the values are either noted on the graph or a reference table is provided. When used for analytical purposes, the inability to read exact values is often not a problem since the intention is to convey the general 'shape' of the data.

The areas between lines on 3D graphs may be transparent or opaque. Sometimes they are left transparent so the viewer could see the nature of the data behind the front surfaces. In cases where the graph would become too confusing, the areas are made opaque so that the front surfaces stand out and the relationship between multiple surfaces are easy to discern. There are good reasons for using colour or shading in a 3D graph:

- to identify and group data;
- to designate areas or data that have equal values;
- to make the data more understandable and easier to interpret; and
- to improve the appearance of the graph.

The amount and direction of tilt and rotation of the 3D graph displayed in an axonometric view may improve the viewer's ability to discern key features of the data .

Spin or continuous rotation is a technique available only on computer screens. With the spin method, the entire graph is rotated so that the viewer can look at it from any angle, i.e. the graph can be viewed from any of 360° around any of the three axes. In this way patterns, trends, relationships, distributions, outliers, anomalies and so on can be observed. While many views are available, only one is available at a time.

In the context of BS, this graph type is not particularly useful because the display will typically become confusing and it is difficult to compare data or identify exact values.

Pie Chart

This is sometimes referred to as a cake chart, divided circle, circular percentage chart, sector chart, circle diagram, sectogram, circle graph or segmented chart. Pie charts are members of the proportional area chart family. Their major purpose is to show the relative sizes of components to one another and to the whole. However, a bar or column chart would usually permit more accurate interpretation. Good practice is to limit the number of segments to about 5 and to include the numeric value alongside the segment label. They are used extensively as communication tools in presentations and publications.

A pie chart consists of a circle divided into wedge-shaped segments. The area of each segment (termed a slice or wedge) is the same percent of the total circle as the data element it represents is of the sum of all the data elements in its data set.

General characteristics of pie chart include the following

- With rare exceptions, negative numbers cannot be displayed.
- Percentages over 100% could be used but rarely are, since this is contrary to one of the major advantages of a pie chart: that viewers tend naturally to associate 100% with a circle.
- From a technical viewpoint segments may be arranged in any order. That said, to make the chart easier to read, segments are typically arranged in some meaningful order such as smallest to largest, natural grouping of the data, alphabetical, *etc.*
- Information may proceed in a clockwise or anti-clockwise direction; the clockwise direction is normally used.
- The starting or reference radius may be located at any point around the circle; it is frequently location at the 12 o'clock position.

- With few exceptions, the values depicted by the pie segments are independent of the radius of the circle.
- The radii of segments in a given pie chart are generally all the same.

Bertin (1981) and Tufte (2001) have stated that a table is nearly always better than a (dumb) pie chart. The only thing worse than a pie chart is several of them, for then the viewer is asked to compare quantities located in spatially disassociated pies. Given their low data density and inability to order numbers along a visual dimension, pie charts should be used sparingly.

In the context of BS, this graphic type is not useful because the data is more effectively displayed using a bar/column graph or even a simple table.

Cartoon Faces

Also called Chernoff faces, these are icons that are occasionally used as symbols to encode three or more variables into charts, graphs, maps or comparison displays. The variables are encoded by assigning values and characteristics to variations in facial features.

Professor Herman Chernoff, a statistician at Stanford University, observed that human beings are sensitive to a wide range of facial expressions and appearance, and suggested that facial features such as the size of the eyes, the height of eyebrows above the eyes and the shape of the mouth are numerous and could, in a cartoon face, take on a sufficiently large number of ‘values’ to offer a useful encoding mechanism. He applied this technique (Chernoff, 1973) to the study of geological samples, each characterised by 18 attributes (for example, salt content, water content, *etc.*), and found that the use of Chernoff faces facilitated the identification of interesting groups of samples. Chernoff faces have also been used to display accountancy data (Stock and Watson, 1984). Studies by De Soete (1986) have established the relative value of the various facial features. Following Chernoff’s proposal it was recognised that half

a face carries the same information as a full symmetrical face, stimulating studies of asymmetrical faces (Flury and Riedwyl, 1981).

In the context of BS, this graph type can be used to display human comfort levels (visual, thermal and acoustic) on a geometrical representation because it provides, at a glance, the necessary data pair of location and human satisfaction. With complex time varying data this technique is likely to prove more effective for less technical inclined users. Figure 2.13 gives an example of this chart.

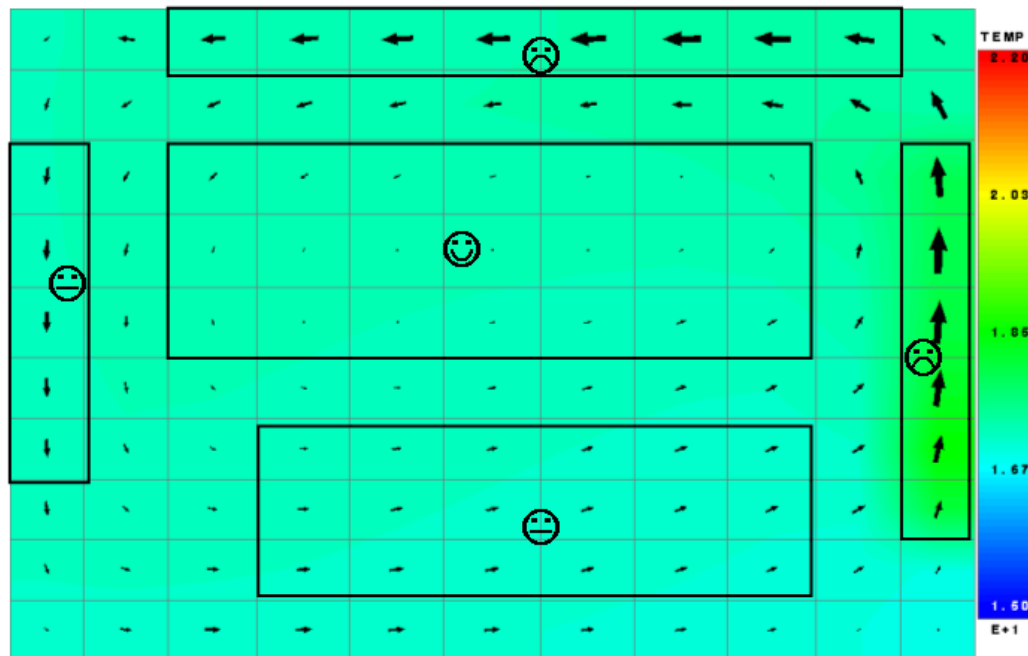


Figure 2.13: A cartoon face example.

Time and Activity Bar Chart

A time and activity bar chart (or Gantt chart) is used for planning, managing, and controlling major programs that have a distinct beginning and end. In this type of chart, each major subprogram or activity involved in the completion of an overall program is represented by a horizontal bar. The two ends of the bar represent the start and finish of the activity. If the chart is for planning purposes only, the start and finish times are estimates or projections. If the chart is for both planning and tracking

purposes, the start and finish times for future activities are estimated or projected and the historical portions are actual times.

The bar chart is the most widely used type of time and activity chart. There are many different variations and applications. Most have the following things in common:

- The major purpose is to relate events, activities, actions, *etc.*, to time.
- Time is displayed on the horizontal axis.
- Either the activities or the people, places, or things involved with the activities are displayed on the vertical axis.
- Horizontal bars, colours, symbols, *etc.*, are used to designate blocks of time.

Major functions of time and activity bar chart: five of the major functions of this type of bar chart are scheduling, loading, project planning, monitoring/managing of activities, and communicating. Almost all charts accomplish the function of communicating, and the majority accomplish two or more of the other four functions.

The lengths of the bars in Gantt charts are generally proportional to the times activities will take. The only limitation on the number of activities or length of time the activities might take in a time and activity bar chart is the physical size of the chart. An alternative to one large chart is to have a master chart plus several small charts covering major segments of the main program.

In the context of BS, the time and activity bar chart (or Gantt chart) can be effective to visually display schedules, such as, common energy usage profiles (e.g. heating, cooling, lighting, *etc.*) or human occupancy, for a given period on a specific space. Figure 2.14 gives an example of this chart.

Activity Schedules

20/08/2005 – First floor

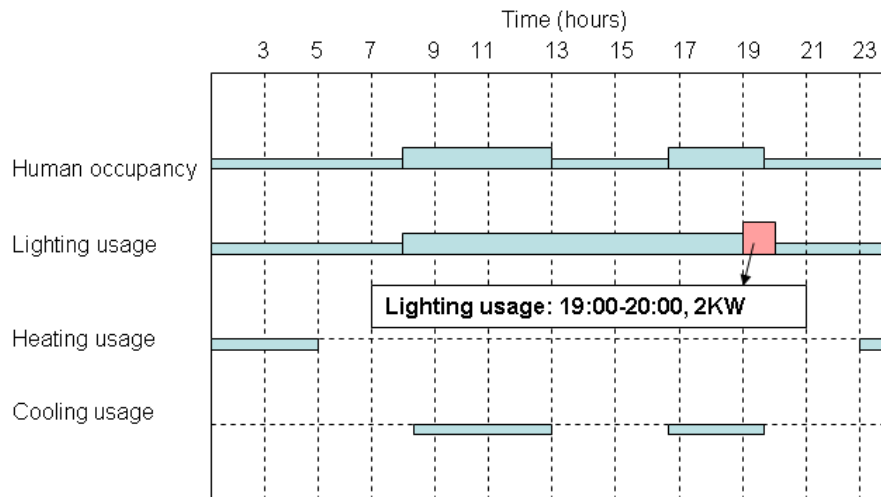


Figure 2.14: Time and activity bar chart (Gantt chart) applied to BS.

Simulated meters

This display type shows one value associated with one continuous variable. Where multiple values are to be displayed it is usually more effective to use bar/column or line graphs.

In the BS context, it may be useful in combination with the dynamic line graph. For example, Figure 2.15 shows the energy demand up to a point in time – similarly, it may be used to show the associated emissions and costs. This is applicable to any cumulative metric over time. Colour may be used to distinguish the normal, warning and critical energy demand levels.

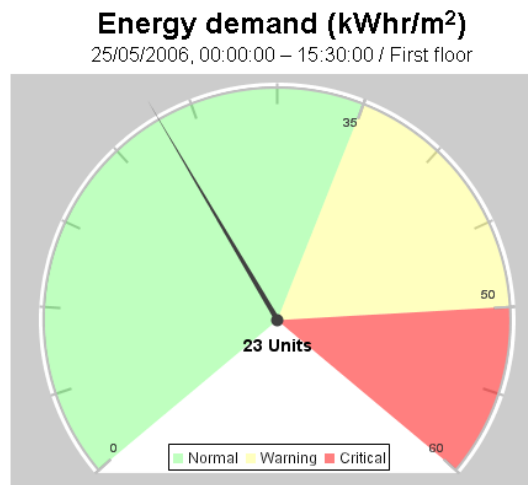


Figure 2.15: Simulated meter to show the energy demand in dynamic mode.

Figure 2.16 shows a simulated meter with the peak-power for any time step within the selected period and space in dynamic mode. Peak resultant temperature can also be used here.

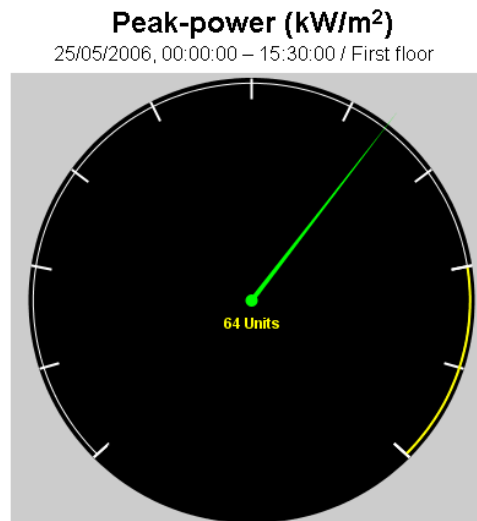


Figure 2.16: Simulated meter to show the peak power in dynamic mode.

The benefit of this approach is the user familiarity to it (e.g. clocks, speed meters in cars, *etc.*) and it is a very visual manner. The drawback is the space required to display each simulated meter, which can be easily substituted by simple numeric displays in dynamic mode. Therefore, the simulated meter is not particularly useful in the context of BS.

The next section considers graphical guidelines for the improvement of display effectiveness.

2.2.1.6 Graphical Elements Guidelines

Some graphical properties have been called retinal properties by Bertin (1967/1983 and 1977/1981) because the retina of the eye is sensitive to these properties independent of position. Table 2.4 shows Bertin's six retinal variables separated into spatial and object properties according to which area of the brain they are believed to be processed by (Kosslyn, 1994). They are cross-separated according to whether the property is good for expressing the extent of a scale (has a natural zero point) or whether its principal use is for differentiating marks.

Some retinal properties are more effective than others for encoding information. Position, for example, is by far the most effective all-around representation. Many properties are more effective for some types of data than for others. Grayscale, for example, is effective when used comparatively for ordinal variables, but it is not effective for encoding absolute quantitative variables. Table 2.4 also gives the relative effectiveness of different retinal properties.

Table 2.4: Relative effectiveness of different retinal properties (from MacEachren, 1995).

	Spatial	Q	O	N	Object	Q	O	N
Extent	<i>Position</i>	1	1	1	<i>Grayscale</i>	0.5	1	0
	<i>Size</i>	1	1	1				
Differential	<i>Orientation</i>	0.5	0.5	1	<i>Colour</i>	0.5	0.5	1
					<i>Texture</i>	0.5	0.5	1
					<i>Shape</i>	0	0	1
Legend: Q=quantitative data; O=ordinal (or sequential) data; N=Nominal data; 1=indicates the property is good for that type of data; 0.5=indicates the property is marginally effective for that type of data; and 0=indicates the property is poor for that type of data.								

Other graphical properties have also been proposed for encoding information. Several of these were collected by Healy *et al.* (1995). Visual features that can be automatically processed include: number, line orientation, length, width, size, curvature, terminators, intersection, closure, colour, intensity, flicker, direction of motion, binocular luster, stereoscopic depth, 3D depth cues and lighting direction.

Maguire (1985) considered the graphical coding of quantitative data and concluded that the graphical display of numerical data is an effective way to communicate trends, errors and breakdowns. Humans prefer graphical charts to tabulated text because the human perception system constantly seeks to find structure in order to understand the environment. Suggestions to improve the visual clarity of graphical charts include:

- clear labelling of axes and data;
- provision of grid lines to improve readability;
- differentiation of chart elements using colour or hatching; and
- the use of a logarithmic scale where the displayed data covers a wide range.

Difference graphs are typically generated using column, bar or line type graphs.

Maguire (1985) compared different coding methods and a summary of the result is discussed here. The bracketed data are the maximum number of codes (i.e. different displayed objects) for each method. The higher value is the maximum possible number, the lower value is a recommended maximum for rapid, error-free recognition:

- *Alphanumeric (unlimited)* - Highly versatile; meaning should be self-evident; location time may be longer than for graphic coding.
- *Shapes (10-20)* - Effective if the shape matches the object or operation being represented.
- *Colour (4-11)* - Attractive and efficient; excessive use is confusing; limited value for the colour blind.
- *Line angle (8-11)* - Good in special cases, e.g. for display of wind direction.
- *Line length (3-4)* – Good but could clutter display if many codes are used.
- *Line width (2-3)* – Good for general use.
- *Line style (5-9)* – Good for general use.
- *Object size (3-5)* – Fair for general use; could take up considerable space; location time longer than for shape and colour.
- *Brightness (2-4)* - Could cause fatigue, especially if screen contrast is poor.

- *Blink (2-4)* - Good for attracting attention but should be suppressible thereafter; annoying if overused; limited to small fields.
- *Reverse video*¹ (*no data*) - Effective for making data stand out; if large area is rendered in reverse video, screen flicker is more easily perceived and may become problematic
- *Underlining (no data)* - Useful but could reduce text legibility.
- *Combination of codes (unlimited)* - Could reinforce coding but complex combinations could be confusing.

In the context of BS, the above provide some useful guidelines for the design of graphs. This mainly includes: clear labelling, the use of grids, the use of colour and/or hatching to differentiate the elements, and the use of log-scales on non-stacked graphs when the data range is too wide. Colour, where possible, should match the label - example: red for heating. In addition, alphanumeric data around or on the graph itself is effective, for example to provide information about the simulated period and the part of the model the results refer to.

Legend

Legends (sometimes referred to as a key) are often critical to the understanding of a chart because they frequently contain information necessary for decoding the data graphics. Three of the major functions of legends are:

- to identify what the data graphics represent;
- to indicate certain characteristics of the entities represented; and
- where quantitative information is encoded, to enable the viewer to estimate the values that individual data graphics represent.

Legends could be located anywhere on the chart. The closer they are to the information they explain, the more convenient it is for the viewer and the lower the chance for errors to occur in the decoding process. Where possible, the information in the legend should be in the same order as it appears on the chart.

¹ Inversed video (or Reversed video): The modification of a display image or a portion thereof by inverting background and foreground colours or shades, usually for highlighting purposes.

In the context of BS, legends are important due to the simultaneous existence of many parameters. It is important to avoid abbreviations – e.g. DWH for domestic hot water - because this could confuse non technical users.

Line Fill

Lines are one of the most versatile building blocks of information graphics. A few considerations are given below.

- *Colour, shade and fill*: different colours and shades could be effective with all line weights. Patterns, fill and outlines generally require thicker lines.
- *Arrows*: the shape of an arrow generally has more to do with appearance than function, although on occasions its shape or colour is used to encode additional information (e.g. air flow speed in a flow vector plot).

The opaque material applied to lines may be used for the purpose of identification, differentiation, encoding, emphasis or appearance. Fills have four distinguishing characteristics: colour, tone, pattern and graduation. Within each characteristic there are several variations.

Patterns formed by parallel lines are referred to as hatched, while patterns with two or more sets of intersecting parallel lines are referred to as crosshatched.

Fills may be used with lines, borders and frames. When used with lines, the exact patterns are sometimes not distinguished because only a portion of the design appears, depending on the width of the line. In many cases this presents no problem, as long as the fill successfully differentiates one line from another. General guidelines include:

- solids such as black and white are many times reserved for small areas;
- lighter colours and finer patterns are generally used in large areas;
- coarse patterns and bold vertical or horizontal lines sometimes give a harsh appearance;

- many copiers cause faint patterns to disappear and dense patterns to turn to solid black; and
- small differences in tones are generally not used to convey quantitative information because of the difficulty of discriminating one from the other.

In the context of BS, arrows could have an important role, for example in the display of air movement, where the arrow orientation may indicate air direction and thickness or length the air speed. Lines in combination with colour can be useful when displaying wire-frame geometry to differentiate individual or groups of zones.

Logarithmic Scale

A logarithm is the power to which a base number must be raised to equal a given value. For example, the logarithm of 100 using a base of 10 is two since 10 must be raised to the power of two (10^2) to equal 100.

If a graph has one logarithmic scale and one non-logarithmic scale (generally quantitative or sequential), it is referred to as a semi-logarithmic or semi-log graph. In a semi-log graph, the logarithmic scale is generally on the vertical axis. If the graph has two logarithmic scales, it is referred to as a full logarithmic or log-log graph.

Logarithmic graphs are mostly used with scatter or line type graphs. It is possible to use other types such as column, bar and area but these types are seldom used because viewers tend to equate the size or area of the data graphics with the values represented, which, in the case of logarithmic graphs, gives an incorrect impression.

Logarithmic scales are always quantitative. Because of the nature of logarithms, a logarithmic scale does not have a zero. If the variable being plotted approaches zero, values such as 0.1, 0.01, 0.001, *etc.* are used as the lower value. For all practical purposes, negative numbers are not plotted on logarithmic graphs. The major scale

intervals on logarithmic scales are called cycles (also referred to as banks, decks, phases or tiers).

A logarithmic scale is useful when displaying data with large differences in numeric values and/or large differences between multiple data series. For example, if values lie between 0.3 to 1.5 in one data-set and 8,719 and 50,444 in another then it would be difficult to display these data on a linear scale that allows the viewer to identify differences with reasonable accuracy. The use of a logarithmic scale improves the resolution of the individual data points in such a case.

In the context of BS, the log-scale would be useful to display energy-related emissions where the likely range of values for CO₂, NO_x and SO_x emissions will be large.

2.2.1.7 Tables

Tables are charts with information arranged in rows and columns in some meaningful way. Tables are often used because they:

- are one of the best ways to convey exact numerical values;
- present data compactly;
- assist the viewer in making comparisons, determining how things are organised and noting relationships between various sets of data;
- are a convenient ways of storing data for rapid access;
- are an excellent vehicle for recording and communicating repetitive information (forms); and
- organise information for which graphing would be inappropriate.

Sometimes parts of a table are given additional names that relate specifically to the application. For example, when used in a database, a column might be called a field, while a row is referred to as a record.

In most cases the purpose of a table influences how the table is designed and how the data in it are organised. For example, when used for reference, the contained data is

usually alphabetised or numerically sequenced. When used for analysis, the information is often ranked in ascending or descending order. Some typical application examples follow.

Analysis: Tables used for analysis are sometimes called statistical, summary or analytical tables. Their major function is to assist the viewer in analyzing the information included in table. There are always two or more variables and the data in the body is normally numerical. Information is generally arranged, ranked and sorted to make relationships, trends, comparisons, distributions, and anomalies stand out.

According to Murdoch and Barnes (1998), statistics is a mathematical science pertaining to the collection, analysis, interpretation, and presentation of data. It is applicable to a wide variety of academic disciplines, from the physical and social science to the humanities; it is also used for making informed decisions in all areas of business, government and engineering. Statistical methods can be used to summarize or describe a collection of data; this is called descriptive. In addition, patterns in the data may be modelled in a way that accounts for randomness and uncertainty in the observations, to draw inferences about the process or population being studied; this is called inferential statistics. Both descriptive and inferential statistics can be considered part of applied statistics. There is also a discipline of mathematical statistics, which is concerned with the theoretical basis of the subject.

In the context of BS, statistical measures are crucial to understand data – values such as: maximum (e.g. maximum capacities in a group of zones), minimum (e.g. minimum temperatures in a group of zones) and average (e.g. average temperatures in a group of zones). Frequency distributions / percentages (and their cumulative values) are also important to provide insight into the data, for example to display resultant temperatures, load profiles, *etc.*

Reference: This type of table is frequently called a reference or source table. The major emphasis of such tables is on ease of data retrieval. Information is generally arranged in alphanumeric order, by geographic area, numerically in ascending or

descending order or chronologically so that specific bits of information may be located rapidly.

Scheduling: Tables used for scheduling are often referred to as charts, as in machines loading charts, Gantt charts, milestones charts, *etc.* The things being scheduled are typically listed on the vertical axis with time intervals on the horizontal axis. Names, numbers, symbols, colour and so on can be used in the body of the table.

Calendar: A calendar represents one of the simplest forms of a table. It has a unique characteristic in that the information therein flows from one line to the next in the same way that text does.

Forms: Most varieties of forms utilise a tabular format.

General: There are a huge number of tables that cannot be easily categorised. They probably constitute the majority of the tables in use today.

If the headings represent sequential (e.g., time series, order of occurrence, *etc.*) or quantitative variables, the individual headings are arranged in their proper sequential or numerical order progressing from left to right along the horizontal axis. On the vertical axis they may progress either up or down.

Headings representing categories may be arranged in any order. Some typical arrangements include:

- alphabetical;
- ascending or descending order ranked by some row or column of data in the body of the table;
- chronological, even if it is not a true sequential series - for example, the event that happened first, second, third, *etc.*;
- geographical;
- qualitative – for example, the thing assumed to be best, second best, *etc.*;

- frequently compared columns and rows placed close together;
- related columns and rows located close to one another, for example columns with actual and cumulative values, or a column of values co-located with a column displaying the percentages of the whole that each value represents; and
- more important values placed near the top or left side where they are most easily noticed by the viewer.

Total columns and rows are frequently located at the far right or bottom. Where these columns and rows are most important in the table, they can be positioned as the first row or column after the headings.

Sometimes tables that display data using words, numbers and other graphic images can be particularly informative. There are no restrictions as to the combination of methods that may be used.

Methods involving grid lines, guidelines, bold text, *etc.*, have been developed to:

- help organise information in tables;
- assist the viewer in visually tracking data;
- emphasise key information; and
- improve the table appearance .

Many organisations have standards for how they would like tables constructed to achieve uniformity. There are no industry standards.

According to Tufte (2001), tables are the best way to show exact numerical values, although the entries could equally well be arranged in semi-graphical form. Tables are preferable to graphics for many small data sets (Ehrenberg, 1977).

Tables also work well when data presentation requires many localised comparisons. A super-table is likely to attract and intrigue readers through its organised, sequential

detail and reference-like quality. One super-table is far better than many individual graphic charts.

In the context of BS, tables provide an excellent way to organise and structure data. Within an IPV, small analysis tables may be used to display annual totals for a given design option (e.g. energy demand and local renewable energy supply). Its location within the IPV must be prominent (e.g. centred, top-left, *etc.*) to increase effectiveness. Another important use of tables is to facilitate the definition of time periods through a Calendar, which is effectively a table populated with alphanumeric data.

Matrix display

This facilitates graphs arranged in a tabular format. It combines the advantages of graphs with the benefits of a table. The concept is applicable to any type of graph. In addition to displaying graphs in a tabular format, maps, diagrams, and even additional small tables may be arranged in similar fashion.


A matrix display consists of multiple charts arranged in rows and column order. The aim is to simplify the analysis of large quantities of data by enabling the viewer to simultaneously study multiple charts.

General observations regarding matrix type displays include:

- they are effective at facilitating analysis, monitoring and communication;
- they have excellent application potential in most fields;
- individual scales may be used for each graph, or a single scale may be used for an entire row or column;
- when the aim is to highlight correlations or deviations, scales may be omitted entirely;
- other than legibility, there is no limit to the number of rows and columns that may be incorporated into a single display;
- derived values such as deviations may be used as effectively as actual values;

- individual charts may abut one another or have spaces between them;
- most of the enhancement techniques applicable to individual charts can be applied to charts within a matrix (e.g. curve fitting, colour coding, confidence limits, use of symbols, *etc.*);
- in cases such as monitoring for deviations and trends or when looking for correlations, individual charts may be small without loss of utility; and
- almost any type of chart may be intermixed.

Figure 2.17 shows the matrix technique applied effectively to a commercial web-site. Here, three comparable city breaks are shown side-by-side. It uses mainly image, alphanumeric and graph formats to summarize the holidays. The key information (e.g. cost of holidays) is highlighted with colour and a type change.

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


















			
	Barcelona	New York City	Madrid
▼ At a glance			
Weekend of 27th May	from £169 27 May - 30 May flight + 3 nights, 3* hotel View all deals in May	from £523 25 May - 29 May flight + 4 nights, 4* hotel View all deals in May	from £378 25 May - 28 May flight + 3 nights, 3* hotel View all deals in May
Summary	Sip sangria on the beach by day, hit some of Europe's top clubs, bars and restaurants by night. Barcelona really does offer all a visitor could wish for, with a rich cultural history, friendly locals and warm weather.	Dynamic, crazy and mesmerising, New York City is the ultimate in urban cool - perfect for a long weekend shopping, partying, sightseeing or all three! An essential destination for any discerning traveller.	Spain's capital is a fantastic place to shop and most importantly party. The city's numerous bars and restaurants keep Madrid's occupants happy well into the early hours of the morning.
Best for	Romance  88% Food  91% Culture  94% Nightlife  98% SightSeeing  92% FamilyFun  84% Shopping  89%	Romance  86% Food  88% Culture  95% Nightlife  98% SightSeeing  99% FamilyFun  88% Shopping  99%	Romance  88% Food  88% Culture  86% Nightlife  96% SightSeeing  86% FamilyFun  85% Shopping  88%
▼ Description			
▼ Weekend of 27th Your preferred weekend	from £169	from £523	from £378

Figure 2.17: Matrix technique to compare city break holidays
(from Expedia Web-site, 2006).

Another example of information being structured by the matrix technique is shown in Figure 2.18. Here, a five day weather forecast information is provided. It mainly uses

image icons and alphanumeric formats plus effective colour applied (combinations of formats and colour increase effectiveness). 24-hour details are also available.



Figure 2.18: Matrix technique to present weather information
 (from BBC Weather Web-site, 2006).

In the context of BS, matrix displays offer a powerful way to present time-varying, multi-variate performance data. It is the display device that the work reported here builds upon. An IPV is a matrix where the cells contain static or animated graphs, images, text and tables. The approach capitalises on the concept of a table, which is an organised and structured way to explore, analyse and present data.

Date and Time

Bounford (2000) has expanded on time/date displays. Time may be considered as a linear record of events, in which case it may be portrayed visually in a number of ways. Time may also be considered cyclical, with recurring events following a repetitive pattern. It is possible to employ the elements of a matrix display to

visualise time in the form of diaries, calendars and timetables: Figure 2.19 gives some examples of a user interface for date and time selection.

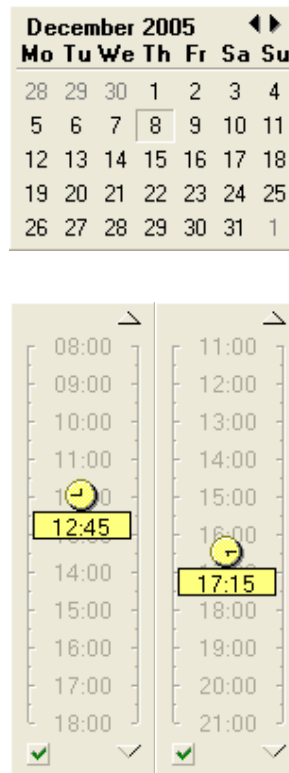


Figure 2.19: Date and time selection interface
(from Lotus Notes Web-site, 2005).

All time visualisations are valid, each having its own use and context. It is informative to plot the course of historical events along a linear path, particular when making comparisons over a period of time. Timetables list a series of comparative options, with the time progression shown along both the horizontal and vertical axes. Cyclical events can usefully be shown on a circular grid (seasonal activities following a natural cycle particularly lend themselves to this treatment).

Apart from straightforward calendars or almanacs, time charts need to include variable, and often substantial, amounts of data types. This may create problems when a time scale of equal divisions is required. Even when divisions may be varied, events involving substantial description are unlikely to conveniently occur side-by-

side. In such cases, skilful graphic design is needed to ensure that the facts are displayed clearly in an easily understood chronological matrix.

Time duration may be indicated in two ways using the clock-face symbol:

- time accumulation, the time of the current action being highlighted; and
- where the arrow emphasises dynamic progress.

Another useful visual device that may be employed in time-chart design is the calendar block. This creates a focus for the particular date, or it can be the commencement point for a month or year.

In the context of BS, the treatment of dates and time are fundamentally important because of their constant:

- To display dates effectively, a calendar is a powerful technique because of user familiarity and the structured way it presents information. When considering a building's annual performance, it is common to simulate a few critical periods in the year (e.g. typical summer, winter and transitional season days) and then scale the figures up to annual. The display of such typical periods on a calendar can be most effective, particularly if the individual days (usually critical hot/cold days) are highlighted with a different colour.
- Performance data often corresponds to a small time step (e.g. second or less for the case of air and electricity flow respectively). In such cases effective time control may be achieved through the use of drill-down applied to a calendar, progressing, for example, from a month, to a day, to an hour, to a second in an interactive manner. Another, common approach to the treatment of time is through a menu. When displaying data in a dynamic way, a virtual clock with hands to indicate the hour, minute and second, in combination with alphanumeric data (e.g. 03:23:45 P.M.) is likely to prove effective.

2.2.1.8 Text

The text used with charts and graphs can often have a significant impact on the appearance and clarity of the display. The definitions of some of the major terms used with text are recounted below:

Typeface: Sometimes referred to font. When alphanumeric characters have the same design features they are termed a typeface. There are hundreds of typefaces with names such as Helvetica, Times, Geneva, *etc.* Three major categories of typefaces are:

- *Serif typeface* – Serif letters have small lines projecting from the ends of each of their main lines or strokes.
- *Sans (without) serif typeface* – Sans serif letters do not have the small lines projecting as the serif typefaces do.
- *Decorative typefaces* – Decorative typeface are mainly used for headings, special effect or to improve the appearance of charts.

Type size: Type size is frequently stated in points, based on a standard of 72 points to the inch. Thus, if a type is designed as 12-point, this means that it is 12/72 or 1/6 of an inch tall, while 36-points is 36/72 or 1/2 of an inch tall. The height is measured from the highest point (highest ascender) on any letter of the typeface to the lowest point (lowest descender).

Leading: Sometimes referred to as line space. Leading (pronounced ledding) is the vertical distance between lines of type. It is measured from the baseline of one line of type to the baseline of the next line. Leading is generally specified in the same point system used to specify type size (i.e. 72 points to the inch).

Tracking and Kerning: Tracking changes the horizontal spacing of whole words, lines or paragraphs. Kerning changes the horizontal spacing between pairs of letters, one of which is generally a capital. Its major function is to improve appearance in those cases where the normal spacing between letters would seem too large.

Type style: Different styles of text are used for many reasons, including placing special emphasis on certain text, indicating book titles, denoting totals, highlighting names, *etc.* The most widely used styles are: **Bold**, *Italics*, Underlined, **Shaded or coloured**, FULL SIZE CAPITALS, SMALL CAPITALS, **Reversed type**, Outlined, Superscript and Subscript.

Alignment: A term that is generally used to describe how text and/or numbers are positioned. It can be applied to stand-alone text, tables, columns of numbers and graphs. There are five major types of alignment: Aligned flush left/ragged right; Aligned flush right/ragged left; Centred; Justified (aligned flush right and left – only applicable for text); and Aligned on decimal points (not applicable for text).

Sometimes the only way to display information is in alphanumeric format. According to Dix *et al* (1998), textual data should be represented in non-capital letters using Serif font for ease of reading. Tullis (1988) has reported that search times decrease where alphanumeric data is aligned, structured, grouped and spaced.

In the context of BS, alphanumeric data (simple text) is important to explain technical concepts of simulation and some outputs. It is also used in help systems, when writing technical reports to clients and on or near graphs to illuminate content. But, as stated in the guidelines mention above, it is crucial that all alphanumeric data be aligned, structured, grouped and spaced to improve clarity and readability.

2.2.1.9 Colour Attribute

The effectiveness of quantitative displays can be vastly improved by the use of the colour attribute. Harris (1999) compiled some of the many potential applications of colour with charts and graphs:

- differentiates various data elements such as multiple data series on a graph, types of natural resources on a map, types of paths on a schematic, *etc.*;
- encodes areas of equal value such as filled contour graphs and quantitative maps;

- alerts the viewer when a predefined condition occurs such as values becoming negative, measurements exceeding limits or an unfavourable condition arising;
- provides emphasis to key elements on all types of charts;
- identifies particular values, places, actions, *etc.*;
- indicates all items, values, organisations and so on that are the same or similar by making them all the same colour;
- signifies changes in directions, time periods, trends, responsibility, type of condition, *etc.*;
- improves the appearance of charts when applied to any or all of the chart elements (such as data graphics, backgrounds, borders, illustrations, *etc.*);
- captures and retains the viewer's attention;
- encodes information into text – for example, the use of red for unfavourable values or colour coded labels to assist identification (e.g. differentiating miles and kilometres on maps);
- distinguishes lines such as grid lines and reference lines from data lines;
- by means of gradations, indicates gradual transitions from one condition to another or emphasises the direction of flow of an activity;
- by means of faint backgrounds, organises information and identifies such items as time periods, area of responsibility, new or old, desirable or undesirable, *etc.*;
- gives more meaning and impact to pictures, illustrations and images;
- colour-coding similar information allows viewers to follow a thread of related information;
- stripes of colour assists the viewer to visually follow long columns or rows of data;
- on maps, differentiates such things as land, water, vegetation, *etc.*; and
- flags end-of-month or end-of-year summaries.

According to Tufte (1990), the human eye is exquisitely sensitive to colour variations: a trained colourist could distinguish between 1,000,000 colours when asked to perform pairwise comparisons. Some 20,000 colours are accessible to many

viewers, with the constraints for practical applications set by the limits of human visual memory rather than the capacity to discriminate locally between adjacent tints. For encoding abstract information, however, more than 20 or 30 colours frequently produce diminishing or negative returns.

Foley *et al.* (1984), Shneiderman (1987), Robertson (1988) and Tufte (1989) have stated that noise is costly, since computer displays are low-resolution devices, working at extremely low data densities, 1/10 to 1/1000 of a map or book page. Colour can significantly improve the information resolution of a computer screen.

Spence (2001) has stated that numerical data can be encoded by colour but its use should be undertaken with caution. There is, for example, a minimum size of line or point whose colour can be discriminated, and therefore a consequent need to exercise care in the construction of graphs. Colour scale to represent magnitude should also be chosen carefully. A popular choice is the spectrum, with red denoting large elements and blue small elements. Grayscale shading can be used to advantage, though there is quite a low limit to the number of shades that can satisfactorily be discriminated. There are many other guidelines to the use of colour (Jackson *et al.*, 1994).

According to Tufte (1990), a grand strategy is to use colours found in nature, especially those on the lighter side, such as blues, yellows and greys of sky and shadow. Nature's colours are familiar and coherent, processing a widely accepted harmony to the human eye – and their source has a certain definitive authority. A palette of nature's colour helps suppress production of garish and content-empty colour-junk. Local emphasis for data is then given by means of spot highlights of strong colour woven through the serene background.

An alternative to the use of different colours are shades, which provide a natural order/hierarchy (lighter to darker shade), are easily comprehended and show varying quantities better than the use of different colours. In the face of the complex,

graphical methods that organise and order the flow of information presented to the eye will maintain clarity.

According to Klee (1945), colour brings to information more than just code naming visual nouns – colour is a natural quantifier, with a perceptually continuous (in value and saturation) span of incredible fineness of distinction, at a precision comparable to most measurement. Figure 2.20 shows the technique being applied to a commercial Web-site.

Select outbound fare *		Select inbound fare *	
PRICE	FARE FAMILY	PRICE	FARE FAMILY
£127.50	Economy Semi Flexible	£42.50	Economy Restrictive
£196.50	Economy Fully Flexible	£52.50	Economy Restrictive
£224.00	Top Executive	£87.50	Economy Restrictive
£305.50	Economy Fully Flexible	£107.50	Economy Semi Flexible
£318.50	Top Executive	£127.50	Economy Semi Flexible
£354.50	Top Executive	£196.50	Economy Fully Flexible

* Fares displayed do not include any surcharges, fees or taxes. Please select your flights and fares and click "Continue". The total amount will be displayed in the next page.

[Need Help?](#) [Fare Guide](#)

Figure 2.20: Online flight booking techniques using colour value scale
(from TAP Web-site, 2005).

Tufte (1990) has stated that although easy to learn and remember, value scales may be vulnerable to the inaccuracies of reading provoked by disturbing contextual effects such as edge fluting and simultaneous contrast.

A widely-used alternative is a scale of rainbow colours, replacing the clear visual sequence of light to dark with the disorderly red, orange, yellow, green, blue, indigo, and violet – an encoding that now and then reduces perplexed viewers to mumbling colour names and numbers they represent. Despite our experiences with the spectrum in science textbooks and rainbows, the mind's eye does not readily give an order to ROYGBIV. In the face of this rainbow encipherment, viewers must turn to other cues (counter, edge, labels) in order to see and interpret data.

Any colour coding of quantity (whether based on variations in hue, value or saturation) is potentially sensitive to interactive contextual effects. These perceived colour shifts, while an infrequent threat to accuracy of reading in day-to-day information design, are surprising and vivid – suggesting that colour differences should not be relied upon as the sole method for sending a message amidst a mosaic of complex and variable data.

Wyszecki and Stiles (1982) and Judd and Wyszecki (1975) have stated that colour itself is subtle and exacting. Furthermore, the process of translating perceived colour marks on paper into quantitative data residing in the viewer's mind is beset by uncertainty and complexity.

Hurvich (1981) and Imhof (1982) stated that these translations are nonlinear (thus gamma curves), often noisy and idiosyncratic, with plenty of differences in perception found among viewers (including several percent who are colour-deficient).

Contour delineators eliminate edge fluting and make each field a more coherent whole, minimising within-field visual variation and maximising between-field differences. Edge lines allow very fine value distinctions, increasing scale precision. Between fields, only the presence of an edge is needed, a thin line of a colour not too distant in value from the scale itself. The technique of graphic design is confirmed by the theory of vision, which indicates that human cognition processing gives considerable and often decisive weight to contour information (Marr, 1985).

Colour is an effective way to support analysis at a glance and to group elements that belong together. However, the attribute has accessibility implications for those with impaired vision. According to Byrne (1984) and Tufte (1990), the use of the primary colours (yellow, red and blue) and black provides maximum differentiation, which may help the colour blind.

Colour can structure and divide information and make it more pleasant to look at. Conversely, excessive use of colour results in colour pollution (Tufte 1990), which can seriously detract from the information content. Travis (1991) claimed that colour is useful to distinguish groups and to highlight prominent features. Davidoff (1987) suggested that colour is an effective segmentation device (i.e. areas that are related have the same or near-same colour) and that its use could assist searching operations (although too many colours increase search times). Colour, as a search-assisting agent, is more helpful to inexperienced users (when compared to black and white displays). Conversely, colour is less useful in categorisation and memorisation.

Figure 2.21 attempts to demonstrate the importance of colour when applied well. The top image shows a block of Java-code (from the I²PV tool) without meaningful colour applied (all black), and the bottom image shows the exact same block of Java-code with meaningful colour applied (i.e. syntax highlighting) on a text editor. This simple change of colour coding for some key strings greatly improves the code's readability and therefore increasing development efficiency.

```

void outputTiming() {
    // TODO: remove TimingCanvas3D and switch these to use view instead of
    // tc when these methods are implemented
    TimingCanvas3D tc = (TimingCanvas3D) canvas;
    long now = System.currentTimeMillis();
    long[] startTimes = new long[10];
    tc.getFrameStartTimes(startTimes);
    long lastFrameDuration = tc.getLastFrameDuration();
    int numFrames = (int)tc.getFrameNumber();

    if (numFrames > 10) numFrames = 10;
    double elapsed = (now - startTimes[numFrames-1]) / 1000.0;
    System.out.println("Last " + numFrames + " frames rendered in " +
        numFormat.format(elapsed, 1) + " seconds, " +
        numFormat.format(numFrames / elapsed, 2) + " frames/sec");
    System.out.println(numTris + " triangles/frame ");
    System.out.println("Overall rate: " +
        numFormat.format((numTris * numFrames) / (1000.0 * elapsed), 0) +
        "K triangles/sec");
    System.out.println("Last frame rendered in " +
        numFormat.format(lastFrameDuration / 1000.0, 3) + " seconds " +
        numFormat.format(1.0 * numTris / lastFrameDuration, 0) +
        "K triangles/sec ");
}

```

```

void outputTiming() {
    // TODO: remove TimingCanvas3D and switch these to use view instead of
    // tc when these methods are implemented
    TimingCanvas3D tc = (TimingCanvas3D) canvas;
    long now = System.currentTimeMillis();
    long[] startTimes = new long[10];
    tc.getFrameStartTimes(startTimes);
    long lastFrameDuration = tc.getLastFrameDuration();
    int numFrames = (int)tc.getFrameNumber();

    if (numFrames > 10) numFrames = 10;
    double elapsed = (now - startTimes[numFrames-1]) / 1000.0;
    System.out.println("Last " + numFrames + " frames rendered in " +
        numFormat.format(elapsed, 1) + " seconds, " +
        numFormat.format(numFrames / elapsed, 2) + " frames/sec");
    System.out.println(numTris + " triangles/frame ");
    System.out.println("Overall rate: " +
        numFormat.format((numTris * numFrames) / (1000.0 * elapsed), 0) +
        "K triangles/sec");
    System.out.println("Last frame rendered in " +
        numFormat.format(lastFrameDuration / 1000.0, 3) + " seconds " +
        numFormat.format(1.0 * numTris / lastFrameDuration, 0) +
        "K triangles/sec ");
}

```

Figure 2.21: Colour applied to alphanumeric format
(from Web-site UltraEdit, 2006).

In the context of BS, colour is an extremely important attribute to differentiate data, to group related data, to highlight specific data or simply to achieve a more attractive display. Some considerations follow.

- An effective way to display indoor environmental data (e.g. temperature, CO₂ concentration, *etc.*) is to use filled counter graph. However, colour blind

people would benefit if value scales or patterns are available through a toggle. Also, bar/column, line or scatter graphs are enhanced when colour is used, in particular when the colour matches the label itself (e.g. red for heating or maximum values, blue for cooling, green for renewable energy, *etc.*).

- In geometry representation (wire-frame or solid), the use of colour allows differentiation of parts (e.g. group of zones) or association of objects (e.g. surfaces with the same temperatures). The use of transparency is an effective way to reveal internal data.
- Coloured images make the display more attractive.
- Alphanumeric data can be effectively coloured to emphasise critical values such as comfort or health threatening situations (e.g. high CO₂ concentrations, low temperatures, *etc.*) or to explain concepts.
- To highlight design option differences not only in terms of alphanumeric data but also to graphs and images.

While colour is an effective way to improve BS displays, its overuse must be avoided especially where users may be visually impaired.

2.2.1.10 Image Icons

According to Maguire (1985) graphic symbols or icons are being used with increasing frequency in computer applications. The Xerox and Apple Macintosh systems, for example, use icons to represent an 'electronic desk'. Familiar office items such as file drawers, folders, wastebaskets, calculators and clocks are all shown in symbol form. The functions they represent are then selected by pointing to them.




























Possible reasons for using icons in human-computer interfaces are as follows:

1. They are visually more distinctive than a set of words.
2. They can represent a lot of information in a small space (space being at a premium on a computer screen).
3. They may be subjectively more desirable than text (Jones, 1984).

In the view of van Dam (1984):

“It has been found that an interface based on menus and icons is preferable by most people over a strictly alphanumeric interface because, when these graphic features are properly designed, they seem more natural, are easier to learn and use, require little memorizing and result in fewer mistakes.”

However, there is a view that while icons are well suited to casual users, they are less suited to experts who may be able to work more efficiently entering textual commands via a keyboard. One disadvantage of icons is that they require the user to learn and remember their meaning. It is not always possible to guess the meaning of an icon. One effective way to solve the problem is to use legends easily accessible to the users. Figures 2.22 and 2.23 show examples of such legends applied to car hire and weather web-sites respectively.

Price and Vehicle Description	Features
○ GBP 265.02 Daihatsu Cuore 1.0 or similar	 4  3  
○ GBP 281.78 Toyota Yaris 1.0 or similar	 5  3  
● GBP 330.04 Smart Forfour 1.1 or similar	 5  2   
○ GBP 406.17 Ford Fiesta or similar	 5  3  
○ GBP 431.55 Renault Megane II 1.4 or similar	 5  3   
○ GBP 487.42 Toyota Corolla Wagon 1.4 or similar	 5  3   
○ GBP 653.66 Seat Toledo 1.6 or similar	 5  3   






Vehicle Features Key	
Approx. Vehicle Size/Type:	
Passenger Capacity:	
Luggage Capacity:	
Manual Transmission:	
Automatic Transmission:	
Air Conditioning:	

Figure 2.22: Image icons and legend of a car hire web-site
(from Hertz Web-site, 2006).

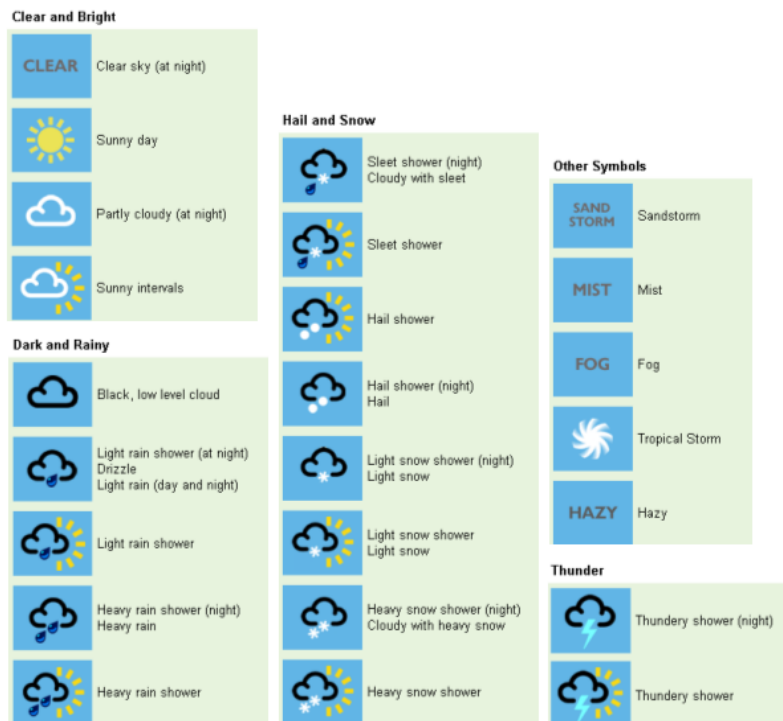


Figure 2.23: Image icons and legend of a weather web-site
 (from BBC Weather Web-site, 2006).

The following constructive advice can be offered in relation to icons:

- Icons are best concrete concepts and are most effective as a miniature representation of the physical object to which they refer. This recommendation is supported by the work of Rogers (1986).
- The more abstract the concept, the harder it is to find acceptable icon.
- When an icon is selected (e.g. clicked on with a mouse), give feedback by redisplaying it in inversed video².
- If the display resolution is too low, causing icons to be poorly represented, consider replacing them with text.
- If the product or system is to be sold overseas, check that the icons will be understandable in the receiving countries.
- Provide icon text labels for novice users and infrequent tasks, which can be turned off as required. Alternatively show an “icon key” on a help screen.
- For common actions provide command equivalents, e.g. to call Help the user may click on the Help icon from the drop down menu. A command such as Ctrl-H could be used to do the same.

Figure 2.24 shows an example of common icons to manipulate a web browser, and figure 2.25 a common calendar icon to select dates to book a flight.

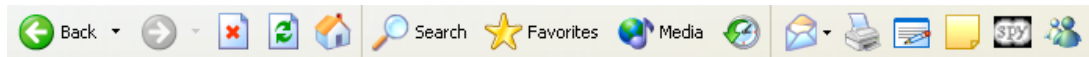


Figure 2.24: Image icons on a web browser
(from Microsoft Web-site, 2006)

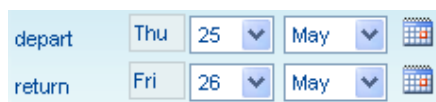


Figure 2.25: Calendar image icon on On-line flight booking system
(from BMI Web-site, 2006).

Figure 2.26 shows an example of how image icons can effectively be linked to coloured alphanumeric information. Here, football clubs or World Cup logos, which have their predominant colours, are linked to the latest related news. This technique increases the search efficiency due to combined visual clues.

² Inversed video (or Reversed video): The modification of a display image or a portion thereof by inverting background and foreground colours or shades, usually for highlighting purposes.



Figure 2.26: Image icons and colour attribute applied on a football web-site (from A Bola Web-site, 2006).

Icons are extremely common in today's chatting software, such as, Skype, ICQ and MSN (see Figure 2.27). The most popular icons are the 'faces' – which the theory is linked to the Cartoon (or Chernoff) faces. Each icon is usually associated with an alphanumeric string (in combination with other characters) for quick displays. The icons can be static or dynamic; the latter increase effectiveness substantially. The icons have effective colour applied. The benefits of icons in chatting software are:

- They increase efficiency of communication, because an icon can usually carry the same message as a full sentence, and therefore speed up the communication process;
- They increase effectiveness of the message, because at a glance the user can perceive the emotion(s) being communicated; and
- They save space, because the dimensions of the icon are usually very small.

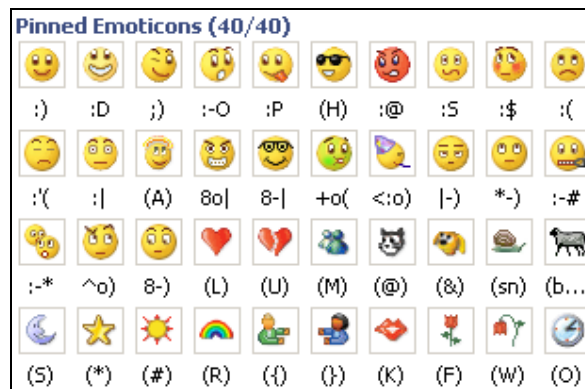


Figure 2.27: Static and dynamic image icons in chatting software
(from MSN Messenger Web-site, 2006).

2.2.1.11 Limitations and Cautions

Information visualisation is a major development that is already having substantial influence. While the technique has great potential, it also has limitations that need to be avoided.

To commence with the obvious: information visualisation is for sighted people; those with limited or no vision will not benefit from tools using the technique.

Another concern is that many users may not be visually oriented. They may prefer textual or numerical data presented in scrolling lists. Preferences do not always align with performance, and some users do better with visual presentations, even if they have a low preference for them. High density displays, richly packed with useful information, may make some users anxious, giving them feelings of information overload. Many users would need training in user interfaces for information visualisation, just as they previously did for graphical user interfaces.

As with any new technique, a danger with information visualisation is that people will misuse it and arrive at incorrect conclusions. Users may misinterpret displays, not realising that data has been occluded or encoded in unexpected ways. Colour or size could inevitably be used in misleading ways, just as it has throughout the history of statistical data presentation.

A likely source of frustration would be the use of incompatible formats for data, non-standard widgets and inconsistent terminology. A successful industry is more likely to emerge if designers of competing products could agree common formats, widgets and terminology. Open standards have proven to be enormously successful in other information technology domains (e.g. the UNIX file format and the TCP/IP network protocol).

The guidelines provided in the visualisation section should not be applied rigidly and must be treated with some scepticism because they are not logically or mathematically certain.

“What is to be sought in designs for the display of information is the clear portrayal of complexity. Not the complication of the simple; rather the task of the designer is to give visual access to the subtle and the difficult – that is, the revelation of the complex.”
(Tufte, 2001)

Regarding the intrinsic or relative effectiveness of the various techniques for presenting quantitative data (Spence, 2001):

- the value of a particular technique depends very much upon the application domain, the user and the task being performed;
- a combination of techniques is typically involved in a real world application; and
- there is no way of evaluating the relative merits of techniques when combined within a complex visualisation tool.

Therefore, the aim of the research reported here is to undertake an analysis of information visualisation in the specific context of building simulation; this is done in Chapter 5.

2.2.2 Sonification

The following concepts and definitions are mainly derived from the work of Spence (2001), Card *et al.* (1999) and Buxton (1995).

Like information visualisation, there is a parallel movement on the theme of sonification (or audiolisation) that seeks to create auditory equivalents of visualisation tools.

Music enthusiasts are capable of identifying not only the different musical instruments, of which there are twenty or so, but also the different notes, chords, tempos and rhythms that are being played. The potential for encoding data in sound therefore appears considerable.

In fact, some researchers argue that our auditory capabilities have unique features that may complement human visual abilities:

1. The capacity to pick up outliers, akin to the missed note in a symphony performance, may be greater in sonic environments.
2. Auditory information is omni-directional and, therefore, easily heard even when the listener's attention is not focused on it. Audiolisations may be effective for long-term monitoring tasks and for attention getting when anomalies appear. One medical lab worker described a system that played the sound of lab results through a speaker, allowing the staff to move about freely. When they heard an anomaly, they would come over and examine the sample in great detail. Indeed, when using automatic teller machines, people are used to hearing a 'beep' to indicate a change of state of the machine - a simple but extremely effective way of encoding data in sound and thereby allowing the state of the machine to be visualised.
3. Another advantage of audiolisations may be its use in telephone-based systems. Users might, for example, listen to a symphony of sounds representing their stock market portfolio, listening for significant patterns that require further attention.

Natural languages and the audio channel are the primary means of human-to-human communication, but these devices are little used between human and machine. The audio channel is not restricted to speech. It is suited to a wide variety of other audio-based interaction. Non-speech audio can play an important role in computer-mediated interactions, for example in factory process control or in aircraft flight management systems.

Although audio is a powerful mode of communication, it is not commonly used in human-computer interaction. In part this is because audio is simply inappropriate in the given context. For example, an individual can only really be attentive to one stream of spoken instructions at a time. Consequently, in cases where we need to control more than one process simultaneously, speech (alone) is generally not an effective mode of communication. Like all other modes of interaction, audio has strengths and weaknesses that need to be understood if it is to be used effectively. Finally, technical and economic difficulties have often discouraged the use of audio input and output.

2.2.2.1 Speech Audio

Speech is often more effective when coupled with other modalities of integration, especially gestures such as pointing and marking. Just as face-to-face conversation is much richer due to the ability to see the accompanying body language, so is it the case when interacting with computers.

Speech has a number of properties that need to be taken into account by an interface designer. For example, while it is faster to speak than to write, it is faster to read than to listen. This is good for input, bad for retrieval. Speech is effective in communicating many concepts, but spatial and temporal relationships are often better articulated with gestures or markings. Speech, and audio in general, is ubiquitous; the visual channel is localised – you have to be looking at something to see it – but the ringing of a telephone can be heard anywhere. If the call is for the person who answers, it is an advantage. If not, it is an intrusion.

Stored-speech

One of the most powerful uses of speech is when it is applied to computer-mediated human-human communication, rather than human-computer interaction. Speech is stored in computer memory and later retrieved for playback or processing. This is a common computer application, including many telephone answering machines and all voice mail.

One of the main benefits of voice store-and-forward comes in integrating voice messaging with other document types, such as written text. In so doing, it is possible to move from voice mail to voice annotation. This capability is now starting to find its way into word processors.

Chalfonte *et al* (1991) compared the relative effectiveness of written and voice annotation of written documents. In their study, written annotations appeared on the paper document itself while voice annotations were recorded on an audio cassette. The main finding was that there was a significant difference in the kinds of annotations for which voice was best: voice was used mainly for global, high-level comments while written annotation lent itself to local, low-level comments.

One conclusion that was drawn was that both kinds of annotations should be supported. Yet the lack of any way to easily anchor voice annotations to specific locations in a document may have prevented the use of voice for localised comments. This weakness is an artefact of the technology used in the study. It would be interesting to repeat the study using a system that would match voice annotation to specific locations on the document, as well as write them to the manuscript.

A problem encountered with speech files is in searching and retrieving information. It is possible to visually skim written documents and search them by content. How to skim a spoken messages is less clear. Arons (1992, 1993, 1993 video) has laid the groundwork for systems that have the capability to perform content-based search and retrieval from within speech files, without full speech recognition. Lie *et al* (1994

video) have demonstrated a visual environment for navigating the data space of voice messages.

2.2.2.2 Non-speech Audio

Other than with the hearing impaired, non-speech audio cues are used on a daily basis. Crossing the street, answering the 'phone, diagnosing problems with a car engine, and whistling for a dog are all common examples. Despite the daily use of this rich mode of interaction, it has had little impact on how we interact with computers. This need not be the case. There are significant potential benefits to be reaped by developing such capabilities.

Audio messages generally fall into one of three categories:

- alarms and alerts;
- status and monitoring indicators; and
- encoded messages and data.

Although alarms and alerts dominate, video games illustrate the potential of non-speech audio to effectively communicate high-level messages. Compare an expert player's score when the audio is turned on with the score when it is off. The likely significant drop in score indicates that the audio conveys strategically critical information.

For non-speech audio to be effective, the meaning of each signal must be known to the intended listener. Just like any other language, this is a learned vocabulary. One is not born knowing the meaning of a fire alarm or police siren. If audio cues are to be used in interactive information systems, then their design is of utmost importance. As graphic design is to effective icons, so is acoustics to effective auditory signs, or *earcons*.

Learning and remembering

One way to assist users in remembering the meaning of non-speech audio signals is by metaphor – having the meaning associated with a sound correspond to the meaning of similar sounds in the everyday world. Yet the extent to which existing acoustics signs could be exploited remains to be seen. Although the application of fire alarm and police siren sounds to computer applications is limited, Gaver (1986, 1989) has offered compelling examples that make effective use of existing world knowledge of the acoustic environment. One such example makes use of our association of reverberation with empty space. He proposed that if there were a reverberation clunk when we saved a file, then the amount of reverberation would provide a good cue as to how much free space was left on the disk. Similarly, on the Apple Macintosh, transferring a file to the trash can is accompanied by an appropriate tinny crash.

On first impression, such use of the audio channel to provide feedback may seem frivolous or unnecessary. However, most actions in the physical world are accompanied by acoustic feedback that is important to performing the associated task. Such feedback can benefit the performance of computer-based tasks. This is especially true for the visually impaired and those working in critical applications where audio feedback can reduce the risk of error.

Musical and everyday listening

Gaver identifies two approaches to non-speech audio:

- musical listening; and
- everyday listening.

In the former, the 'message' is derived from the relationships among the acoustical components of the sound, such as its pitch, timing and timbre. In everyday listening, what is heard is not perceived in such an analytical way - what is heard is the source of the sound not its acoustic attributes. For example, when a person hears a door slam, they pay attention to the fact that it was a door, perhaps how big it is, what

material it is made from, and how hard it was slammed. The musical equivalent will deal with issues such as whether it is a long or short sound, low or high in pitch, and loud or soft. The auditory icons described by Gaver and Smith (1990) are an example of auditory design targeting at everyday listening.

The raw materials of auditory design based on musical listening are as follows. These are the musical equivalent to typography, layout and colour in graphic design.

- Pitch: the primary basis for traditional melody.
- Rhythm: relative changes in the timing of the attacks of successive events.
- Tempo: the speed of events.
- Dynamics: the relative loudness of events (static or varying).
- Timbre: the difference of spectral content and energy over time, which is what differentiates a saxophone from a flute.
- Location: where the sound is coming from.

Human factors

There is ample literature on human factors from which useful guidelines about the use of non-speech audio cues may be obtained. Three excellent sources are Deatherage (1972), Kantowitz and Sorkin (1983) and Sanders and McCormick (1987). Each use the term 'audio display' to describe this use of the audio channel. Table 2.5 summarises Deatherage's view as to the use of audio displays rather than visual ones.

Perhaps the prime attribute of computer-generated audio output is that messages can be conveyed without making use of the visual channel. Visual messages must be seen to be understood. Audio messages are perceived regardless of the attention focus. This is of particular importance in cases where the visual channel is necessarily focused elsewhere, or where the task does not require constant visual monitoring. When the amount of information to be conveyed is high and pushes the visual channel to its limits, the audio channel can also be used to carry some of the information, thereby reducing the overall load. Unfortunately, one person's auditory icon is another person's noise.

Table 2.5: When to use audio or visual displays: Guidelines for determining whether to use the audio or visual channel in displaying information (from Deatherage, 1972).

Use auditory presentation if:	Use visual presentation if:
The message is simple	The message is complex
The message is short	The message is long
The message would not be referred to later	The message would be referred to later
The message deals with events in time	The message deals with location in space
The message calls for immediate action	The message does not call for immediate action
The visual system of the person is overburdened	The auditory system of the person is overburdened
The receiving location is too bright or dark – adaptation integrity is necessary	The receiving location is too noisy
The person’s job requires him/her to move about continually	The person’s job allows him/her to remain in one position

Other Auditory Issues

Sound perception is the perception of pitch, duration and loudness of acoustic signals. Masking is the phenomenon of one sound (e.g. a noise) obscuring another one (such as an alarm or a voice).

Testing and validation are important issues. While missing a few references in an opera may not be life threatening, the opposite is true in piloting an aircraft or monitoring a nuclear power plant. Clearly, the use of sound is not a panacea. If audio cues are to be employed, they must be clear and easily differentiable. Careful design and testing is required for them to be effective.

The change is a technological one that has resulted from the music industry adopting a standard protocol for interfacing electronic sound synthesis and processing equipment to computers. There is a wide range of equipment and interfaces available to those who wish to study this area. As personal computers become ever more powerful and cheaper, users will rely less on peripherals to produce sound. Digital recording of sound can be stored in memory and played back on demand in the same way as stored speech messages.

Some of the earliest work using non-speech audio was in data display, or auralisation. This can be considered the acoustics equivalent of scientific

visualisation. This work was motivated by a need to make scientific data accessible to those with visual impairments (Edwards, 1989). It is important here to note that all computer users are visually impaired to some degree. This is especially true in collaborative work at a distance, where one user cannot always visually monitor the activities of a collaborator. This is one areas where sound has the most potential. The work of Gaver and Smith (1990) and Gaver *et al.* (1991) provide an exploration of some of this design space.

In the context of BS, sound is potentially important although presently underutilised. There are many situations where sound could prove useful:

- where the user is visually impaired;
- where the visual sense is overburdened – e.g. within an IPV;
- when gathering background information about the site, local sounds (e.g. traffic) can be recorded for attenuation in the light of predictions emanating from acoustic simulations;
- because it is easier to speak than to write, high-level voice annotations would be an effective means of storing design intent alongside model parameters; and
- when assessing acoustic comfort, a musical sound (or non-musical sound such as a conversation or the acoustics of a cooling system) could be played so that the sound decay effect from the source to the target location may be perceived (i.e. an experiential appraisal).

Technology is advanced at present, so digitalisation of sounds and the embedding of these within tools to complement visualisation of data is possible. The portability of digital sound is easy due to the proliferation of low cost, high capacity devices. The sound and visual data held on such devices are readily transmissible through wireless and Internet technology to other locations for possible use within information presentation systems of the future.

2.2.3 Haptisation

This term is used when the sense of touch is employed to display abstract data. The sense of touch differs from vision and hearing in that it relies on action from the user to generate the stimuli. This process is described as bimodal. For example, a person must press against a surface to feel its hardness or move their hand across a surface to feel the surface texture (Nesbitt, 2003).

The term ‘information tactilisation’ has also been suggested (Card et al. 1999). Here, tactile refers to the sensation experienced on contact with a surface. The term haptic refers to both the tactile and kinaesthetic components of touch. The kinaesthetic receptors provide a sense of position in space. Since most interactions involving the sense of touch rely on a combination of both tactile and kinaesthetic feedback the term Information Haptisation is employed in the present work.

Although information haptisation is a new domain, some interesting applications have been developed. For example, haptics has been used to display soil properties such as density, cohesion and angle of internal friction by allowing the user to move a simulated plough blade through various sandy soils (Green and Salsibury, 1998). Force feedback was used to display a small set of properties such as static friction and surface deviation (Green, 1997). This allowed the user to feel surface textures on simulated surfaces. In this way, different grades of sandpaper could be simulated.

In the context of BS, haptisation can be used to experience a comfort level through the use of an external device or immersed VR system (using data gloves and data suit). Haptisation may also be used to control a simulation in a virtual manner, by, for example, pressing a button or selecting an option from a menu without the use of a keyboard/mouse.

2.2.4 Odourisation

The term ‘Odourisation’ is commonly used within the term: ‘Odourisation Plant for Natural Gas’. Natural gas has no smell. The smell we associate with it is added by

National Grid, at special odourisation plants, for safety reasons, so that leaks can be easily detected.

In comparison to other animals, humans do not have a very sharp sense of smell. Nevertheless, it is useful sense to spot danger, e.g. gas leakage. Some industries developed and continue to evolve further due to this sense, such as: perfume, deodorant, air fresheners, cleaning products, *etc.* With the Internet, such industries started looking at ways to sell their products in a more effective and efficient way.

Technology to deliver odours through the Internet is now a reality. This is possible through cartridges containing common odours which can be mixed to create other smells (a similar concept to colour printers). Then, a small amount of the aroma is emitted by the device in the direct vicinity of the user – an example of such device is provided in Figure 2.28.

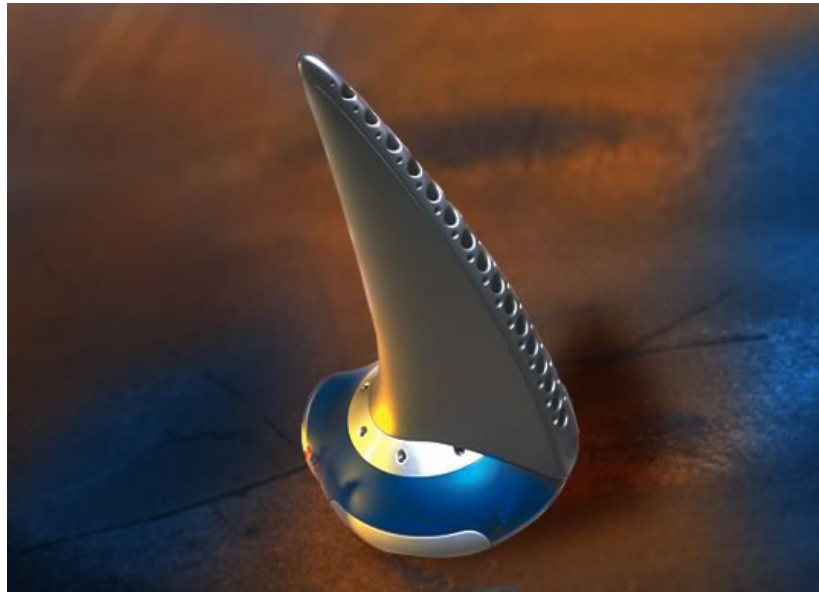


Figure 2.28: A commercial product (iSmell) to deliver odours through the Internet
(from DigiScents Web-site, 2006).

In the context of BS displays, the sense of smell could be useful in a few ways, for example to check the effectiveness of ventilation systems to disperse odours/smoke,

in particular when high relative humidity levels exist. This may be achieved with a stand alone device (as above) or through immersed virtual reality.

Next, the virtual reality topic is discussed which can include all relevant perceptions to BS (in immersed VR).

2.2.5 Virtual Reality

Virtual reality (VR) is a technology which allows a user to interact with a computer-simulated environment, be it a real or imagined one. Most current virtual reality environments are primarily visual experiences, displayed either on a computer screen or through special stereoscopic displays, but some simulations include additional sensory information, such as sound through speakers or headphones. Some advanced, haptic systems now include tactile information, generally known as force feedback, in medical and gaming applications. Users can interact with a virtual environment or a virtual artifact (VA) either through the use of standard input devices such as a keyboard and mouse, or through multimodal devices such as a wired glove, the Polhemus boom arm, and/or omnidirectional treadmill. The simulated environment can be similar to the real world, for example, simulations for pilot or combat training (see Figure 2.29), or it can differ significantly from reality, as in VR games. In practice, it is currently very difficult to create a high-fidelity virtual reality experience, due largely to technical limitations on processing power, image resolution and communication bandwidth. However, those limitations are expected to eventually be overcome as processor, imaging and data communication technologies become more powerful and cost-effective over time.



Figure 2.29: U.S. Navy personnel using a VR parachute trainer
(from U.S. Navy Web-site, 2006).

It is unclear exactly where the future of virtual reality is headed. In the short run, the graphics displayed in the HMD (Head Mounted Display) will soon reach a point of near realism. The aural aspect will move into a new realm of three dimensional sound. This refers to the addition of sound channels both above and below the individual. The virtual reality application of this future technology will most likely be in the form of over ear headphones.

With our technological limits today, sight and sound are the only two senses that will be able to be replicated almost flawlessly. There are however attempts being currently made to simulate smell. The purpose of current research is linked to a project aimed at treating PTSD (Post Traumatic Stress Disorder) in veterans by exposing them to combat simulations, complete with smells. Although it's often seen in the context of entertainment by popular culture, this illustrates the point that the future of VR is very much tied into therapeutic, training, and engineering demands. Given that fact, a full sensory immersion beyond basic tactile feedback, sight, sound, and smell is unlikely to be a goal in the industry. It's worth mentioning that simulating smells, while it can be done very realistically requires costly R&D to make each odour, and the machine itself is expensive and specialized, using capsules tailor made for it. Thus far basic, and very strong smells such as burning rubber, cordite, gasoline fumes, etc have been made. Something complex such as a food product or specific flower would be prohibitively expensive.

In order to engage the other senses of touch, and taste, the brain must be manipulated directly. This would move virtual reality into the realm of a vivid dream similar to "The Matrix" (a science fiction/action film written and directed by Larry and Andy Wachowski). Although no form of this has been seriously developed at this point, Sony has taken the first step. On April 7th, 2005 Sony went public with the information that they had filed for and received a patent for the idea of the non-invasive beaming of different frequencies and patterns of ultrasonic waves directly into the brain to recreate all five senses (Horsnell, 2005). There has been research to show that this is possible. Sony has not conducted any tests as of yet and says that it is still only an idea.

There has been increasing interest in the potential social impact of new technologies, such as virtual reality (as may be seen in utopian literature, within the social sciences, and in popular culture). Cline (2005) argues that virtual reality will lead to a number of important changes in human life and activity:

- Virtual reality will be integrated into daily life and activity and will be used in various human ways;
- Techniques will be developed to influence human behaviour, interpersonal communication, and cognition (i.e., virtual genetics);
- As we spend more and more time in virtual space, there will be a gradual "migration to virtual space," resulting in important changes in economics, worldview, and culture; and
- The design of virtual environments may be used to extend basic human rights into virtual space, to promote human freedom and well-being, and to promote social stability as we move from one stage in socio-political development to the next.

Brooks (1986, 1988) has reported on the advantages of adopting a virtual reality approach to data presentation. Principally, it has the advantages of 'bringing alive' the domain by providing a means for user interaction with domain objects. The

explicit selection of an interface metaphor helps to define issues and retain consistent decisions (e.g. navigation through a 3D scene may be by walking or flying).

Objects should always move realistically through sacrificing image resolution or reducing model complexity (as soon as the user terminates their virtual motion, the resolution or complexity can then return to normal). To enhance illusion, other senses may be used (e.g. sound effects when objects collide). Preece (1994) argues for compelling sensory cues to be created to give the user a strong subjective sense of physical presence and direct experience. These cues may be visual, aural, haptic, smell or some combination. Immersion systems include peripherals such as helmets, gloves and suits.

Desktop systems use a single, large colour screen for input and output, a 3D pointing device and keyboard. 3D virtual sound makes tasks such as tracking moving objects, navigating and being aware of location easier, quicker and more pleasant to perform. Modelling forces and impenetrable objects, requires the representation of tactile perception (e.g. senses of contact, pressure, pain and temperature) and kinaesthetic cues (e.g. awareness where body parts and limbs are in space, both statically and dynamically). The combination of both perceptions is the haptic perception (e.g. perception of object solidity, texture, vibration, inertia, weight, elasticity, viscosity, *etc.*).

According to Brooks (1999), four technologies are crucial for VR:

- the visual (and aural and haptic) displays that immerse the user in the virtual world and that block out contradictory sensory impressions from the real world;
- the graphics rendering system that generates, at 20 to 30 frames per second, the ever-changing images;
- the tracking system that continually reports the position and orientation of the user's head and limbs; and

- the database construction and maintenance system for building and maintaining detailed and realistic models of the virtual world.

And four auxiliary technologies are important, but not nearly so crucial:

- synthesized sound, displayed to the ears, including directional sound and simulated sound fields;
- display of synthesized forces and other haptic sensations to the kinesthetic senses;
- devices, such as tracked gloves with pushbuttons, by which the user specifies interactions with virtual objects; and
- interaction techniques that substitute for the real interactions possible with the physical world.

The benefits of immersed VR are self-evident because buildings are physical 3D objects which can be touched, seen, heard and smelt. Being able to enter a new design or refurbishment at the planning stage would be the ultimate experience for a design team. Such a system would provide more than just a walkthrough to help sell a design to a client; it would also facilitate a test drive in order to appreciate the likely performance under typical weather conditions and/or internal activities. This might be achieved by the immediate feedback of cost-performance statistics presented in the form of an interactive IPV.

2.3 Summary

This chapter has provided an overview of the human senses and introduced the four different information perceptualisations types (visualisation, sonification, haptisation and odourisation) as used in fields such as finance and marketing.

The emphasis was placed on visualisation because this is where the majority of the research has been done. Coverage included techniques to explore, analyse and present information in order to reduce the effort of translating data to information that may be acted upon. Guidelines were suggested for the display of quantitative information.

The chapter also provided information on sonification techniques that can complement the visual channel when this is overloaded (or vice-versa).

Finally, the chapter discussed the possibility of employing haptisation and odourisation although these modalities are beyond the scope of the present work because of the absence of suitable testing facilities.

The next chapter presents a specification for an information display tool in terms of the displays required and the technology used to develop the I²PV tool.

This chapter applies the techniques of the previous chapter in the building simulation context – for example, interactivity to enhance information insight by allowing the display of different perspectives, information ‘animation’ to support data comparison, sound to provide alarms and alerts, and virtual reality devices to facilitate experiential appraisals.

In order to test the perceptualisation techniques, a tool, I²PV (Integrated, Interactive Performance View), was developed using Java, Java 3D, VRML and HTML, which are all extensible and well integrated with the Internet. The design of I²PV evolved from brainstorming sessions with academic colleagues and practitioners.

Throughout the work, the ESP-r program (Clarke 2001) was used to create a neutral file results format containing the simulation results for a given design option. Such a file may then be uploaded to I²PV for analysis, exploration, presentation and reporting.

3.1 Introduction

According to Pilgrim (2003), in order to improve the communication of building simulation information to users, six key tasks should be supported by a tool:

- checking that the input has been entered correctly;
- obtaining an overview of the input and output data;
- quality assuring models;
- identifying how output variables relate to each other and to the input data;
- understanding the influence of changes to principal parameters; and
- comparing the results of multiple analyses.

In addition to the above functionality, two further features are required. First, tasks should be grouped into the four main categories (i.e. exploration, analysis, presentation and reporting) because appropriate perceptualisation techniques may

differ by category. Second, the circumstantial deployment of a given perceptualisation technique will depend on the user type being serviced (e.g. engineers, architects, students and so on who each possess different technical skills and knowledge of building simulation).

The evaluation of the I²PV tool was carried out against three criteria – effectiveness, flexibility and efficiency:

- effectiveness at communicating the messages inherent in the simulation predictions;
- flexibility in dealing with the different requirements of the members of the design team and others; and
- efficiency in terms of how quickly tasks may be performed.

The different communication and user types are discussed in the following sections.

3.1.1 Communication types

There are two main aspects of communicating BS information: internal requirements requiring results exploration, analysis and presentation, and external requirements involving the generation of reports for clients. These aspects require different techniques to be applied depending on the specific purpose. In any given project, both aspects will be present, with users exploring and comparing design options before presenting result to the other members of the design team and client.

3.1.1.1 Internal aspect

Exploration

In order to explore information, users need to interact with displays in order to view information from different perspectives, to have a close-up look, or to request additional information. Interactivity is particularly useful when applied to manipulate 3D geometry, retrieve information using a ‘tool-tip’ feature, or to control the speed rate of a looped image depicting, for example, air movement.

Analysis

In order to make effective decisions the user must be well informed by the information being displayed. This means that the format employed must allow ready appreciation and the inferring of conclusions. Displays must invite the user to make comparisons – for example, through the use of animation that is intuitive and commensurate with the dynamic nature of BS.

Presentation

This is similar to a typical PowerPoint presentation but with the added advantage of information interactivity and dynamicity because of the digital format and the structured nature of the information.

3.1.1.2 External aspect

Reporting

Typically, this would include key information presented textually, several illuminating graphs and a collection of IPVs that depict the overall performance of alternative design hypotheses.

3.1.2 User types

Users from different backgrounds and possessing different technical skills and levels of BS knowledge would each benefit from different perceptualisation techniques. The functionality of I²PV must therefore be flexible enough to embrace different user types.

Table 3.1 presents the results of several focus groups when charged to consider user concerns when addressing the outputs from BS. In all cases group members were active users of ESP-r.

Table 3.1: Summary of user concerns.

Type of User	Number of Users	Users knowledge of BS	Users Concerns for BS outputs
Consultant (BS specialists)	3	Advanced (10-20 years)	- compare design options; - produce quality report; - present results quickly and intuitively.
Consultant (engineers)	3	Medium-to-advanced (2.5 – 6 years)	- present results intuitively; - provide a concise summary of results.
Consultant (architects)	3	Basic (1 year)	- less results complexity; - practical advice from outputs.
Academic researcher	4	Medium-to-advanced (3-6 years)	- have flexible outputs; - compare design options; - have visual feedback of results; - interrogate behaviour; - search for patterns.
Academic researcher	4	Basic (1 year)	- have visual feedback of results.

While it is recognised that a low number of users per group represents a shortcoming, nevertheless the message is clear: targeted techniques are required to tackle the possible tasks as these might be undertaken by the different possible user types.

In the context of this PhD study, a qualitative method (i.e. in-depth interviews) is more useful than a quantitative method (i.e. questionnaires) to allow insight into the underlying reasons of user preferences (Taylor and Bogdan, 1984; and Seaman, 1999). However, the researcher tried to quantify the analysis by requesting the users to express their satisfaction level with the technique(s) being used in the task towards an attribute/format.

The next section describes the techniques that are useful in the BS context and which are implemented in Chapter 4 and tested in Chapter 5.

3.2 BS Information

This section explores techniques for processing complex BS information in order to assist with the ready assimilation of the inherent message.

As depicted in Figure 3.1, BS information may be delivered in many formats – most notably via geometry-based, graphic-based, image-based, text-based, sound-assisted, haptic and smell-experienced displays.

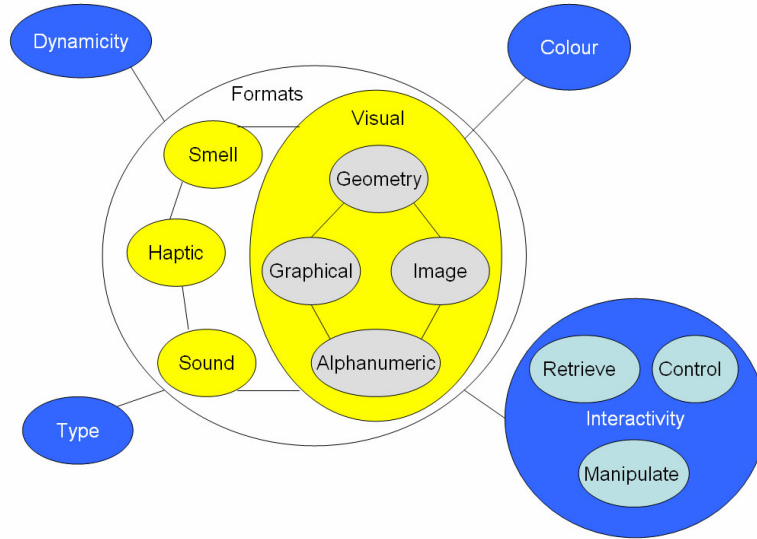


Figure 3.1: BS data formats and attributes.

Furthermore, each format may have assigned attributes (Prazeres and Clarke, 2003 and 2005) such as interactivity, dynamicity, colour and type. Clearly, some attributes might not be applicable to some formats (e.g. application of the colour attribute to a non-visual format).

3.2.1 Attributes

The following four attributes have been employed within the present work and are the object of testing reported in chapter 5.

3.2.1.1 Interactivity

This attribute plays a crucial role in BS data exploration and analysis and may be divided into 3 components as follows.

- Direct manipulation: this requires the user to ‘touch’ the information directly by means of a mouse or haptic senses, for example, when zooming, panning or rotating a 3D geometry or zooming into a graph. The user might also use data-gloves in conjunction with an immersed VR system in order to control such interactions.

- Control of information: This requires the user to manipulate the display without ‘touching’ it directly – for example, through the use of a keyboard button to control the animation speed or resize a display window or graph. In this way the user is able to prepare information for viewing by another party (for example, by stopping an animation at a specific point).

- Retrieval of information: Here the user requests specific information in order to illuminate an issue. Examples include the use of tool-tips to locate information that is otherwise hidden to avoid display clutter or the use of hyperlink text to facilitate ‘drill-down’ to more detail.

In the researcher’s view, interactivity is more important in exploration and analysis than in presentation and reporting. That said, it is used to rearrange information before presentation. Interactivity is intrinsic to the act of exploration and analysis; only when a user actively examines data from different perspectives, removes unwanted parts, occult the superfluous and so on does complete understanding emerge.

And while interactivity is a technique that most users appreciate, a senior BS specialist would derive more benefit because of the extra flexibility that is offered. Less technical practitioners tend to rely more on the default settings/displays accompanying a tool.

3.2.1.2 Dynamicity

This is a crucial attribute because building simulation is inherently dynamic in nature and so presenting it in that manner is more intuitive. Some examples follow.

- When displaying a line graph in dynamic mode, say the zone resultant temperature over an extended time period, the history of the simulation might unfold itself at a rate that allows users to recognise and retain critical events. Such events might usefully be signalled by acoustic and/or graphic means. Such an approach should be contrasted with the present practice of displaying the complete data set at once.
- When displaying a filled counter graph superimposed on a geometry representation, an appropriate technique is to arrange that the graph swipes the full length (in any direction/angle) of a zone for a fixed date/time, as represented in Figure 3.2 (or alternatively the graph may remain static and the animated information swipes a time period). This technique is powerful because the geometry and the information are displayed simultaneously allowing the ready identification of value-location pairs.

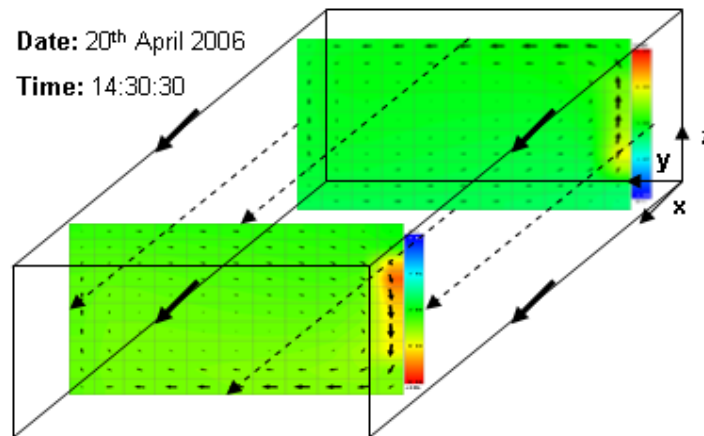


Figure 3.2: A Filled Counter Graph in dynamic mode.

In the researcher's view, dynamicity is more important in exploration and analysis than presentation and reporting. The reason for this is that presentation/reporting of data is usually static because users expect summary data to be presented by default rather than having to call it up themselves through data interaction. In regards to exploration and analysis, dynamicity is important because it can convey a huge volume of information in a small display space. More specifically, it can unfold data at optimum speed to enable user assimilation.

And dynamicity is applicable to all user types although less technical users would benefit more from dynamic information because it is more intuitive.

3.2.1.3 Colour

Colour, when appropriately used, can impart real advantages to information displays. Some benefits follow:

- Colour supports analysis at a glance. In order to make information stand out, the colour adopted must contrast with its surroundings so that the user is attracted by its uniqueness.
- The consistent use of apposite colours to denote heating (red), cooling (blue), lighting (yellow) and renewable energy (green), while an effective device in BS, has yet to be standardised. Using red to denote maximum values and blue for minimum values is just as rational but can give rise to semantic ambiguities. However utilised such colour-label perception matches, when used consistently, are most helpful because the human brain tends to readily adopt such natural associations. For the same reason, it is essential to consistently use the same colour for the same performance metric because the human brain is unwilling to replace established conventions with new ones.
- In general it is best to adopt generally held colour conventions such as traffic light colours to indicate stop, go or proceed with caution, or sequences to indicate likely future states (red and amber flagging a pending 'go' state). A BS-related example occurs where a tool is supporting a user's high level analysis of several competing design options. In such a case, green might indicate options that are unconstrained in terms of user-specified performance criteria, red might indicate options that are seriously constrained and may not proceed, and amber might indicate options that have borderline constraints that may be easily remedied.

In the researcher's view, colour is equally important in exploration/analysis and presentation/reporting modes because it makes important information stand out to improve analysis efficiency, group related information, impart consistency to displays and warn users of critical situations. On the other hand colour must be used in a way that is mindful of the needs of the visually impaired and the potential for ambiguity associated with the use of non-colour printers.

And while colour will likely be appreciated by all user types, it will bring greater benefit to less technical users because it can be used to create more intuitive displays.

3.2.1.4 Type

As used here this term defines the nature of the display – for example, a graph may be pie, bar or line chart; an audio segment may convey speech (explanation or experiential appraisal) or an alert; or geometry may be displayed in wire-frame or solid format.

The choice of the type in a given format is not straightforward because there are no strict guidelines on how best to display BS information. On the other hand an incorrect choice could have dramatic consequences on the task at hand be this exploration, analysis, presentation or reporting:

- When a user needs to check for geometry errors, it is more appropriate to display a wire-frame model because the inside of the model may then be seen.
- When displaying graphs, it is important that the appropriate type is employed. For example, 'Energy Demand per Unit Time (kW)' is best displayed on a line graph; using a pie chart or scatter graph would be confusing.
- The display of alphanumeric information can be done using different fonts, which ultimately would impact on clarity and readability. For best results, a Serif font should be used, made bold where important issues are to be

highlighted (underlining should not be used to avoid confusion with hyperlinks).

- When employing sound to alert a user about a critical value, it is inappropriate to employ a voice message. Instead a short and non-human sound should be employed that is semantically related to the nature of the alert.

In the researcher's view, type is equally important in exploration/analysis and presentation/reporting because it is the fundamental building block of effective displays that may be acted upon.

And type is appreciated by, and is equally beneficial to, all user types.

3.2.1.5 Attribute combinations

There are many possible combinations of attributes that could be applied to the BS information formats; some follow:

- *Geometry*: this may be solid or wire-frame; it may allow model zooming, panning and rotation, information retrieval and window resizing; it may allow animated surface temperature or heat flux display over time; and it may support the grouping of zones that share common attributes such as control set points.
- *Graphical*: this may comprise line, bar or filled counter graph; it may have meaningful colour applied; it may have animated time displays; and it may allow zooming, results retrieval and window resizing.
- *Image*: this may be static or animated - if the latter the images may be continuous to create a movie effect; the speed rate may be controlled and the window resized; it may have meaningful colour applied; and it may be an animated-GIF, a simple JPEG format or a movie in WAV format.

- *Alphanumeric*: this may have colour applied to highlight important items; it may be 'line dynamic' to occupy less space as with the bottom part of a TV news channels displaying breaking news; it will be Serif font, perhaps emboldened; it may have a hyperlink connection to permit drill-down to more detailed information; and it may support scrolling to control which part of the text is viewed.
- *Sound*: this may be WAV, AIFF or 3D audio format in a VR system; it may be controlled by the user (e.g. still, play, rewind, *etc.*); and it may be continuous or discrete.
- *Haptic*: this may be delivered via an external device or a VR system; it may be used to receive a continuous sensation or to touch in a specific location and hence activate a specific function.
- *Smell*: this may be delivered via an external device or a VR system; it may be used to receive a continuous sensation or a discrete one.

The combinations above are presented as examples of the many possibilities for attribute combinations that can improve the effectiveness and flexibility of BS displays and thereby increase task efficiency.

3.2.2 Formats

The main information formats in the BS context are (in order of importance) geometry, graphical, image, alphanumeric, sound, haptic and smell.

3.2.2.1 Geometry

Essentially, there are two methods to display 3D models, wire-frame and solid-object: A wire-frame model comprises a line drawing from which the inside and outside cannot be differentiated. Such a model is useful for tasks in which surface structure is less important than internal structure. A solid-object model has a high degree of fidelity and lends itself well to the application of colour and shading. It

therefore provides more information about the form of the object and is more useful for resolving ambiguities relating to shape. By enabling the user to distinguish between the inside and outside of an object, it presents less risk of misinterpretation and assists with accurate geometrical selections.

A useful functionality to have is the quick swap between both formats. Such user control of surface transparency level offers advantage because interior partitions may be viewed in relation to external boundary surfaces.

VR is the ultimate experience in BS because it allows users to ‘walk through’ a model and enquire about performance. Within such systems geometry defines the foundation of all information display because it is fundamental to the human perception system and all performance data is somehow related to it. For example, the display of HVAC (e.g. radiators) or renewable energy (e.g. solar panels and wind turbines) systems on the VR scene benefit users in providing their immediate location and/or orientation, in particular, if the objects are sensitised to allow user interactivity for system performance enquires. Also, distinguishable sensors, to allow user interactivity on the VR scene, per zone that has control systems applied (e.g. lighting) benefits users by providing the control scheduling information.

BS derives substantial benefits from the superimposition of performance data on a 3D building representation. For example, the representation of mould growth on the surfaces of a solid-object model along with some key technical data is more effective than a line graph depicting the surface temperature and relative humidity profiles from which mould growth potential may be inferred.

3.2.2.2 Graphical

In relation to building simulation, several display techniques are appropriate:

- *bubble graphs* to depict correlations (e.g. energy costs versus capital cost with the bubble radius depicting the overall benefit of a design options);
- *radar graphs* to depict patterns (e.g. visual comfort);

- *column/bar or histogram graphs* to invite comparison between different sets (e.g. maximum capacity or thermal comfort);
- *line graphs* to show how two continuous variables are related and highlight variable changes over time;
- *filled counter graphs* to display spatial distributions (e.g. daylight availability and air movement);
- *cartoon (or Chernoff) faces charts* to display comfort levels (e.g. thermal, visual and acoustics) for inexperienced users; and
- *time and activity bar chart* to display schedules (e.g. occupancy schedules) of a given space and period.

Those graphs that are well suited to being superimposed on a 3D model are most likely to increase display effectiveness (e.g. radar, filled counter graphs and cartoon faces).

3.2.2.3 Image

Image is used to increase insight or convey motion or change. For example, images embedded within project information helps to provide an insight into design intent while images associated with help messages are an effective way to support tool learning. Images can also be used to place results in context as in the case of animated air flows or a depiction of glare sources superimposed on a related building zone.

3.2.2.4 Alphanumeric

Sometimes the only way to display information is in alphanumeric format (e.g. a table of wall U-values or a listing of weather data over time). In such cases, it is important that the text is displayed in an easy to read format and is organised by topic.

The use of this format in combination with a graphic would help to put results into context – this is useful in IPVs where information density is high. For example, the

use of a calendar facilitates efficient interaction by allowing users to choose the date and time of an enquiry when operating in drill-down mode.

3.2.2.5 Sound

Relying solely on visual senses (i.e. all the above formats) may provide barriers to users with visual impairments. The potential of sound in BS information display is immense. For example, when examining a large and complex data-set it is difficult to detect inherent issues. Anomalies may be usefully flagged by an accompanying ‘beep’ to draw the user’s attention to the issue or to illicit an action. Advanced uses of sound are also possible, for example to support an experiential appraisal of a room’s acoustic properties.

Another use of sound is to enable the quick acquisition of information through voice annotation of practitioners/consultants on site. This high level information could be recorded on a PDA or mobile device as a voice-memo and readily downloaded to a laptop for later use within the I²PV tool. This is an effective way to effect project management at a distance.

3.2.2.6 Haptic

Relying solely on visual or aural senses (i.e. all the above formats) may provide barriers to users with visual or audio impairments respectively. One possibility is to use an external device to allow the user to experience, for example, a surface’s temperature or heat flux (Hand, 2002). However, at present this approach has the drawback of requiring a physical device attached to the computer and can only support a discrete and limited number of experiences.

In future, the Haptic format has high potential because users of BS tools within an immersed VR environment may use skin and kinesthesia senses to acquire useful information in a natural manner. Such VR systems are not only able to create natural environments but are able to go a step further by adding mental aids and accelerators to the user’s view. For example, instead of a real keyboard, the user might access a

virtual keyboard with buttons that control the simulation process, from the setting up of the BS model to the exploration of predicted results and preparation of client reports. VR techniques will be discussed in more detail in a later section.

Clearly, the use of a virtual space which requires haptic manipulation would not overcome the barriers confronted by users with mobility impairment.

3.2.2.7 Smell

Relying solely on visual, aural or haptic senses (i.e. all the above formats) may provide barriers to users with visual, audio or mobility impairments respectively. So, the addition of another sense to perceive the BS data is beneficial to users, for example, to assess ventilation strategies (natural or artificial) to disperse odours or smoke, in particular in highly humid environments – experiential appraisal. External devices could be used to achieve that as well as within an immersed VR system.

3.2.2.8 Format combinations

Relying solely on visual, aural, haptic or smell senses would not resolve the problems facing users with visual, audio, mobility or smell impairments respectively. The best solution is to complement the sense modalities by using multiple formats simultaneously. Even inside one modality, a combination of formats is the most powerful approach to the effective display of information.

In VR systems, the information transfer process is more effective because the approach gives rise to the prospect of direct model enquiry whereby the model itself is used to initiate user requests for information on material properties, occupancy schedules, performance variables, system states and the like. For example, a user might move effortlessly around the building, interact with data-sensors to call up performance information, assess acoustic performance by listening to a recorded sequence as it would sound from that precise building location or assess the odour/smoke level in a space by smelling it.

To test the above perceptualisation techniques as implemented within the I²PV tool, a detailed building performance modelling tool was required for use within the present work. This is discussed next.

3.3 Building performance modelling

The performance modelling program used in the present project was the ESP-r system from ESRU at the University of Strathclyde (www.esru.strath.ac.uk).

ESP-r (Clarke, 2001) is an integrated modelling tool for the simulation of the thermal, visual and acoustic performance of buildings along with the energy use and gaseous emissions associated with environmental control systems and constructional materials. In undertaking its assessments, the system is equipped to model heat, air, moisture and electrical power flows at high resolution. ESP-r is made available under a no cost open source licence. The system has a variety of possible applications in consultancy, research and teaching. Figure 3.3 shows a collage of a typical ESP-r session involving model definition/visualisation, weather selection and results analysis.

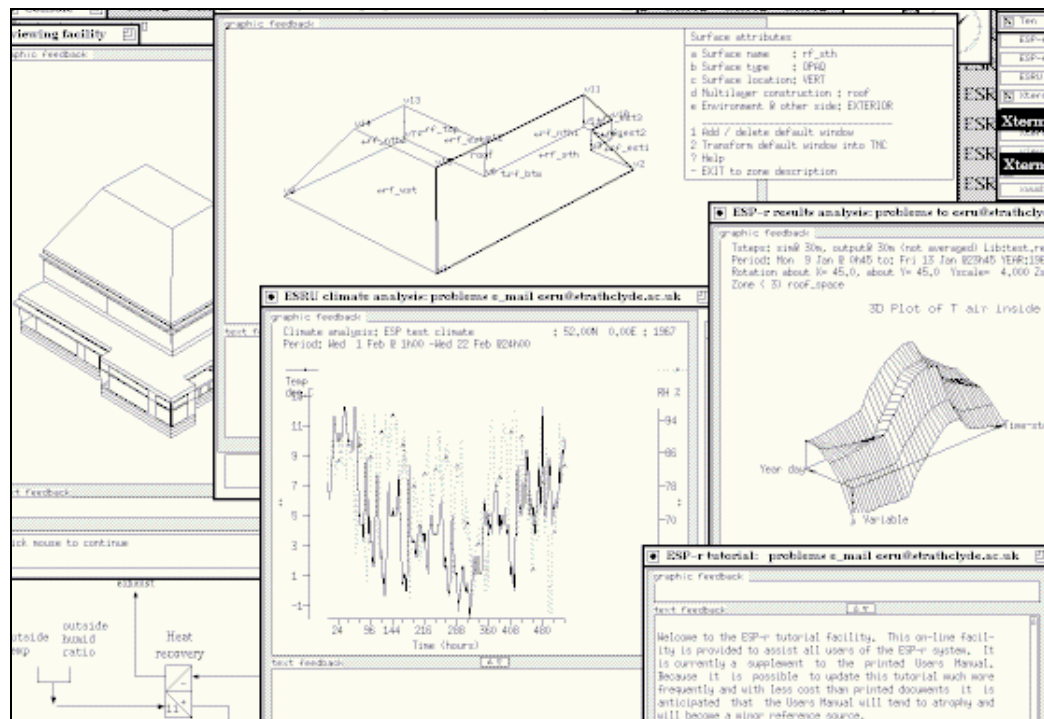


Figure 3.3: A few screen-shots of ESP-r software package (from ESRU, 2005).

Within ESP-r, an Integrated Performance View (IPV) is defined as a standard set of performance metrics that represent the multi-variate behaviour of the building. IPVs corresponding to different design options may then be compared to determine in which respects one design option gives rise to performance advantages over another. A typical IPV is shown in Figure 3.4:

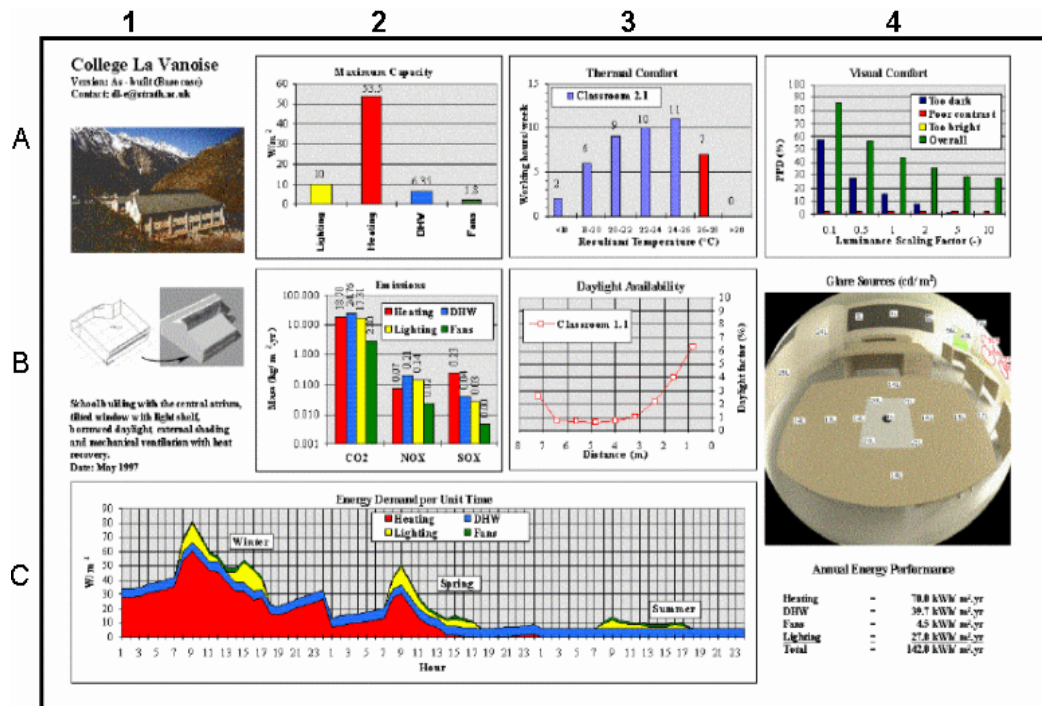


Figure 3.4: An IPV prior to application of cognition rules (from Clarke, 2001).

The contents include:

A1 & B1: general information such as project descriptors, images and contact details.

A2: maximum plant capacity in terms of diversified totals for heating, cooling and lighting to represent critical equipment sizes and hence capital costs.

A3: thermal comfort expressed as temporal distributions of a relevant index to indicate the severity of any departure from an acceptable comfort zone.

A4: visual comfort expressed as a temporal distribution of some relevant index that relates visual discomfort to any excess/lack of light or problematic contrasts in the field of view.

B2: environmental emissions by season and expressed in terms of primary energy demands converted to equivalent gaseous emissions relating to principal pollutants.

B3: daylight availability expressed as a distribution of daylight levels that give an indication of the potential for daylight utilisation.

B4: glare sources indicating potential problem areas within a synthetic colour picture.

C1-3: primary energy consumption expressed as patterns of primary energy demand by fuel type, expressed as cumulative profiles for typical seasons.

C4: energy performance indicators comprising the building's annual energy consumption per unit of floor area for each of the fuel use categories.

These IPV entities were taken as the starting point within the present project so that refinements related to the cognitive and perceptual aspects described earlier could be applied.

3.3.1 IPV data file

ESP-r outputs a neutral format results file (NFRF) that may also be made readily available by other modelling programs.

The NFRF has four parts:

- overview information;
- simulated periods information;
- individual days (included in the respective simulation period sections); and
- summary data.

Figure 3.5 gives an example of the overview information.


```

*IPV_REPORT,abertay1.0.ipv

*title,Solar study for Abertay
*version,open windows 1m
*date,Sun Aug 7 16:34:40 2005
*contact,See synopsis
*location,See synopsis
*climate,OBAN SCO GBR
*latitude, 56.50
*longitude, -1.01
*synopsis,:The abertay top floor design with 1m deep lens grill

*simulations, 5
# start & finish days for each season
Thu 7 Feb 1980,Wed 13 Feb 1980,abertay 1st winter run
Fri 4 Apr 1980,Thu 10 Apr 1980,abertay spring run
Wed 23 Jul 1980,Thu 31 Jul 1980,abertay summer run
Fri 3 Oct 1980,Thu 9 Oct 1980,abertay autumn run
Fri 14 Nov 1980,Thu 20 Nov 1980,abertay 2nd winter run

*days,5
# list of days with detailed information
Fri 8 Feb 1980
Sat 5 Apr 1980
Thu 24 Jul 1980
Sat 4 Oct 1980
Sat 15 Nov 1980

*groups, 7
# group name & number of zones & zone names
lens,7,lens_void,lens_5_a,mezanine,lens_mez_a,lense_doub,lens_5_b,lens_m
ez_b
other,6,cellular_a,analysis,skylight,gen_chem,gen_corid,break_corid
occup_lens,
6,lens_void,lens_5_a,lens_mez_a,lense_doub,lens_5_b,lens_mez_b
ocup_other, 5,cellular_a,analysis,gen_chem,gen_corid,break_corid
rh_lens, 6,lens_void,lens_5_a,lens_mez_a,lens_mez_b,lens_5_b,lense_doub
rh_other, 5,cellular_a,analysis,gen_chem,gen_corid,break_corid
infil_zones, 5,lens_void,lens_5_a,lens_mez_a,cellular_a,lense_doub
*end_heading

*images_sound,3,abertay_ext_anima_1.0.gif,lens_summer_T_win_ctl_1.0.gif,
wire_of_model_1.0.gif

*vrml,1,abertay1.vrml

```

Figure 3.5: Example of overview information within a NFRF.

This section of the file provides some general details, defines the simulation periods and individual days, defines zone groupings, and references related image files.

The simulation periods information comes next; an example of part of this is given in Figure 3.6.

```

*assessment, 1, abertay 1st winter run

*report, 70, diversified, capacity, lens
*title, Diversified capacity, W
*format, table, 1, 7
*fields, Heating, Cooling, Lighting (unctld), Lighting (ctld), Fans, Small
Power, Hot water
*data, 0.000, 0.000, 4064.550, 0.000, 0.000, 4169.670, 0.000
*end_report

...

*report, 6, distribution, comfort, occup_lens
*title, Resultant temperature, degC
*format, frequency, 12, 5, 12.0, 2.0, 30.0
*fields, range, distribution, percent, cumulative_distrib, cumulative_percent
*data
'<12', 229, 0.0, 0.0, 0.0
'12-14', 97, 47.78, 97, 47.78
'14-16', 68, 33.50, 165, 81.28
'16-18', 37, 18.23, 202, 99.51
'18-20', 1, 0.49, 203, 100.00
'20-22', 0, 0.00, 203, 100.00
'22-24', 0, 0.00, 203, 100.00
'24-26', 0, 0.00, 203, 100.00
'26-28', 0, 0.00, 203, 100.00
'28-30', 0, 0.00, 203, 100.00
'30-32', 0, 0.00, 203, 100.00
'>32', 0, 0.0, 0.0, 0.0
*end_report

...

*end_assessment

```

Figure 3.6: Part of the simulated periods part of an NFRF.

A simulated period can include any metric for specific groups of zones – in the example above, group ‘lens’ has ‘Diversified capacity’ while group ‘occup_lens’ has ‘Resultant temperature’.

Individual typical days are included in the assessment period that covers them; a part example is given in Figure 3.7.

```

*day_to_display,Fri  8 Feb 1980

*report,70,demand,per_unit_time,lens
*title,Energy Demand per Unit Time,W
*format,tabular,24,7
*fields,Time,Heating,Cooling,Lighting,Fans,Small Power,Hot water
*data
'00:30:30',0.0,0.0,0.0,0.0,0.0,0.0
'01:30:30',0.0,0.0,0.0,0.0,0.0,0.0
'02:30:30',0.0,0.0,0.0,0.0,0.0,0.0
'03:30:30',0.0,0.0,0.0,0.0,0.0,0.0
'04:30:30',0.0,0.0,0.0,0.0,0.0,0.0
'05:30:30',0.0,0.0,0.0,0.0,0.0,0.0
'06:30:30',0.0,0.0,0.0,0.0,0.0,0.0
'07:30:30',0.0,0.0,211.0,0.0,260.6,0.0
'08:30:30',0.0,0.0,3164.5,0.0,3909.1,0.0
'09:30:30',0.0,0.0,3375.5,0.0,4169.7,0.0
'10:30:30',0.0,0.0,3375.5,0.0,4169.7,0.0
'11:30:30',0.0,0.0,3375.5,0.0,4169.7,0.0
'12:30:30',0.0,0.0,3375.5,0.0,4169.7,0.0
'13:30:30',0.0,0.0,3375.5,0.0,4169.7,0.0
'14:30:30',0.0,0.0,3375.5,0.0,4169.7,0.0
'15:30:30',0.0,0.0,3375.5,0.0,4169.7,0.0
'16:30:30',0.0,0.0,3375.5,0.0,4169.7,0.0
'17:30:30',0.0,0.0,3375.5,0.0,4169.7,0.0
'18:30:30',0.0,0.0,3375.5,0.0,4169.7,0.0
'19:30:30',0.0,0.0,3164.5,0.0,3909.1,0.0
'20:30:30',0.0,0.0,211.0,0.0,260.6,0.0
'21:30:30',0.0,0.0,0.0,0.0,0.0,0.0
'22:30:30',0.0,0.0,0.0,0.0,0.0,0.0
'23:30:30',0.0,0.0,0.0,0.0,0.0,0.0
*end_report

...

*end_day_to_display

```

Figure 3.7: Part of the output for a typical day within an NFRF.

Individual days can include any metric – in the example above ‘Fri 8 Feb 1980’ is considered and for group ‘lens’ the performance entity ‘Energy Demand per Unit Time’ is given.

Finally, seasonal and year-aggregated summaries are included at the end of the file; a complete example for the year-aggregated summary is provided in Figures 3.8.

```

*Summary

*report,98,energy,performance,aggregate
*title,Integrated demand,kWh/m^2.a
*format,table,1,6
*fields,Heating,Cooling,Lighting,Fans,Small Power,Hot water
*data,0.000,0.000,23.273,0.000,25.427,0.000
*end_report

*report,74,power,capacity,aggregate
*title,Maximum capacity,W/m^2
*format,table,1,6
*fields,Heating,Cooling,Lighting,Fans,Small Power,Hot water
*data,0.000,0.000,6.202,0.000,6.807,0.000
*end_report

*report,75,emissions,pollutant,aggregate
*title,Pollutant emissions,kg/m^2.a
*format,table,3,6
*fields,Pollutant,CO2,NOx,SOx,Heating,Cooling,Lighting,Fans,Small
Power,Hot water
*data,0.000,0.000,20.510,0.000,56.021,0.000
*data,0.000,0.000,0.069,0.000,0.189,0.000
*data,0.000,0.000,0.254,0.000,0.693,0.000
*end_report

*report76,distribution,thermal_comfort,aggregate
*title,Resultant Temperature,degC
*format,frequency,9,6,16.0,2.0,30.0
*fields,range,winter_early,spring,summer,autumn,winter_late
*data
'<16',283,0,0,0,275
'16-18',50,0,0,0,43
'18-20',27,15,0,27,34
'20-22',0,99,0,157,8
'22-24',0,198,144,168,0
'24-26',0,48,275,8,0
'26-28',0,0,42,0,0
'28-30',0,0,18,0,0
'>30',0,0,1,0,0
*end_report
*end

```

Figure 3.8: The year-aggregated summary section of an NFRF.

This presents the scaled-up results for the whole year and whole model as indicated by the group definition of ‘aggregate’. Usually, the metrics displayed here are ‘Integrated demand’, ‘Maximum capacity’, ‘Pollutant emissions’ and ‘Resultant temperature’.

The seasonal summaries (one for each simulated period) are similar to the year-aggregated summary but with specific results for the season in question (i.e. actual simulated results with no scaled-up calculations).

Please refer to Appendix A for the complete IPV file for the above example.

Performance metrics can have a diverse level of detail in terms of associated period and location. Table 3.2 provides a list of performance metrics and their level of detail that may be included in the NFRF.

Table 3.2: Performance metrics' level of detail in NFRF.

Performance Metrics	Associated Time/Period				Associated Location		
	Point in time	Typical day	Period	Aggregated year	Specific point(s)	Group of zone(s)	Aggregated model
Maximum capacity	X	X	√	√	X	√	√
Thermal Comfort	X	√	√	√	X	√	√
Acoustics comfort	√	X	X	X	X	√	X
Visual comfort	√	X	X	X	√	X	X
Daylight availability	√	X	X	X	√	X	X
Glare sources	√	X	X	X	√	X	X
Pollution emissions	X	X	√	√	X	√	√
Energy demand	X	√	√	√	X	√	√
Notes: 'Typical day' has hourly data; 'Period' has non-scaled-up results; and 'Aggregated year/model' has scaled-up results.							

(Note: It is generally assumed that a database is a collection of ‘perfect’ data, in the sense that they are error-free. This might not be true for certain views, for which the data may be tainted with incertitude, related to the reliability of the data. To address that, MacDonald (2002) implemented in ESP-r the uncertainty analysis capability which has been used in the new database design, but is beyond the scope of the presented work.)

3.4 Technology Used

To ensure platform independence, I²PV was built using Java/Java 3D, VRML and HTML and is thus Web-enabled. Both VRML and Java 3D are designed to allow 3D applets and applications to run on the user’s desktop. VRML defines a standard for 3D for the Internet. It is not an extension to HTML; it is a file format for describing interactive 3D objects and worlds. VRML is capable of representing static and animated 3D and multimedia objects, with hyperlinks to other media such as text, sounds, movies and images.

Next, these technologies are described in the context of BS.

3.4.1 Java/Java 3D

Appendix B provides general information about Java/Java 3D technology, but in the context of BS the following considerations are relevant.

Direct benefits

- Platform-independence is important because users work with different operating systems such as Windows, Mac OS X, Linux, *etc.* Being able to run the I²PV application under multiple operating systems is essential.
- Networking is important. The I²PV tool could, for example, run as an Applet through the Internet, which only requires the user to have a JRE installed locally and a Java enabled Web browser. In addition, network data exchange would be important where the design team is scattered around different

locations. For example, an engineering consultant could create a client report in digital format and then allow a client to access it via the Internet. This same report could integrate multimedia features within the 3D geometry model to be potentially explored by the client in order to impart insight into the performance benefits associated with the proposed design.

- Internationalisation is important because the same I²PV tool can support efficient task execution within different countries (Java uses 16-bit Unicode characters that represent the phonetic alphabets and ideographic character sets of the entire world).
- The Java 3D API is a natural choice because it allows optimum performance targeted to the platform being used. Performance is important when the user is manipulating large data-sets with embedded multimedia features.
- Java 3D supports 3D object display integrated with multimedia features such as video, images, audio, *etc.* which are the essential ingredients of effective and flexible displays that permit task efficiency.
- Advanced features in Java 3D are important because they offer the potential to create immersed VR solutions which will play a crucial part in the future of BS information displays.

Indirect benefits

- While security is not critical in BS, having good security features is a bonus, in particular when networks are used.
- Dynamic extensibility is not directly important, but does allow efficient bug fixing and automatic updates through the network.

Direct drawbacks

- Performance is important when displaying IPVs with many performance entities. Java is slower than computer languages that compile to native machine code and this reduced efficiency will affect the overall process of exploration, analysis, internal presentation and external reporting of information.

Based on the above benefits of Java/Java 3D the language has been adopted in the development of the I²PV tool.

3.4.2 VRML

The VRML technology has many embedded features that may be useful in the BS context, such as: lighting, image in VR scene, background and fog. Their brief descriptions based on Ames (1997) and Web3D Consortium Web-site (2006) follows:

Lighting

If one takes no steps to provide a world with lighting then what the viewer sees would be illuminated only by the viewer's headlight, if it's switched on. Otherwise everything would be black.

The effect of the headlight is that parts of objects that are facing the viewer would be brightly lit, whereas parts that are seen nearly sideways on would be shaded.

The headlight is a simple mode of lighting which ensures that, as the viewer moves around, they would be able to see whatever shapes they come to, and at the same time there is sufficient shading to reveal the form of the shapes. But, the effect could be unnatural, like walking around a dark cave with a torch. For a more realistic effect, it is possible to switch off the viewer's headlight and provide sources of light located at various positions in the scene.

There are three kinds of light source available:

- A point light source that radiates from a particular position in space, like the light from a light bulb or a candle flame. This is described by a `PointLight` node.
- A directional light that shines in a constant direction. It is like the light from a very distant source such as the sun. This is described by a `DirectionalLight` node.
- A spot light. This is located at a particular position in space, like a point light source, but it doesn't shine equally in all directions. It could be concentrated in a certain direction like the light from a desk lamp. This is described by a `SpotLight` node.

For more realism, one can add multiple lights: Suns, light bulbs, candles, flashlights, spotlights, firelight, *etc.* All lights can be positioned, oriented and coloured. All lights have an on/off, intensity, ambient effect and colour. Point and spot lights have a location, radius, and attenuation. Directional and spot lights have a direction.

All these light sources would illuminate any shapes included the group that contains the light node.

Note that these light sources are not shapes. One cannot see the source itself, only the effect they have illuminating shapes around them. If one wants the viewer to see a visible source such as an electric light bulb at the source of a point light, then one must construct a suitable shape to represent the light bulb, and position it at the same place as the point light.

In addition, to the light provided directly by the light sources mentioned above, a scene could have an additional level of illumination that applies throughout the scene. This is called ambient light. When one defines a light source, one could specify how much it should contribute to the ambient light. The browser would calculate the total amount of ambient light in a scene, and then apply it to each shape in turn. A shape would only be affected by ambient light if it has a `Material` node with a nonzero value for its `ambientIntensity` field.

Note that shadows are not supported. The reason is that it could be very time-consuming to calculate the shadows formed when one object prevents light from a source reaching another object. VRML is a real-time system that should be able to render rapidly changing animated worlds, and respond quickly to user interaction such as mouse clicks.

In the context of BS, point and spot lights may be included in the VR scene for realism and their intensity can be controlled by their actual powers. Different lighting types/sizes can be modelled (e.g. light bulb, fluorescent light, *etc.*) and applied as appropriate in different locations within the model. Timers can be set up to represent the lighting schedules in dynamic mode. The directional light may be used as the sunlight, its location may be controlled by a date/time and position of the model on Earth, and its intensity may be controlled by the weather conditions (e.g. sunny, cloudy, *etc.*). If any of these lights are used, the default light, headlight, must be turned off.

Image in VR Scene

Excluding background images; images (static or in dynamic mode) can be included in the VR scene. Its orientation, size and location can be controlled by the user.

Figure 3.9 provides an example of glare sources in a VR scene.

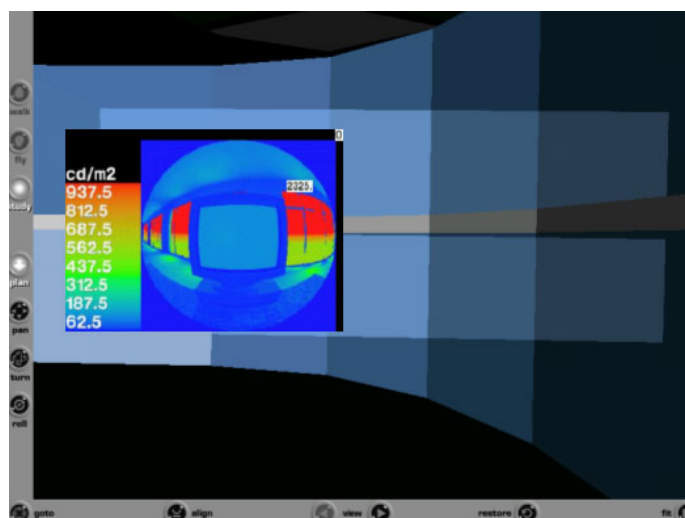


Figure 3.9: Glare sources image in VR scene.

In the context of BS, being able to include images in the VR scene may be beneficial as a mechanism to deliver information about glare sources. The images would provide a real visual perception of what one would actually see in reality (image from Radiance – a lighting simulation program). A viewpoint (or camera view) could be automatically set up to provide realistic position, orientation and field of view to the user (through ViewPoint Node in VRML).

Background

If the scene is outdoors, the effect could be enhanced by providing a background that shows a horizon and sky and possibly an image of some distant scenery.

A background creates three special shapes: a sky sphere, a ground sphere inside the sky sphere and a panorama box inside the ground sphere. The sky and ground spheres are shaded with a colour gradient. The panorama box is texture mapped with six images.

Figure 3.10 provides two examples of realistic backgrounds.

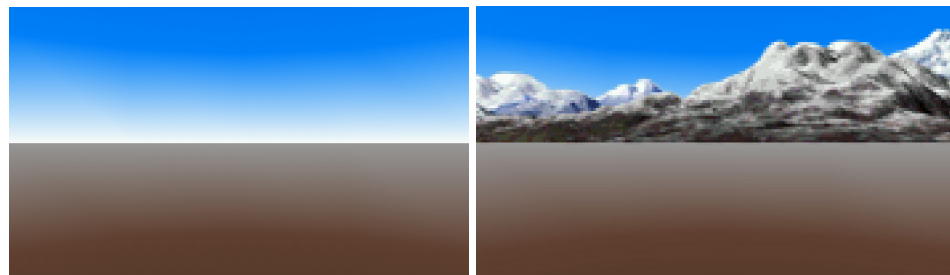


Figure 3.10: Background gradient and image in VR scene.

In summary, the background describes the ground and sky colour gradients on ground and sky spheres and the panorama images on a panorama box. The viewer can look around, but never get closer to the background.

In the context of BS, the inclusion of a background is beneficial because it is more realistic, by providing the horizontal line. Images may also be introduced to mimic clouds. Different background properties may be saved and applied to models when necessary.

Fog

For a more atmospheric effect, a slight mistiness could be added to the scene, so that distant objects appear not only smaller, but fainter.

Fog increases realism of the VR scene. Fog can be added: to the outside to create hazy worlds; to the inside to create dark dungeons or simply to set a mood. The further the viewer can see, the more one needs to have a model and draw. To reduce development time and drawing time, limiting the viewer's sight by using fog might be an option.

Figures 3.11 and 3.12 provide examples of fog colour and intensity level.

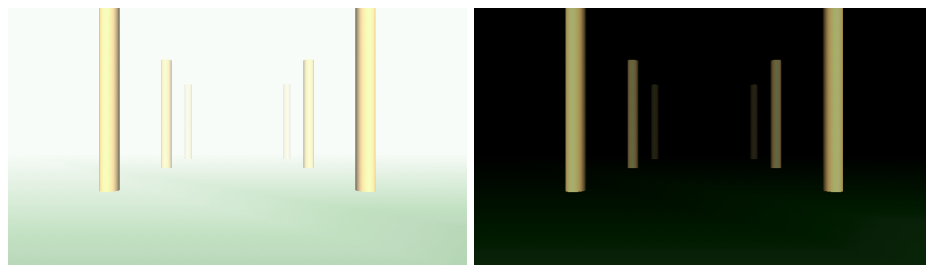


Figure 3.11: Different fog colours in a VR scene.

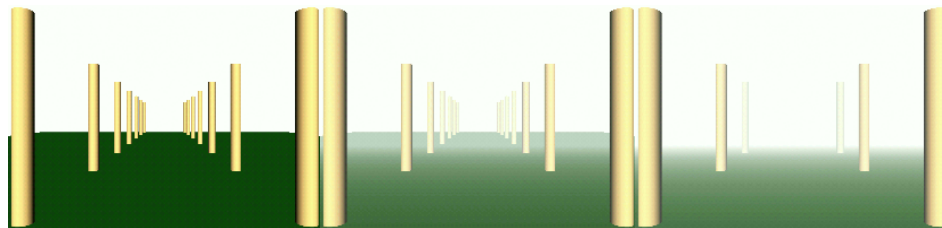


Figure 3.12: Different levels of mistiness in a VR scene.

In summary, fog has a colour, a type, and a visibility range. Fog can be used to set a mood, even indoors. Fog limits the viewer's sight, which reduces the amount of the world one has to build and reduces the amount of the world that must be drawn.

In the context of BS, inclusion of fog in the VR scene is beneficial because it is more realistic, by replicating mistiness of different levels. Different fog properties may be saved and applied to models when necessary.

Appendix C presents further information on VRML features.

In the present study, some VR techniques are partially explored but without the use of devices that would permit total immersion. Such a qualitative analysis is undertaken in chapter 5.

Partial VR has been adopted in the development of the I²PV tool.

3.4.3 HTML

Appendix D provides general information about HTML technology, but in the context of BS the following considerations are relevant.

HTML could support multimedia features on its own over the Internet, for example, hyperlinks, animated objects, *etc.* In addition, it could be used as the carrier for important technologies such as Java/Java 3D and VRML over the Internet, working as a foundation platform to support distant project management, where design teams and client might be geographically scattered. In this case a digital report with multimedia features could be viewed and explored by members of the design team or client over the Internet in order to obtain a timely insight into the project's state.

HTML has been adopted in the development of the I²PV tool.

3.5 Summary

BS information should be displayed flexibly so that information can be understood and user tasks performed efficiently so that less time is spent on the overall process. To achieve this, applications must support the different BS user types and assessment stages.

This chapter described and discussed the potential information formats that could be used in the BS context.

In order to test conjectures about the display of complex simulation data, an integrated building performance simulation tool was required. The ESP-r package was selected and its features briefly described. Further, ESP-r was enhanced in order to generate a neutral file results format that contains the performance data corresponding to a given design option and is used as input to the new I²PV tool reported later.

Finally, a review of programming languages was reported. This led to the decision to use Java APIs, VRML and HTML to develop the I²PV tool as described in the next chapter.

This chapter describes the *I²PV* tool that encapsulates the cognitive rules as previously discussed and provides a test-bed for rule confirmation. The tool was developed following extensive discussions with BS developers and users.

While the tool is fully functional, it is the subject of ongoing refinement as discussed in the last chapter of this thesis.

As stated previously, the four stages in the BS process within a given project are: exploration, analysis, internal presentation and external reporting. This chapter considers the different aspects of the *I²PV* tool which are linked to these stages of the BS process. In each case, the tool's functionality is described and the cognitive rules that enable results interpretation elaborated. In the small number of cases when it was not possible to implement a particular cognitive rule, a mock-up is used to explain the future intention.

The chapter is divided into two main parts. First, the tool's functionality is described from both an internal and external perspective. Second, the tool's software architecture is discussed, including outstanding problems and possible future solutions.

4.1 Functionality and Perceptualisation Techniques

In the *I²PV* tool developed, image icons were applied to drop down menus. Examples are: open, remove, about, help, print, save or exit (see Figure 4.1). The combination with alphanumeric format and the selection accelerators (e.g. Ctrl-E for Exit) increases tool's operation efficiency. These or similar menus are applied to all window interfaces and therefore will not be mentioned hereafter.



Figure 4.1: Image icons in drop down menus within the I²PV tool.

4.1.1 Projects Manager

The user can load an unlimited number of projects, each with an unlimited number of design options. This is done by loading all design options that belong to the same project and as located within a related directory.

Figure 4.2 illustrates two loaded projects, one entitled '*Solar study for Abertay*' with design options entitled '*open window 1m*', '*open window 0.5m*' and '*restricted vents 0.5m*', all taken from respective IPV results files.

Flexibility exists to allow users to open/close projects and design options as necessary, although an error message and sound warning will occur if an illegal action is taken, for example, if the user tries to add a design option to the wrong project or if they try to create a project or design option that already exists.

Colour is used at this stage to differentiate design options in terms of principal performance parameters such as discomfort risk, excessive energy consumption or pollutant emission. For example, the associated design option would be coloured red or green where the values are above or below a critical value respectively. A third colour, yellow, is displayed if the value is borderline (e.g. within the $\pm 5\%$ of the critical value; this is user customizable). A detailed record of all performance evaluations to date is displayed at the bottom of the window for reference.

Essentially, the *Projects Manager* interface supports exploration and high-level analysis of information, with elements of the display representing the following functionality:

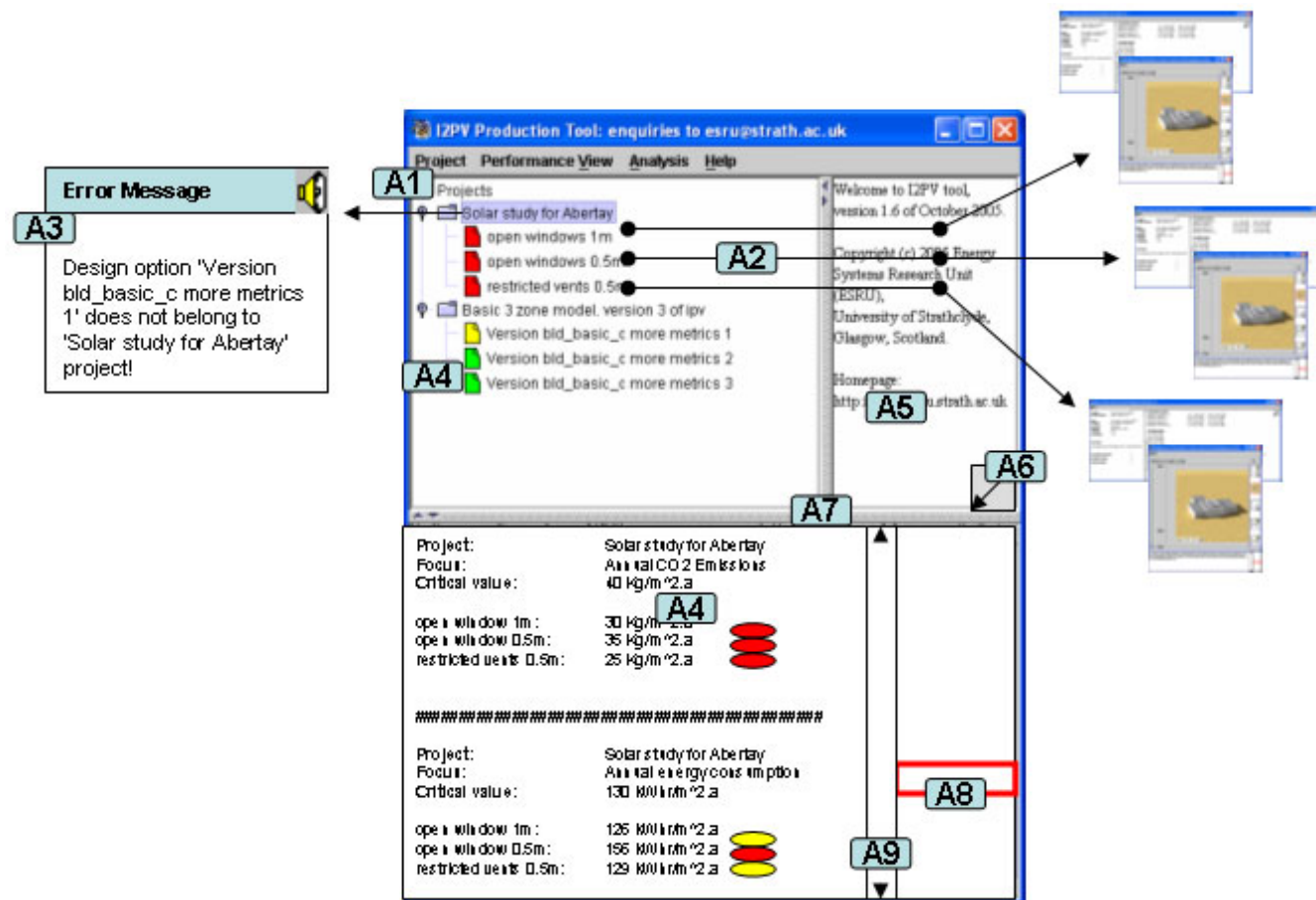


Figure 4.2: Projects manager interface.

A1: A tree structure supports the display of alphanumeric information in a structured, aligned, spaced and grouped manner.

Note: The alphanumeric format has type attributes of Serif, non-capital, bold and not underlined. The Serif and non-capital letters improves readability. The bold type makes information stand out, which has a similar effect to colour although in a more limited way. The ‘not underlined’ attribute applies only to non-hyperlinks. Since all the alphanumeric information in the tool follows these principles, it will not be mentioned hereafter unless specifically important to the display being described.

A2: An interaction attribute to retrieval information about a design option or project. In addition, this information might include images or performance data emanating from another source such as a monitoring programme.

A3: A combination of sound and alphanumeric formats displayed when an illegal action is performed by the user.

A4: A combination of colour and alphanumeric format where the former helps to differentiate design options at a glance while the latter provides detail. Colour also allows users to indicate the selected projects or design options when highlighted.

A5: This alphanumeric format supports initial user guidance. The space is sometimes used to display other information and thereby avoid overlapping windows.

A6: This interaction attribute increases display flexibility by allowing the user to display information in a separate window.

A7: A suppress technique is included to allow the user to suppress the information when unnecessary and thereby unclutter the display.

A8: A context and focus feature avoids the user getting lost within the alphanumeric information panel.

A9: A scrolling function allows efficient change of focus within the alphanumeric information panel.

4.1.2 Help

As shown in Figure 4.3 the user may invoke a help facility from any window. The help window is always loaded with information about the current window's

functionality and loaded concepts. All topics are inter-linked and it is possible to navigate within the history of pages viewed. All of these have the intention of increasing efficiency. The *Help* facility has the following functionality.

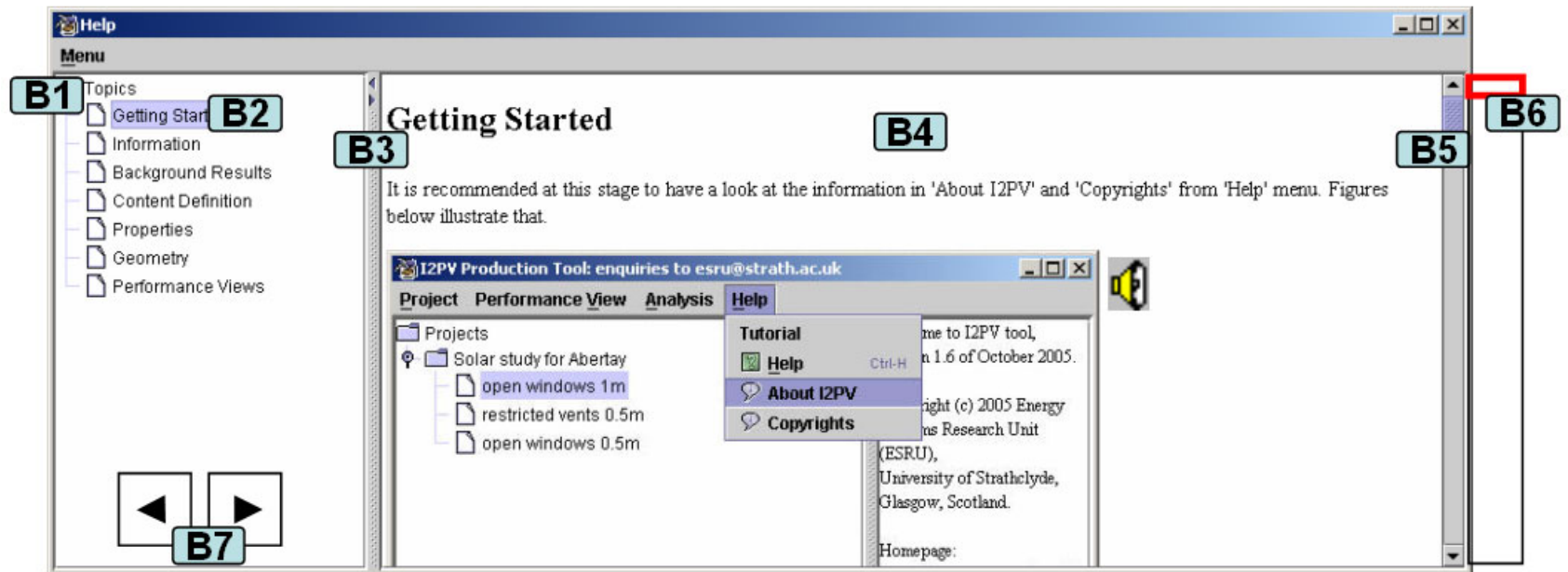


Figure 4.3: Help interface.

B1: A tree technique supports the display of alphanumeric information in a structured, aligned, spaced and grouped manner.

B2: Colour allows the user to visualise the selected topic as displayed in B4.

B3: Again a suppress technique is included to allow the user to suppress unnecessary information and hence unclutter the display.

B4: A combination of formats, such as alphanumeric, images and sound, is used to guide the user. The alphanumeric information is used to provide explanations of technical issues. Screen shots are used extensively to convey the I²PV tool working in practice. Sound is employed to complement alphanumeric information or to issue a warning. A combination of attributes, particularly colour, dynamicity and interactivity, is used to increase intuitive understanding. Colour makes information standout, dynamicity helps to exemplify a task, while interactivity allows the user to control, retrieve or manipulate information as required.

B5: The scroll technique allows rapid change of focus within the main information panel (B4).

B6: The context and focus technique helps to avoid the user getting lost within the main information panel.

B7: The user may go backward and forward within the help history to rapidly locate previously viewed information.

4.1.3 General Information

As illustrated in Figure 4.4, the *About* interface provides general information about a project and related design options may be retrieved, including: project and design option name, date when simulation was performed, contact details, site location, climate file name, synopsis of design intent, simulated periods, and user defined object groupings.

In addition, an annual calendar may be displayed (within a separate window or inside the main window to avoid window overlap) to show the different periods simulated in an intuitive manner.

C1: This alphanumeric format informs the users of the simulation details for each project and design option.

C2: The suppress technique is again used to avoid a cluttered display.

C3: The interaction attribute allows the user to change the alphanumeric format to a more user familiar display (here a calendar). The calendar may be displayed within the main window or as a separate window.

4.1.4 Calendar

As shown in Figure 4.5, a calendar may be displayed to show the different simulation periods and user defined typical days. The calendar is an efficient way to view simulated periods because the user gains insight at a glance. The calendar also gives access to additional information such as days of the week, weekends, public holidays and so on, all of which will have an impact on the building's energy usage.

In addition, the calendar triggers the interactivity attribute to allow information retrieval (such as performance metrics) or to send requests to the simulator for new simulations to be performed.

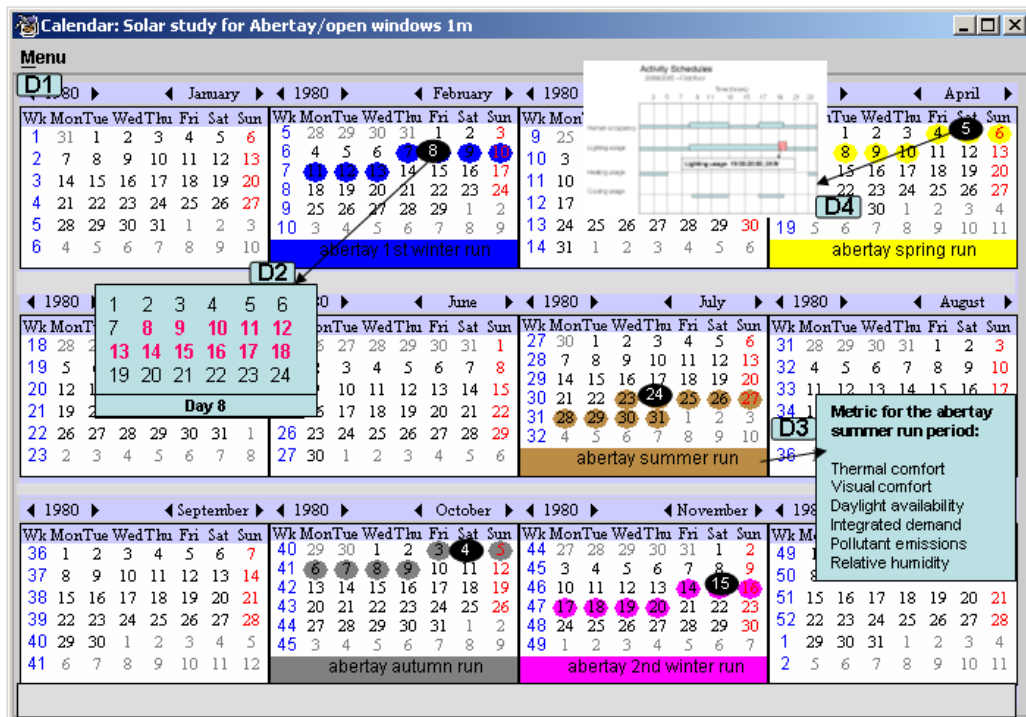


Figure 4.5: Calendar interface.

D1: The alphanumeric format presents information in a structured way while providing additional details such as user-defined period names and week numbers. Colour is used to differentiate simulation periods (blue, yellow, brown, grey and magenta) and individual days (black) at a glance. Colour is also used to highlight weekends and week numbers.

D2: The interactive attribute allows the user to control the information being displayed by ‘drilling-down’ to the hour or second scale. The default display is on the cell of the month that the day/hour enquiry relates to (to avoid window overlap), although the user is able to display the information within a separate window if required.

D3: This interactive attribute allows the user to retrieve information about a simulation period or individual day. In an advanced mode of operation the calendar could be used to drive a simulation and recover results for display and analysis.

D4: A schedule graph can be retrieved through interaction with the different periods or individual days. The related ‘where’ focus could be the whole model or a user defined group of zones (selectable intuitively through geometry model representation or drop-down menu). The user could interact with the schedules (which become

colour highlighted) to find exact numbers/values (information retrieval). The different thicknesses make the chart more informative because they represent different amounts. See Figure 2.14 for an example.

4.1.5 Background Information

As illustrated in Figures 4.6, the *Background Information* interface provides background information on a project, including voice annotation, photographs and results from external programs.

When a voice annotation is available, the button at the top-right corner is enabled. This facility allows one member of the design team to record information for later recovery by a colleague.

The user may control the speed rate of displayed images to facilitate a better understanding of the information presented. This is particularly useful where the images are continuous (such as air movement or a site movie) because it allows controlled evaluation of differences. The supported formats are GIF, JPG, JPEG and PNG for images and WAV and AIFF for sound.

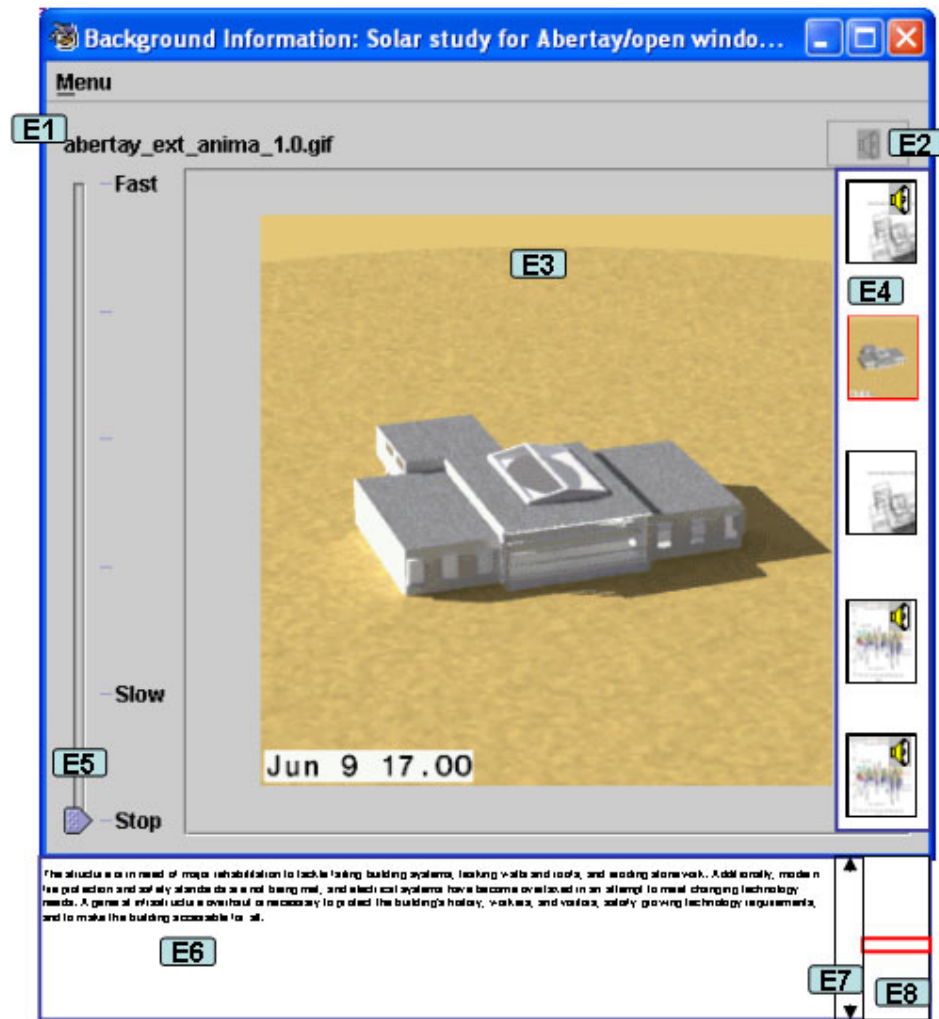


Figure 4.6: Background information interface.

E1: This alphanumeric format (image file name) is associated with the main image as displayed in E3.

E2: The sound format (high-level annotations) is associated with the main image as displayed in E3 when enabled.

E3: The image format supports the presentation of site or design background information for a given project or design option.

E4: This context and focus feature is presented in the form of thumbnails in order to allow the user to place the image displayed in E3 in context. It also indicates the images that have associated audio clips. Colour is used to highlight the image being displayed in E3.

E5: The interactive attribute is used to control the information being displayed in E3 in terms of the looping speed rate.

E6: The alphanumeric format is associated with the image in E3 and audio in E2. The combination allows effective user insight into the overall information being conveyed.

E7: The context and focus technique is used to avoid the user getting lost within the alphanumeric information panel in E6.

E8: The scroll technique allows an efficient change of focus within the alphanumeric information panel in E6.

4.1.6 Content Definition

As illustrated in Figure 4.7, the user may customise IPVs through the *Content Definition* interface, where the available metrics and their associated data are presented in a structured manner. These metrics are flexibly based on the uploaded IPV results files rather than being hard-coded. The user is then able to display metric data for any valid period by using a ‘when’ focus.

The user may also create a customized default IPV by saving a defined metrics list (via the *Save List* button) and load such an IPV via the *User Defined IPV* button. This feature allows the rapid generation and comparison of standard IPVs for several alternative designs.

If the user wishes to be warned about performance values that exceed critical values, the *Critical Value* column must be completed. Any parameter that exceeds the critical value will then result in a warning sound, a change in the graph background colour and the appearance of a line on the graph to indicate the critical value as detected.

The user may also clear the table using the *Clear* button or remove individual rows using the *Remove* button. Users are also able to add rows immediately after the highlighted one; this supports the assimilation of results because it allows related metrics to be displayed together.

The user may name a particular IPV, which corresponds to a specific group of performance metrics.

For line graphs (non-stacked) with more than 4 lines, users are asked if they wish to proceed or change to another format: this avoids overlapping lines and therefore confusing displays. In addition, the line graph may have the dynamic attribute, for example to display a day's *Energy Demand per Unit Time* or the *Resultant Temperature* for group of zones in slow mode to support a more intuitive display of the simulation results. Users are able to control the speed rate and are warned when values become critical (a record is kept) with a sound alert, graph background colour change and critical value line being superimposed on the graph itself.

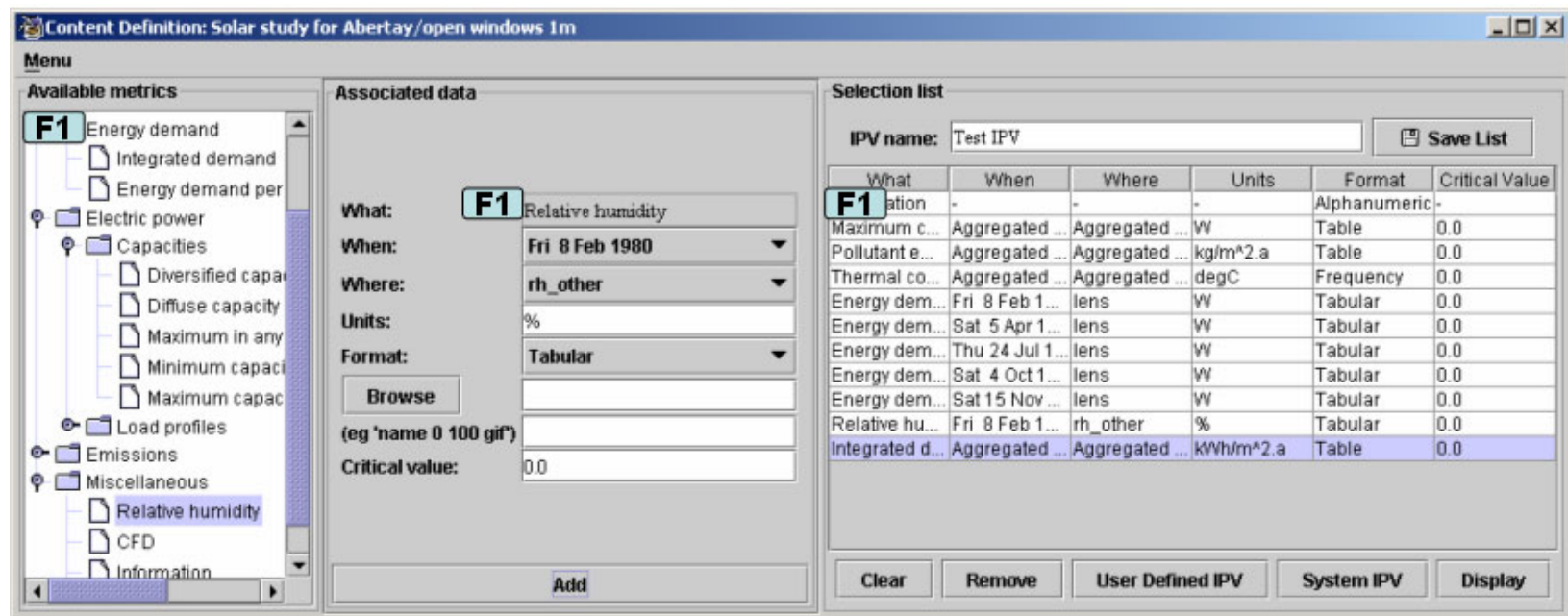


Figure 4.7: Content definition interface.

F1: The alphanumeric format is complemented by the use of tree and table techniques with aligned labels, text fields and menus.

4.1.7 Performance View

As illustrated in Figure 4.8, the *Performance View* interface supports exploration, analysis, internal presentation and external reporting. The user can display a default IPV, which typically might include: general information, images of the site and model geometry, required plant capacity, pollutant emissions, thermal comfort, visual comfort, glare sources, daylight availability, profiles of energy demand per unit time and integrated demand. Significantly, the general information cell is editable so that the user may add extra performance information before selecting the *Print* or *Save As* option.

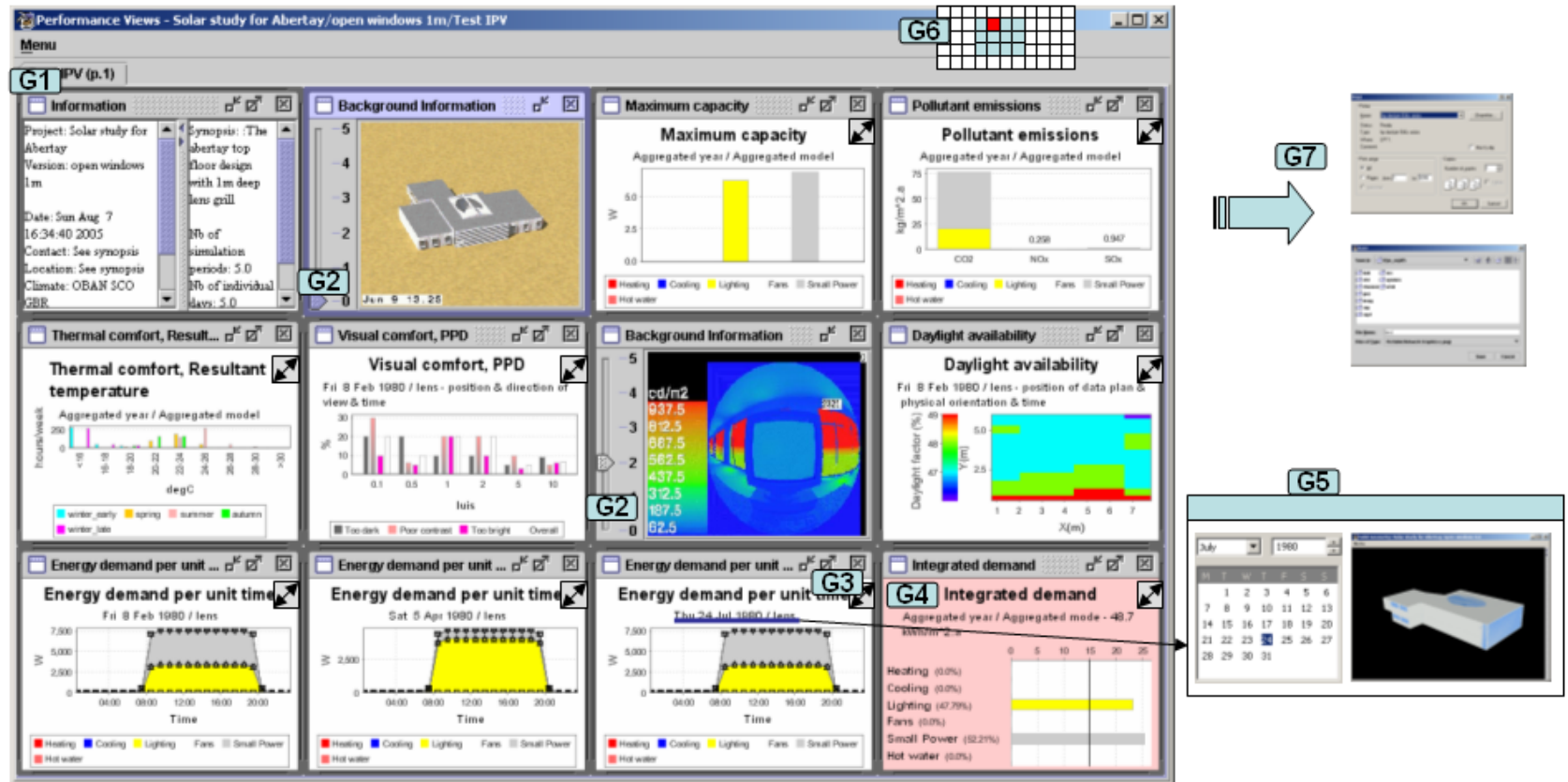


Figure 4.8: Performance view interface.

G1: The matrix display technique can be used to combine many formats/attributes at once, for example alphanumeric, images, graphs, sound, animations, *etc.*, all in a structured manner.

Note: All graphical displays have grids to help readability, colour to differentiate elements, legends as near as possible to data points, clear labelling with no abbreviations, a log-scale where the data range is wide (used only with non-stacked graphs), and alphanumeric information to put the graph in a when/where context. It is possible to toggle off graphical elements (e.g. a grid) or to change the type (non-stacked graph to stacked) or format (line to alphanumeric table). This principle of flexibility applies to all graphs within the I²PV tool.

G2: An interactive attribute allows users to control the images being displayed.

G3: An interactivity attribute allows the graphical information type to be changed (e.g. from line to stacked line) as well as the format (graphic to alphanumeric).

G4: Sound, colour and a visual line is applied to a graph to indicate a critical condition. This alerts the user about unacceptable discomfort levels, running costs, non-compliance with regulations and so on. This alarm and alert feature is available for all metrics.

G5: The interactivity attribute allows a more intuitive way of information retrieval through an alphanumeric (when/where) hyperlink.

G6: The context and focus technique prevents the user becoming disoriented within the presentation matrix. The colour attribute is used to highlight and differentiate between the focus and the active cell.

G7: The functionality *Print* and *Save As* allows the users to record a complete IPV for later use at design team meetings and the like – all component images may additionally be printed at A4 size.

Each IPV cell is independent. This means that the user is allowed to maximise, minimise (i.e. create an icon), close or resize any window as necessary. This is useful when data needs to be rearranged to optimum size to allow readability when printed or saved.

As illustrated in Figures 4.9 and 4.10, graphs are completely customisable in terms of their display properties (e.g. colour, annotations, scale, *etc.*). This is useful because it allows amendments to be applied as necessary. In addition, the user can invoke zooming either through a menu or by direct interaction with the graph (information may be retrieved by positioning the mouse on the data-points; and the graph printed or saved by right-clicking in it and selecting *Print* or *Save As* from the drop-down menu).

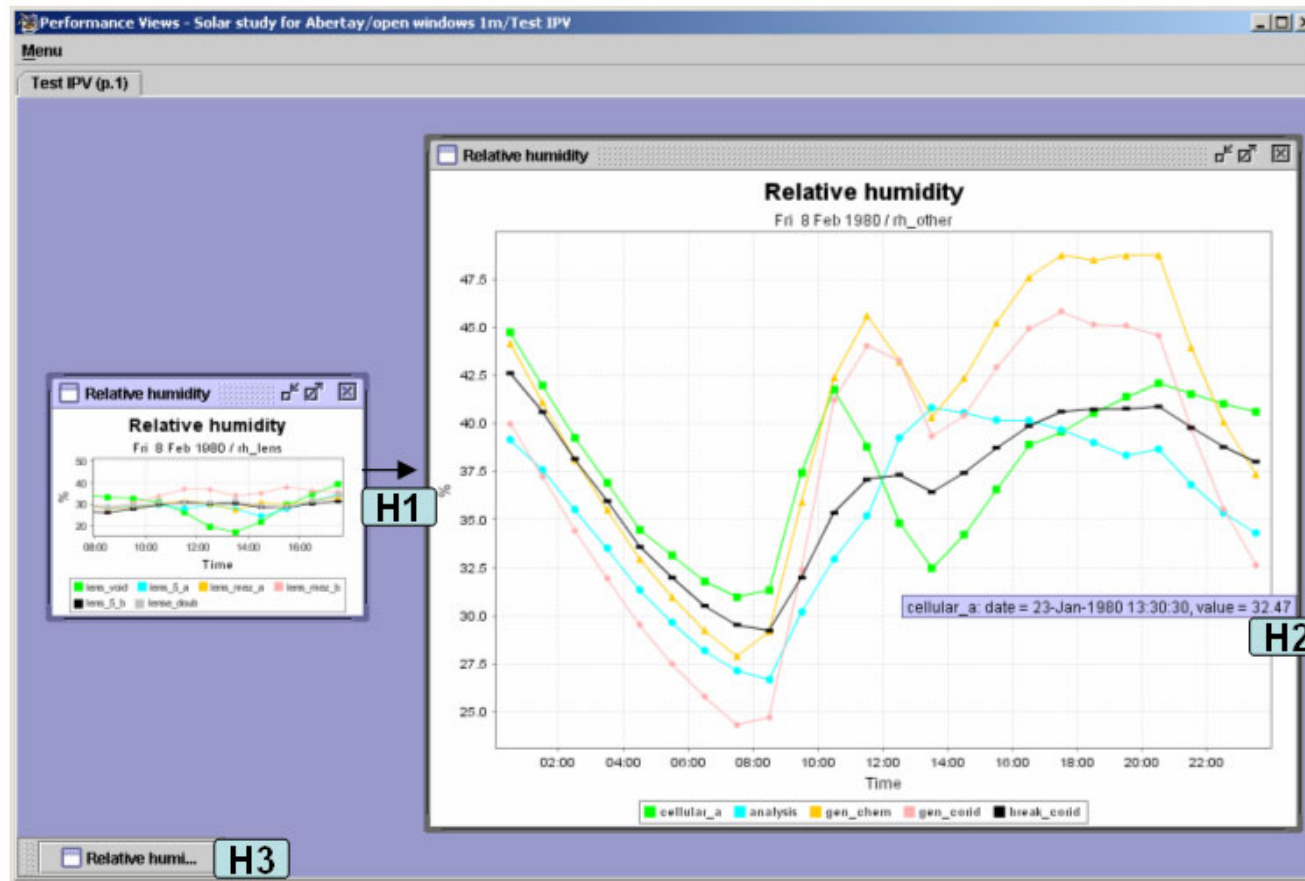


Figure 4.9: Performance view (graphical / cell functionality) interface.

H1: The interactive attribute is used to control the information display by resizing the window. This allows the user to determine the optimum size that provides clear insight into the information being presented.

H2: The interactive attribute is used to retrieve information relating to a particular data point (e.g. cellular_a: date = 23-Jan 13:30:30, value = 32.5%).

H3: The suppress technique is available to avoid display clutter.

H4: The *Print* and *Save As* options allow users to record the individual values of each cell.

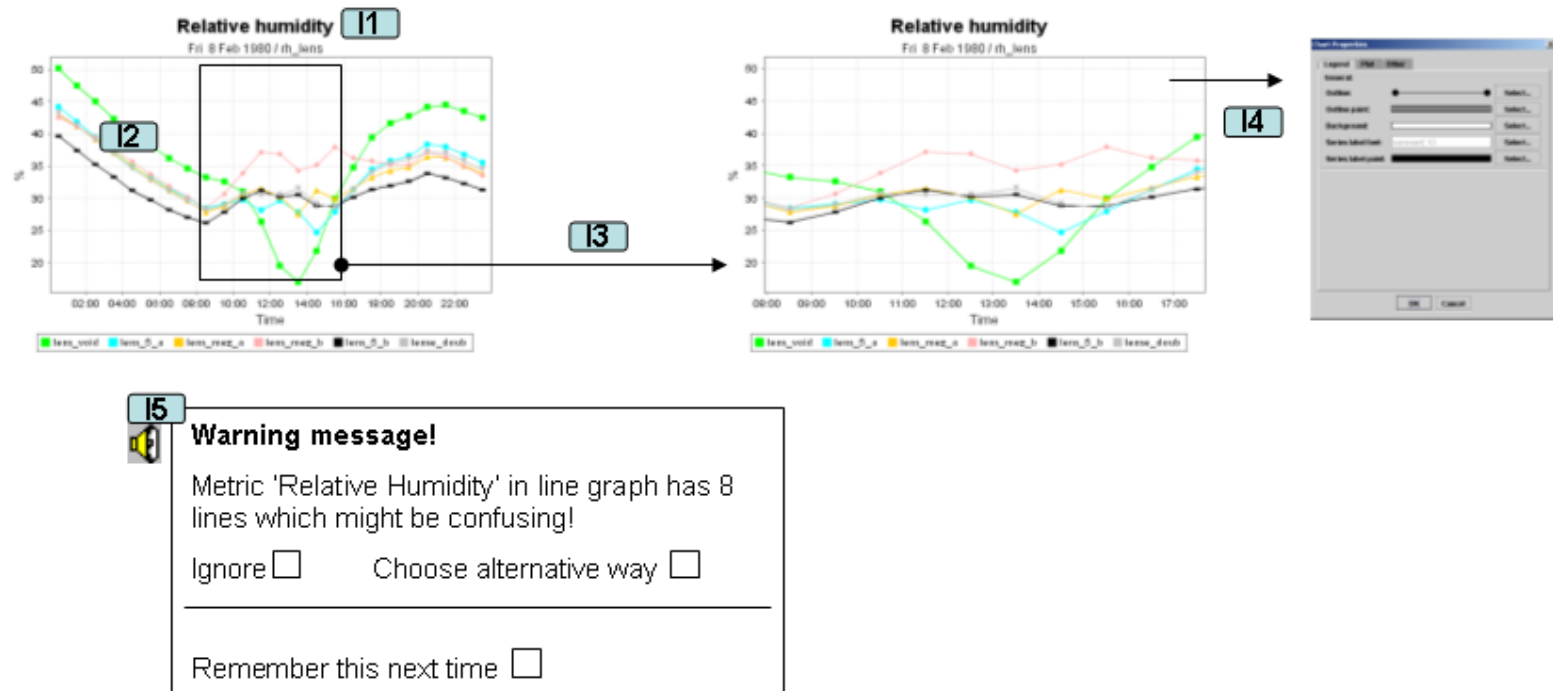


Figure 4.10: Performance view (graphical functionality) interface.

I1: The alphanumeric format puts the performance metric into context by indicating the when (e.g. Fri 9 Feb 1980) and where (e.g. rh_lens – group of zones).

I2: The colour attribute differentiates the different elements in the graph. Where possible, the colour matches the associated property (e.g. red for Heating, blue for Cooling, yellow for Lighting and green for Renewable Energy). The dynamic attribute might also be applied here for a given period so that the user would see lines moving from the right to the left hand side.

I3: Here the interactive attribute is used to allow the user to directly manipulate information by zooming into the graph. During the zoom, a box is displayed on the graph to indicate the focus of the zoom.

I4: Here the interactive attribute allows the user to control the information being displayed by changing graphical properties. In the example shown, the user may change the *Legend* related properties, *Plot* related properties (*Domain Axis*, *Range Axis* and *Appearance*) and *Other* general properties.

I5: The combination of alphanumeric text and sound is used to inform the user that a potentially confusing graph is about to be displayed (e.g. a line graph with more than 4 lines). The user then has the choice to ignore the warning or display the information in an alternative way.

As shown in Figure 4.11, where a cell contains an animation, the user may control the loop speed rate and, where the images are continuous (e.g. air movement), percentage progress is displayed on a progress monitor bar to assist user understanding. This concept is equivalent to a dynamic line graph because the user need not visualise the entire data-set at once; instead, the data unfolds in a user controlled manner.

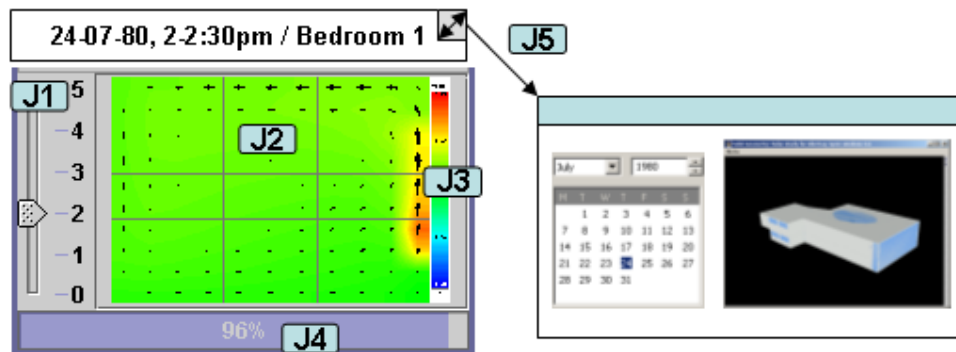


Figure 4.11: Performance view (continuous images display) interface.

J1: The interactive attribute allows the user to control information feedback rate.

J2: The dynamic attribute allows the user to focus on the differences between images (e.g. across time steps or between locations);

J3: The colour attribute allows the user to differentiate values in the display. Where possible the colour matches the associated parameter (e.g. red for maximum and blue for minimum).

J4: The progression bar is used to provide the user with feedback on the number of images displayed to date.

J5: The interaction attribute allows the user to change the ‘when’ and ‘where’ focus of the analysis for the existing third party results.

Figure 4.12 illustrates the multiple use of the above concept within a tailored IPV, where the dynamic looping has been halted at different stages (e.g. time-steps or locations) and in a certain order from left to right and top to bottom. This display is the equivalent of a static line graph because the entire information may be visualised at once.

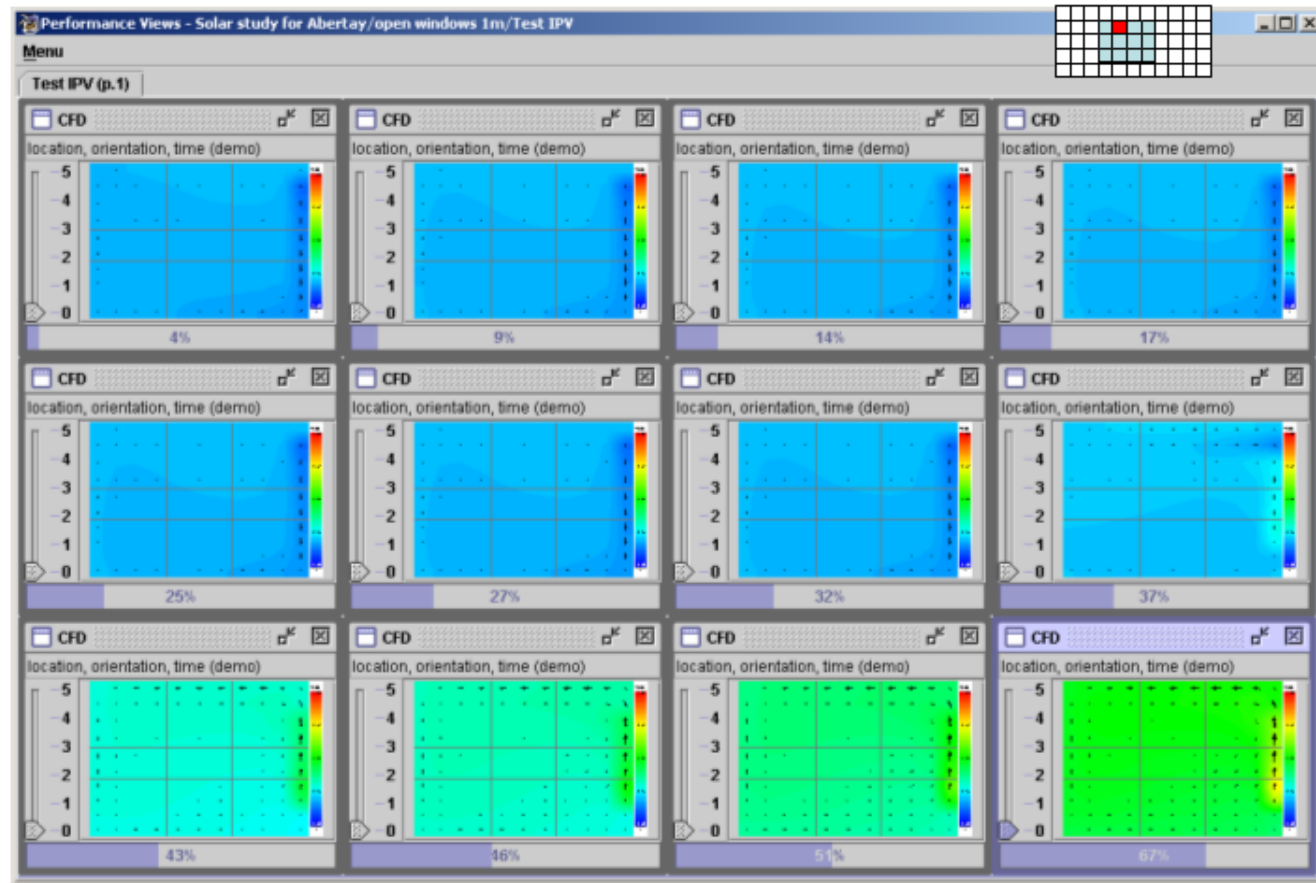


Figure 4.12: Performance view (multiple instances of continuous image displays) interface.

Figure 4.13 illustrates a performance view that is specialised to the display of air movement, daylight availability and the like (i.e. spatially and temporally varying data).

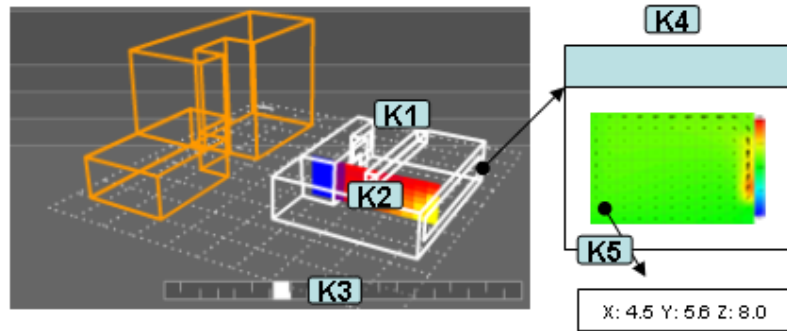


Figure 4.13: Performance view (spatial data) interface.

K1: Here the interaction attribute allows the user to directly rotate, zoom and pan the geometrical model.

K2: The colour attribute is used to differentiate the different data values.

K3: The interactive attribute is used to allow the user to dynamically control the display.

K4: The interactive attribute allows the user to retrieve information so that it may be analysed in greater detail.

K5: The interactive attribute allow the user to retrieve information corresponding to individual data points.

Figure 4.14 illustrates a display tailored to visual comfort.

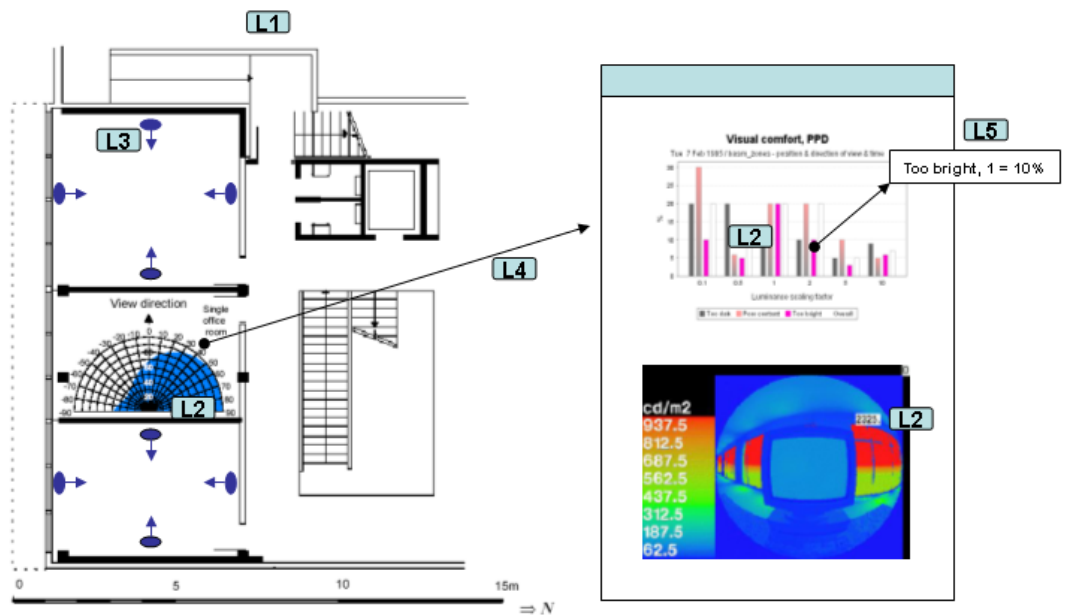


Figure 4.14: Performance view (visual comfort) interface.

L1: Here the interaction attribute allows the user to directly manipulate the geometrical model by rotating, zooming and panning it.

L2: The colour attribute helps the user to differentiate the different data values.

L3: The interactive attribute allows the user to control the data-point and view direction to be evaluated.

L4: The interactive attribute allows the user to retrieve information so that it may be analysed in more detail.

L5: The interactive attribute allows the user to retrieve individual data points.

Figure 4.15 illustrates a display tailored to an acoustic assessment.

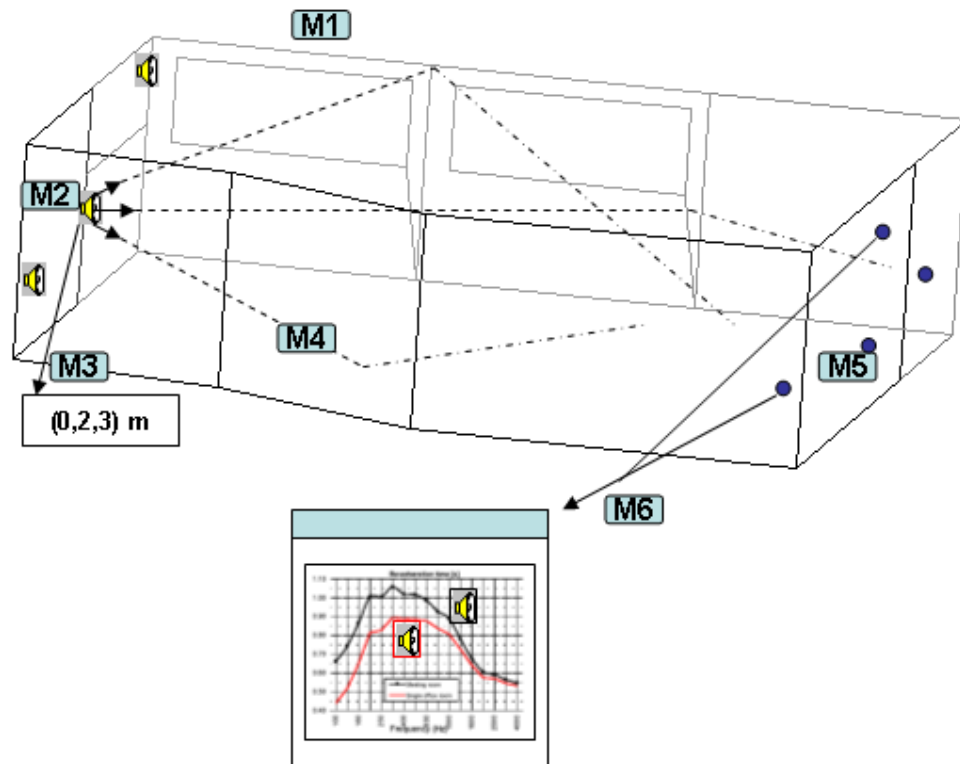


Figure 4.15: Performance view (acoustic comfort) interface.

M1: As before the interaction attribute allows the user to directly manipulate the geometrical model by rotating, zooming and panning it.

M2: Available audio source types may be selected so that the user can listen to the source sound and compare it to the quality of the sound that reaches the targets.

M3: The interactive attribute allows the user to retrieve information on the exact source location.

M4: Visual feedback is given on the sound travel paths and their decay rate to help the user analyse where the majority of the decay is occurring.

M5: The user may define target locations at which acoustics comfort is assessed.

M6: The interactive attribute allows the user to retrieval information at the target location such as reverberation times for different frequencies and to experience the sound quality at that location.

4.1.8 Geometry

The I²PV tool has two ways of displaying the geometry model: either using the VRML files created by ESP-r or the VRML/WF files created by the I²PV tool itself (by directly converting the ESP-r geometry files to VRML or WF formats.)

The researcher strongly believes that geometry is the core display format in BS because all information is somehow directly or indirectly related to it. Two types of geometry, wire-frame and solid, are important for a clear understanding of the information. In this section, three different ways for displaying geometry with the I²PV tool are described:

- The two Java-based (WF or Solid) formats, which use the same interface and can be toggled between each other; and
- The HTML-based format, was added to increase the tool's flexibility in allowing geometry display by commercial software, e.g. Cortona.

In the context of BS, the Java-based displays have the potential to become more powerful in the future because they would be customized to BS exact needs.

The *Geometry* interfaces support exploration, internal presentation and external reporting of information.

4.1.8.1 Wire-frame (Java-based)

The WF format is used to check for geometry inconsistencies. The user may set a group indicator so that related zones stand out in the zones list. The displayed geometry may be printed (*Print*) or saved (*Save As*). Figure 4.16 illustrates this format.

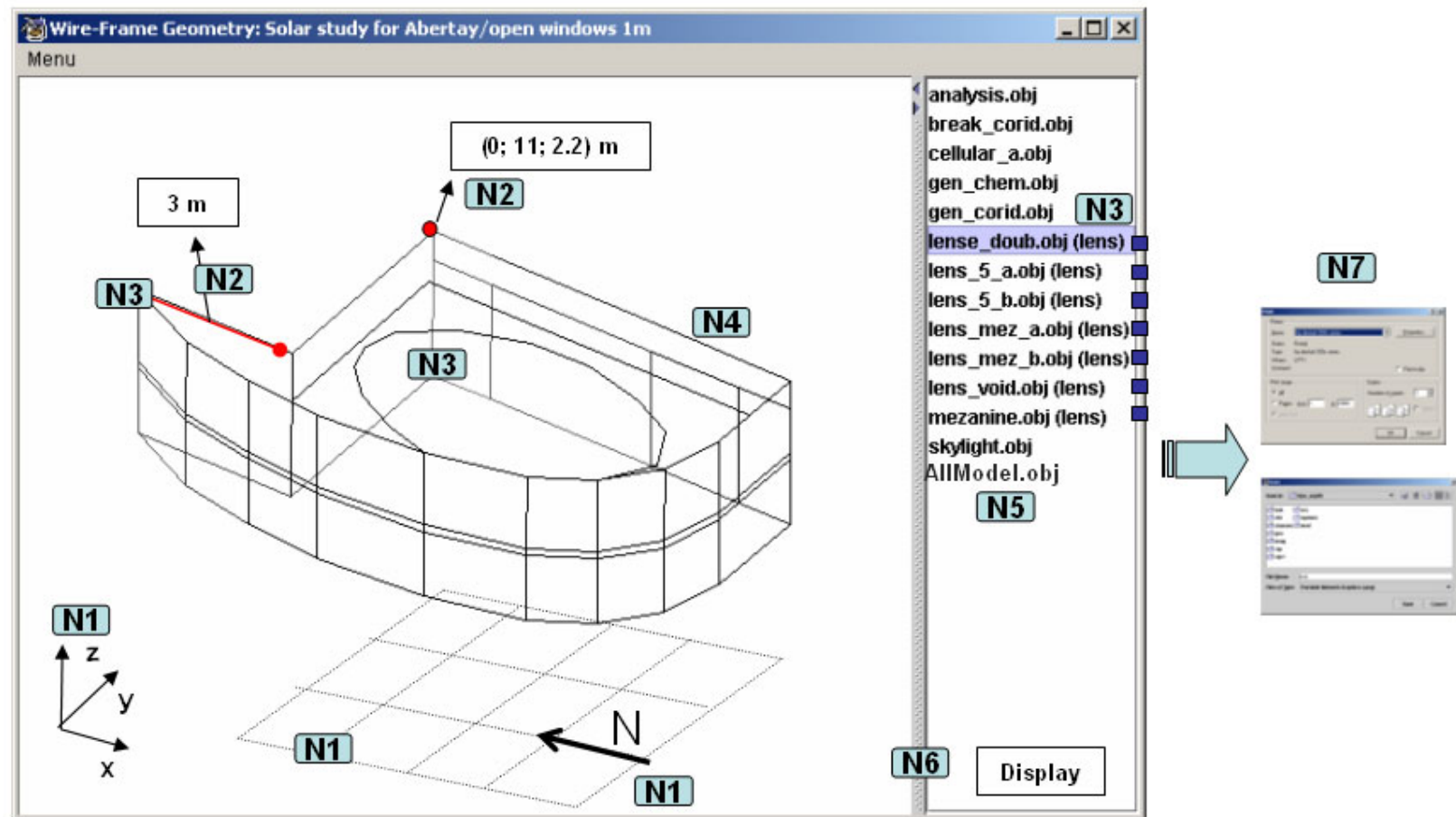


Figure 4.16: Wire-frame geometry interface.

N1: The origin, north-direction indicator and ground plan are essential geometry assistants. The X, Y and Z axes inform the user about the relative distances inherent in the model, the north-direction arrow gives the model orientation, and the ground-plan informs the user about the distance of the model floor to the ground and of any inclination.

N2: The interactive attribute allows the user to retrieve information on data points and distances. This is mainly used to check the model geometry.

N3: The colour attribute highlights the selected line, point or zone(s). It also allows the line differentiation between black and grey lines. In the latter case, the grey gets lighter depending on the distance the line is from the foreground in order to provide depth perception.

N4: The interactive attribute allows the user to manipulate the display (i.e. rotate, pan or zoom).

N5: The alphanumeric format employs a list technique. The user may display the entire model (by selecting AllModel.obj) or may display any combination of zones (through multi-selection from within the list).

N6: The suppress technique allows the user to suppress unwanted or unnecessary information.

N7: The functionalities *Print* and *Save As* allow the user to record the contents of each cell.

4.1.8.2 Solid (Java-based)

As illustrated in Figure 4.17, the Solid format is a more realistic approach to geometry display due to the addition of surface colour (e.g. transparent blue for windows). Also, the user may use colour as a group indicator so that related zones stand out within a zones list and are corresponding highlighted in the model. Typically, the user is able to display any combination of zones or the entire model at once.

From the Solid geometry interface the user has pre-defined viewpoints, two navigation modes (examine and fly) and may turn on or off a headlight.

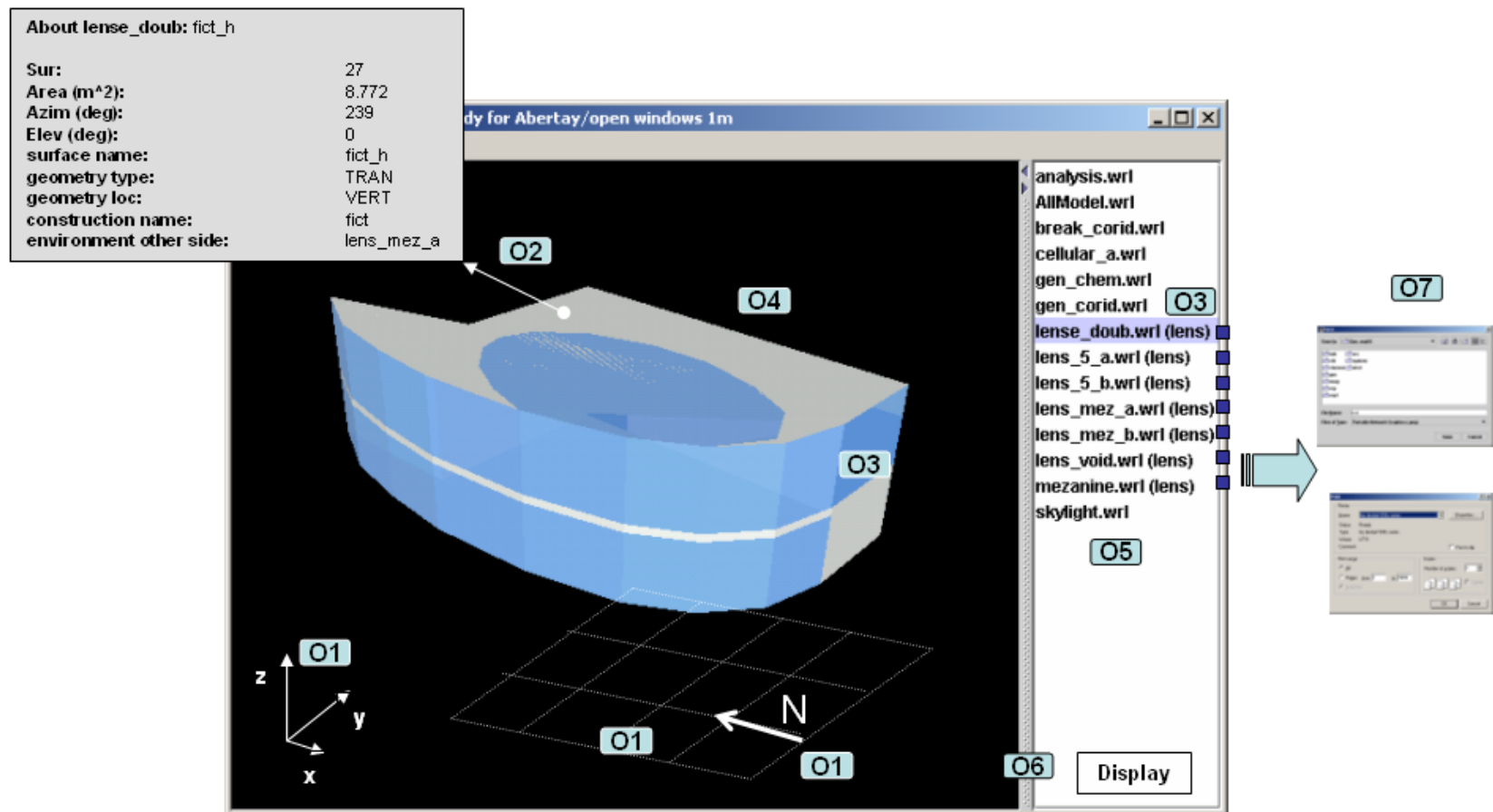


Figure 4.17: Solid geometry interface.

O1: The origin, north-direction indicator and ground plan are crucial geometry features because they inform users about orientation, inclination and scale.

O2: The interactive attribute allows the retrieval of information at the surface or zone level. This feature supports input checking and output browsing – for example, information at the surface level might comprise properties of materials (example in Table 4.1) and finishes, dimensions or data on mould growth likelihood, and at the zone level occupancy schedules, performance variables or system states.

Table 4.1: Layer information retrieved (Solid Java-based).

Belongs to surface <i>passg</i> (construction name <i>mass_part</i> – standard U value $1.54 \text{ W/m}^2\text{K}$)	
Layer number	<i>1</i>
Material DB number	<i>35</i>
Thickness	<i>0.240 m</i>
Conductivity	<i>0.510 W/mK</i>
Density	<i>1400 Kg/m³</i>
Specific heat	<i>1000 J/kgK</i>
IR emission	<i>0.900 kW/m²</i>
Solar absorption	<i>0.250 kW/m²</i>
Description	<i>Block white ptd inner (3% mc)</i>

O3: The colour attribute is here applied to highlight the selected zone(s) and it allows the differentiation of groups of zones or surfaces (e.g. by temperature).

O4: The interactive attribute allows the user to manipulate the display (rotate, pan, zoom, *etc.*).

O5: The structured alphanumeric format is used to provide the user with a list of parts from which zone combination selections may be made.

O6: The suppress technique is again offered to allow the user to suppress unnecessary information and thereby un-clutter the display.

O7: The functionalities *Print* and *Save As* allow users to preserve the content of any cell.

4.1.8.3 Solid (Cortona/HTML-based)

As illustrated in Figure 4.18, an ESP-r geometry model may be converted to a VRML model by the click of a button. This information is included in the IPV results files for immediate use by the I²PV tool when displaying the geometry of each design option. The user is then able to interact directly with the model to retrieve information such as shown in Table 4.2.

Table 4.2: Surface information retrieved (Cortona/HTML-based).

Belongs to zone <i>gen_chem</i>	
Surface name	<i>ptn_mezz_a</i>
Surface number	<i>6</i>
Area	<i>23.625 m²</i>
Azim	<i>63°</i>
Elevation	<i>0°</i>
Geometry type and location	<i>Opaque and vertical</i>
Construction name	<i>clay_partnn</i>
Environment on the other side	<i>lens_mez_a</i>

This provides the zone name that the surface is associated with, the surface name and number, area, angle orientations, geometry type and location, construction name and the zone name on the other side of the surface. This is a new concept of browsing a model; it is effective because it is more intuitive than using menus and similar information recovery devices.

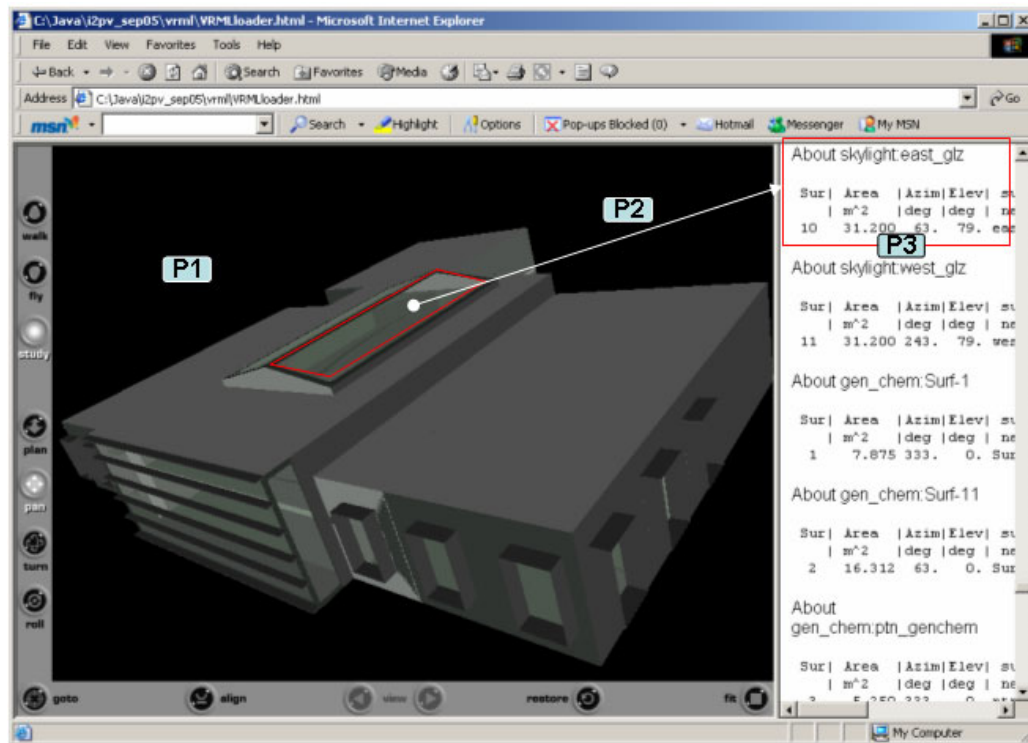


Figure 4.18: Solid geometry (Cortona/HTML-based) interface.

P1: The interactive attribute allows the user to manipulate the display (i.e. rotate, pan, zoom, *etc.*).

P2: The interactive attribute allows the user to retrieve information at the surface or zone level as in the previous example.

P3: A combination of alphanumeric format and colour attribute is used to support the efficient acquisition of information: the former presenting information; the latter highlighting the model part(s) to which the information relates.

4.1.9 VRML Properties

As shown in Figure 4.19, the user is able to set VRML properties of the model such as lighting sources, environmental conditions, background image and navigation properties. Appendix C gives more information on these VRML properties.

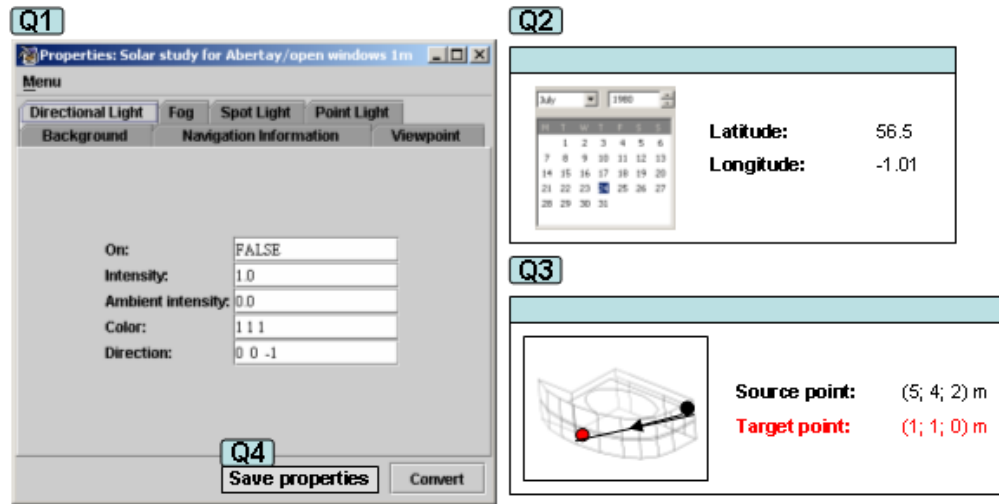


Figure 4.19: VRML properties interface.

Q1: This interface allows the user to change the display properties, e.g. by adding interior lighting, sunlight, landscaping, weather conditions, *etc.*

Q2: This interface allows the user to choose the date/time and location to allow the directional light to be automatically calculated.

Q3: This interface allows the user to choose the source and target for a spotlight. The interactivity and colour attributes are again used to support information retrieval and the differentiation of displayed objects.

Q4: The *Save* function allows the user to retain certain conditions (e.g. winter, summer, foggy, *etc.*) for future application to all related design options of a given project.

4.1.10 Design Options Comparison

As shown in Figure 4.20, I²PV allows the user to compare design options in terms of a scatter graph of energy cost versus a nominated performance parameter (i.e. benefit). Alternatively, a bubble graph may be used to include an additional parameter such as capital cost.

It is also possible to express the benefit as a function of more than one performance parameter. Here a multi-variate comparison is automatically performed by rating

each selected performance 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 determined 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%). B_d will vary in the range 0-2.

R1

Menu

restricted vents 0.5m open windows 0.5m

Weightings

open windows 1m

Weightings:

Maximum capacity (aggregate):

60 %

Pollutant emissions (aggregate):

10 %

Thermal comfort (aggregate):

30 %

Compare

Menu

restricted vents 0.5m open windows 0.5m

Weightings

open windows 1m

Metrics:

Maximum capacity (aggregate)

☐ Does not meet the goal

☒ Just meets the goal

☐ Perfectly meets the goal

Pollutant emissions (aggregate)

☒ Does not meet the goal

☐ Just meets the goal

☐ Perfectly meets the goal

Thermal comfort (aggregate)

☐ Does not meet the goal

☐ Just meets the goal

☒ Perfectly meets the goal

Compare

R3

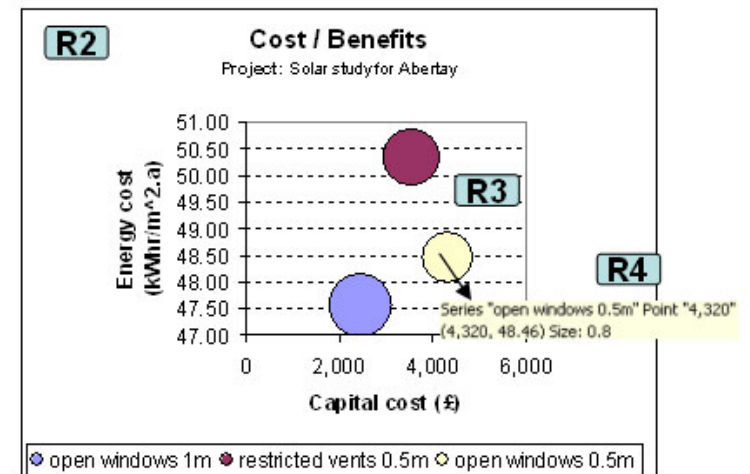


Figure 4.20: Cost-benefit comparison interface.

R1: This facilitates user defined performance metric definition and individual metric weighting (the latter may be project specific targets or recommended values as stored in the *Regulations* database). The alphanumeric format is delivered in a structured manner through tabs, radio buttons and aligned labels.

R2: The bubble graph format provides an effective way to compare design options at a glance.

R3: The colour attribute allows the user to differentiate design options within the bubble graph and elsewhere within the user interface. Non-opaque colours should be applied, specially when the level of overlapping is high.

R4: The interactive attribute supports retrieval information such as the exact values of the costs and benefits.

Figure 4.21 illustrates the use of a dynamic line graph to effectively compare the energy demand of design options. The user is able to relate the results back to cost and pollutant emissions as well as breaking costs down into components (corresponding to heating, cooling, *etc.*). Here, the dynamicity, interactivity and colour attribute work in harmony.

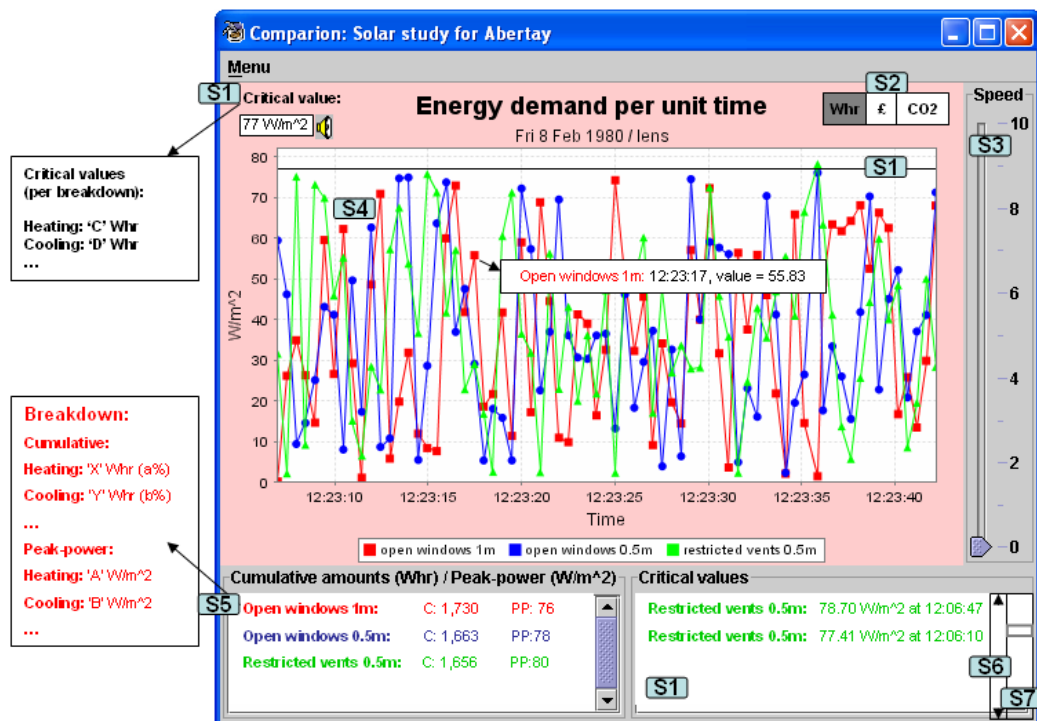


Figure 4.21: Dynamic line graph used to compare design options.

S1: A combination of the sound and alphanumeric formats, with the colour and interactivity attributes are used here along with a visual clue to alert the user about the values that exceed some critical limit. A record is kept of all critical values (which are then coloured to match the related design option). The graph background colour turns to light red when a critical is exceeded and a horizontal line shown on the graph to indicate the departure from critical.

S2: The user may investigate energy demand (as shown here), cost or CO₂ emissions.

S3: The interactive attribute allows the user to control the speed rate setting of the information being displayed. This may be used to animate the displayed profiles in order to assist with the scanning and comparison of large data sets.

S4: The line graph format is the most appropriate to show time based information. Colour and dynamicity are used to give the user to a better insight into the information.

S5: Here the alphanumeric format and colour, interactivity and dynamicity attributes are used together. Alphanumeric information is shown in a structured, aligned, spaced and grouped manner. Colour differentiates the information related to the

different design options. Interactivity allows information retrieval and supports drill-down to acquire breakdowns. And dynamicity updates the cumulative and peak power values at the same animation rate.

S6: The scroll technique allows efficient change of focus within the alphanumeric information panel.

S7: The context and focus technique prevents the user getting lost within the alphanumeric information panel.

As illustrated in Figure 4.22, another way to compare design options is through quick tab-switching.

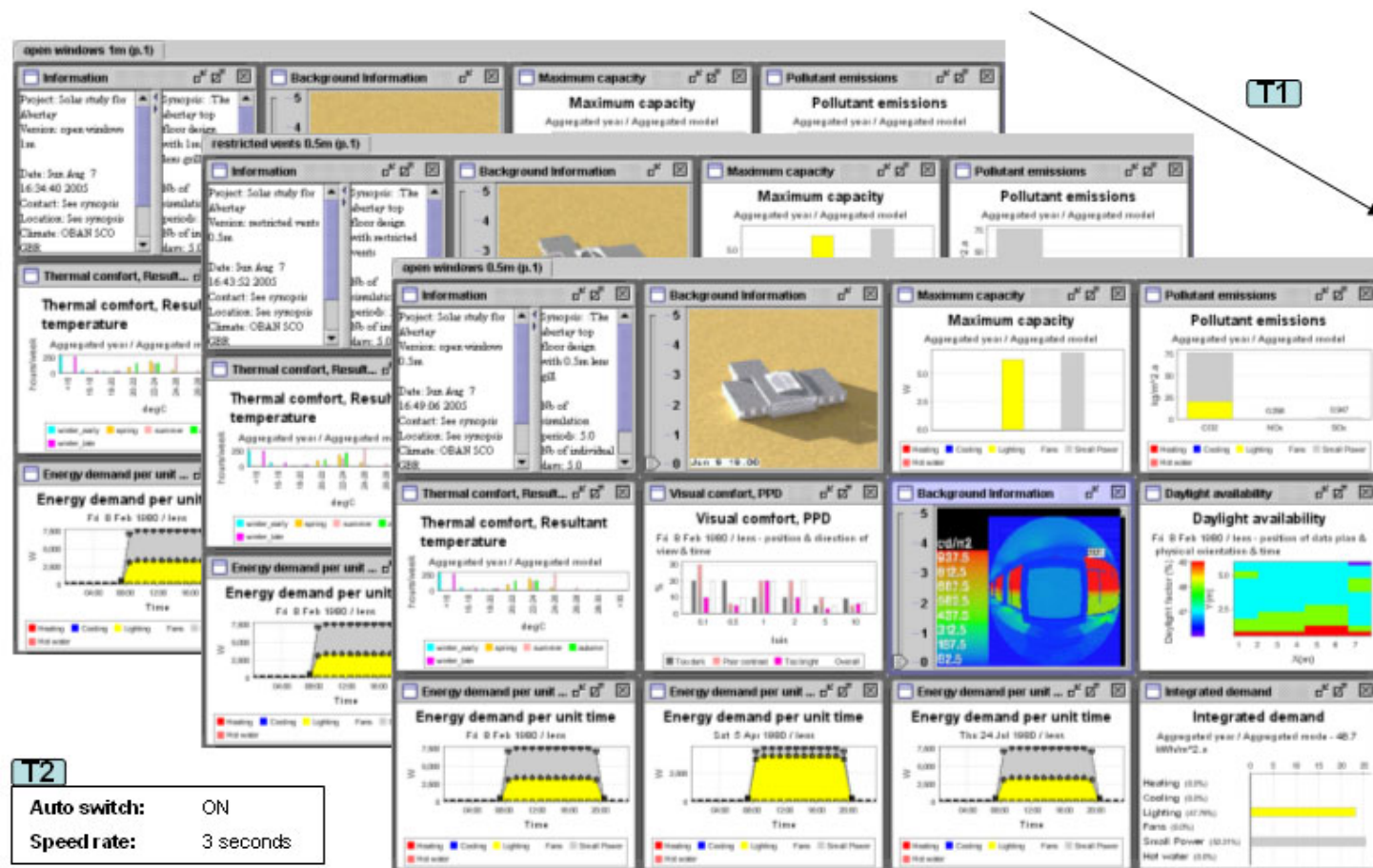


Figure 4.22: Tab-switching comparison interface.

T1: The user may compare design options by switching between tabs because the cells are in the same position within the IPV matrix and the scales may be made the same for a given performance metric.

T2: The user may automate the process by setting the Auto-switch to ON and the speed rate to a value that allows optimum insight.

As illustrated in Figure 4.23, it is also possible to compare design options using an IPV where the rows contain performance metrics and columns design options.

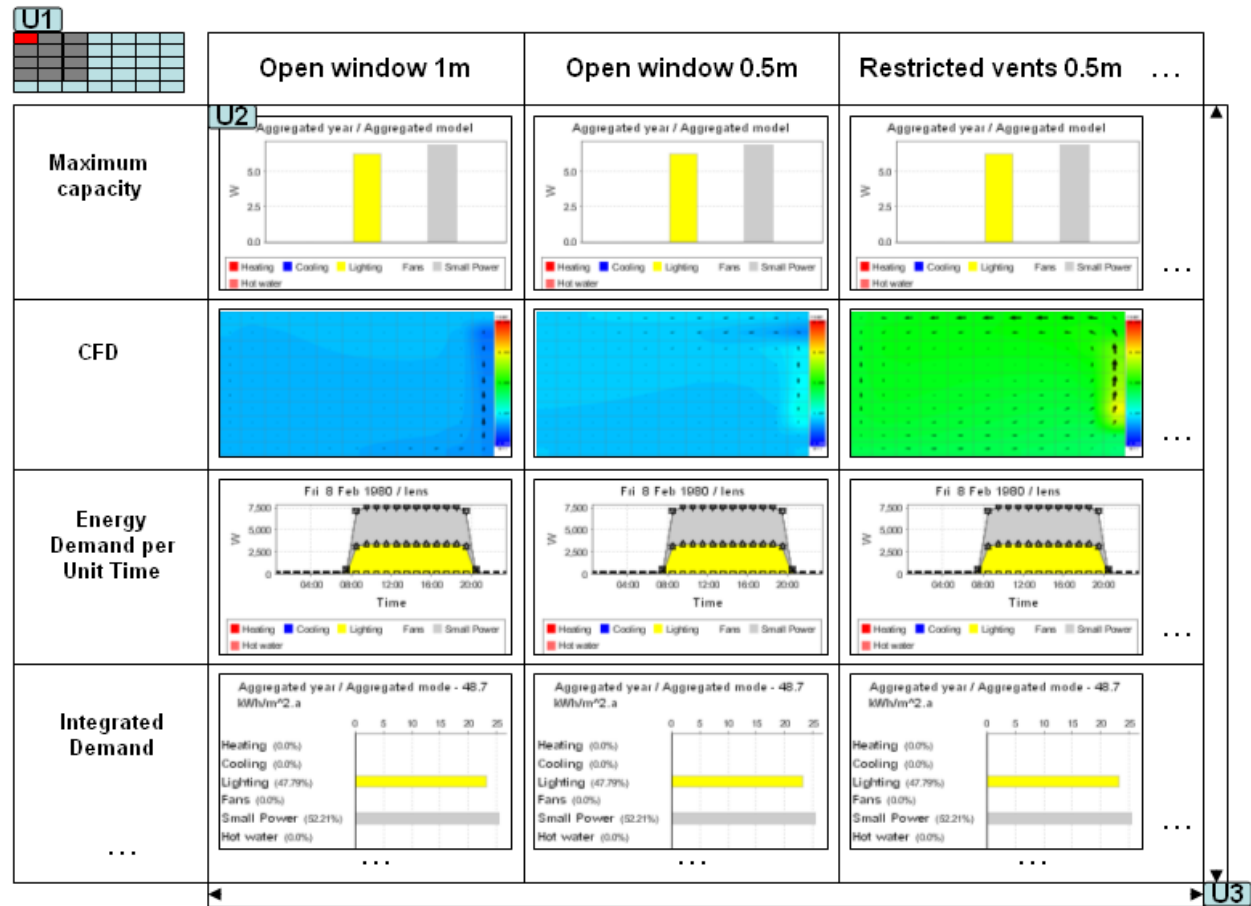


Figure 4.23: Matrix-based options comparison technique.

U1: The context and focus technique is used to avoid the user getting lost within the matrix. Colour is used to differentiate the focus and active cells.

U2: The matrix can hold any format (graphs, geometry, images, alphanumeric and sound) and be assigned any attribute (interactivity, dynamicity, colour and type).

U3: The scrolling technique allows efficient change of focus within the matrix.

Figure 4.24 shows the matrix technique being applied in the actual I²PV tool (i.e. non mock-up display). The columns represent the design options being compared and the rows represent the different metrics. Here, there are 12 design options and 9 metrics, which makes a total of 108 graphs displayed in the comparison matrix. The small size was chosen in order to create a more compact display.

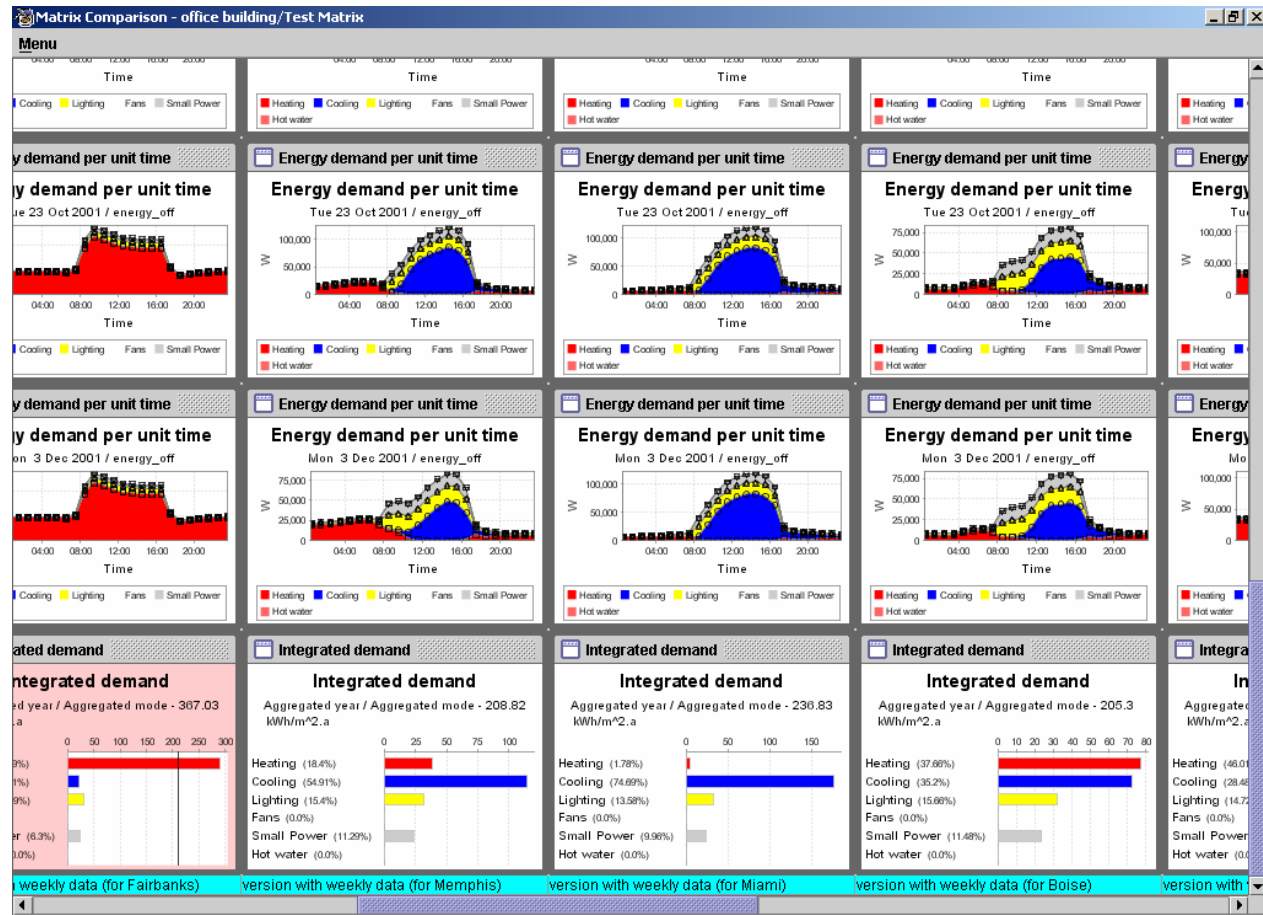


Figure 4.24: Matrix-based options comparison interface.

4.1.11 Client Reporting

As depicted in Figure 4.25, client reporting may be done in two ways: static or dynamic. Although sometimes required, the static approach is less intuitive and flexible. The dynamic approach on the other hand allows the user to explore, initiate further analysis as required and, most importantly, to compose bespoke reports.

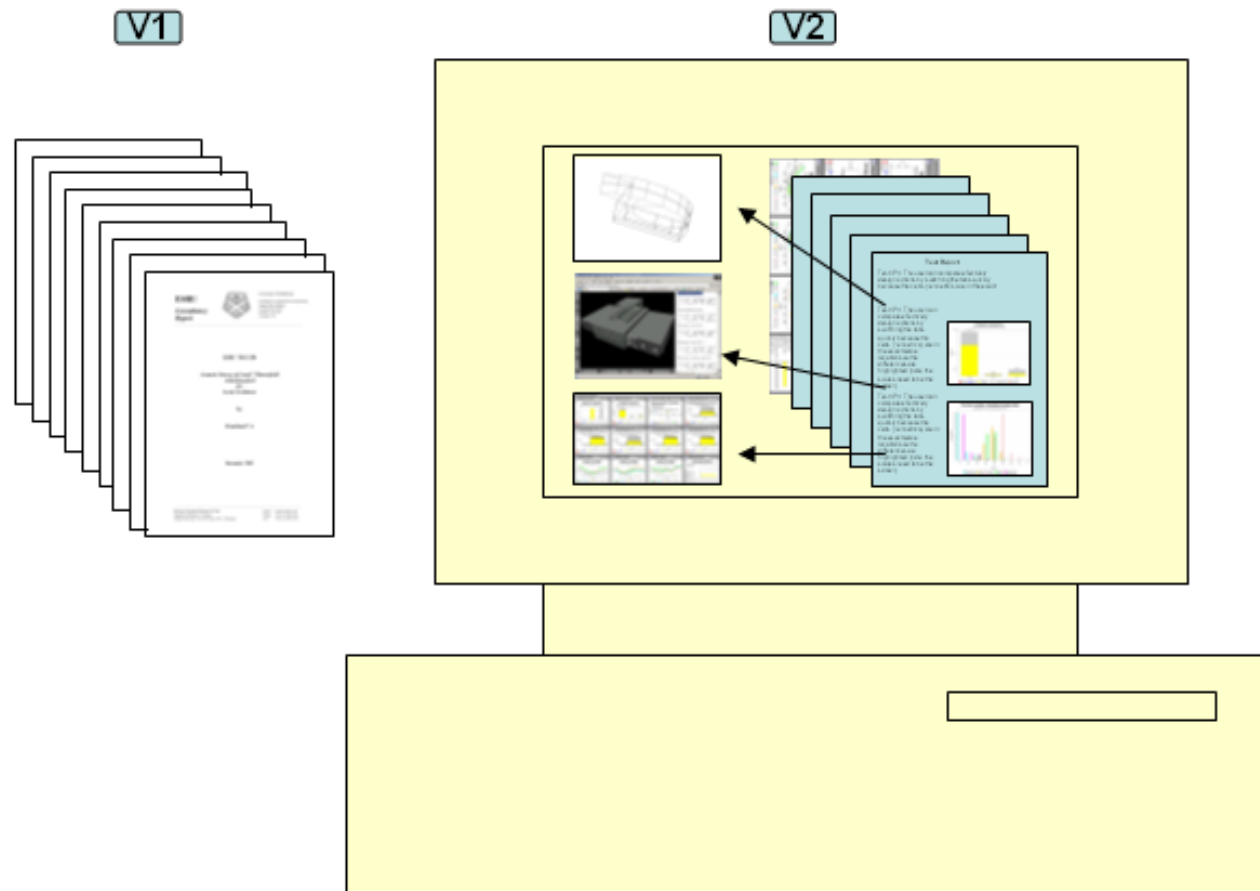


Figure 4.25: Client reporting interface.

V1: This represents a client report in hardcopy format (static), created automatically by I²PV. This report corresponds to a standard format whereby all design options are compared and the best solution presented using a few key values, graphs and images. The user is then required to edit the front page through a simple interface. It is possible to customise this standard report before emailing it in PDF format to the client.

V2: This represents a client report in digital format (dynamic and interactive), again created automatically by I²PV. This report may be tailored by the user before being sent to the client as a Web link that gives access to the report as stored on the user's server. The report may then be viewed via a Java Applet residing within the client's Web browser (similar concept to *Live Meeting* from *Microsoft*). This report might typically be targeted at clients who are technically advanced and therefore able to explore the results in detail.

4.2 I²PV Architecture Design

This section describes the current architecture of the I²PV tool and prospects for future enhancement to further increase the effectiveness and flexibility of the displays and increase task efficiency.

4.2.1 Current Status

The data flows underlying I²PV are relatively simple to facilitate ease of extension as new perceptualisation techniques are added. The input to I²PV is arranged in a NFRF to enable inter-working with any building performance assessment application that possesses the required simulation capabilities. In summary, an I²PV input file contains data arranged in five categories:

- image or other files (e.g. VRML or voice annotation) associated with design options;
- statistical data (as usually displayed in bar/column graphs);
- frequency data (usually displayed in histograms);
- time based data (usually displayed in line graphs); and
- spatial data (usually displayed in filled counter or radar graphs).

At the present time specific parsers exist for each category. This is recognised as a deficiency since a new parser will be required where a particular simulator wishes to make available a new data-format or express an old one in a new way. Removing this limitation is a work-in-progress. That said, the present approach does allow the user some flexibility without the need to change a parser. For example, the metrics corresponding to a default IPV and the colours assigned to graphic elements may both be readily redefined. Examples of system files are presented in Appendix E.

4.2.2 Future Intentions

As an evolution of the I²PV tool, a relational database capability could usefully be added along with Internet database connectivity (using, for example, JDBC) and contemporary Web interface design (for example, XML and XSL technologies). These prospects are now considered in turn.

4.2.2.1 Relational database

The use of a relational database (e.g. Oracle, Sybase, MySQL) imparts added value to the simulation process given the large amounts of inter-related data produced. Being able to efficiently store, retrieve and update data has a major impact on performance. In comparison to storing the data in large text files to be processed by specific parsers (i.e. as implemented in the current I²PV tool), the relational database approach supports information analysis by comparing and sorting data and finding patterns.

A study by Stravoravdis and Marsh (2005) argues that scripts to automate the generation of building performance data and on-line databases for storing and managing this data (which could be accessed by any member of the design team) improves design decision making.

In the context of BS, a relational database is an ideal mechanism to store default values which may be used by the I²PV tool. These values could be easily accessed

and managed which may increase effectiveness/flexibility of displays and efficiency of tasks. These values could be about:

- ‘Good practice’ energy demand (and associated CO₂ emissions and costs) per building type (e.g. office, school, hospital, *etc.*). Table 4.3 shows data for the office type;
- Comfort levels (e.g. thermal, visual, acoustics, air movement, humidity, *etc.*); and
- Human life critical levels (e.g. temperature, fresh air, CO₂ concentrations, mould growths, *etc.*).

Table 4.3: Office typical and best practice annual energy costs (Business Guide to Energy Costs in Buildings, 1996)

Building Type: Offices	Level of Usage	Annual Energy Costs (£/m ²)	
		Fossil Fuel	Electricity
Naturally ventilated cellular	Typical	1.9	2.7
	Good Practice	0.9	2.0
Naturally ventilated open plan	Typical	1.9	4.7
	Good Practice	0.9	3.4
Air-conditioned	Typical	2.2	11.1
	Good Practice	1.0	7.3
Prestige air-conditioned	Typical	2.6	19.9
	Good Practice	1.3	14.4
Assumptions: <i>Unit fuel cost:</i> Fossil fuel 1.2p/kWh Electricity 6.2p/kWh <i>Occupancy:</i> Monday – Friday, 8am – 7pm <i>Floor area:</i> Gross Note: On average, 100 m ² of office space produces 14 tonnes of CO ₂ each year.			

Such default values may be used as an automatic outputs checker. However, the I²PV tool should be flexible enough to allow customisation of such values, which would be useful in projects where targets are set initially and used throughout the entire process of exploration, analysis and presentation of information.

4.2.2.2 JDBC

Java Database Connectivity - JDBC - is a Java API for executing SQL statements. By using the JDBC API, a program can access almost any data source, from

relational databases, through spreadsheets to flat files. Some benefits include (Bales, 2003):

- Since JDBC is included with the Java Platform, it is available whenever Java is available. This makes the Java application that uses the JDBC API portable to most platforms;
- Since Java applications that use the JDBC API use only interfaces from the JDBC packages, the code has a high likelihood of being portable between vendor databases;
- The JDBC API encourages Java applications to be designed into multiple tiers, separating business logic from presentation logic. This promotes scalability, reliability and maintainability of applications; and
- When written in Java, a JDBC application automatically enjoys the benefits of robustness, security and automatic downloadability.

In the context of BS, if a relational database is used, then the JDBC API should be included in the tool's implementation because it is in synchronisation with the Java technology as described in the previous chapter.

4.2.2.3 XML and XSL

The following explanations/definitions are based on the work of Harold and Means (2004) and Fitzgerald (2001).

The Extensible Markup Language (XML) has many benefits:

- **Simplicity:** Information coded in XML is easy to read and understand. It could also be computer processed;
- **Openness:** XML is a W3C standard, endorsed by software industry market leaders;
- **Extensibility:** There is no fixed set of tags. New tags could be created as required;
- **Self-description:** In traditional databases, data records require schemas set up by the database administrator. XML documents could be stored without

such definitions because they contain meta data in the form of tags and attributes. XML provides a basis for author identification and versioning at the element level. Any XML tag could possess an unlimited number of attributes such as author or version;

- **Contains machine-readable context information:** Tags, attributes and element structure provide context information that could be used to interpret the meaning of content, opening up new possibilities for highly efficient search engines, intelligent data mining, agents, *etc.* This is a major advantage over plain text or HTML, where context information is difficult or impossible to evaluate;
- **Separates content from presentation:** XML tags describe meaning not presentation. The motto of HTML is "I know how it looks", whereas, the motto of XML is "I know what it means, and you tell me how it should look". The look and feel of an XML document could be controlled by XSL style sheets, allowing the look of a document (or of a complete Web site) to be changed without touching the content of the document. Multiple views or presentations of the same content are easily rendered;
- **Supports multilingual documents and Unicode:** This is important for the internationalisation of applications;
- **Facilitates the comparison and aggregation of data:** The tree structure of XML documents allows documents to be compared and aggregated efficiently on an element by element basis;
- **Could embed multiple data types:** XML documents could contain any possible data type - from multimedia data (image, sound, video) to active components (Java applets, ActiveX);
- **Could embed existing data:** Mapping existing data structures like file systems or relational databases to XML is simple since the language supports multiple data formats and covers all existing data types;
- **Provides a 'one-server view' for distributed data:** XML documents could consist of nested elements that are distributed over multiple remote servers. XML is currently the most sophisticated format for distributed data - the Web could be seen as one huge XML database; and

- **Rapid adoption by industry:** Software AG, IBM, Sun, Microsoft, Netscape, DataChannel, SAP and many others have announced support for XML. Microsoft will use XML as the exchange format for its Office product line, while both Microsoft's and Netscape's Web browsers support XML. SAP has announced support of XML through the SAP Business Connector with R/3. Software AG supports XML in its Bolero and Natural product lines and provides Tamino, a native XML database.

XSL is a family of recommendations for defining XML document transformation and presentation. It consists of three parts as follows.

- **XSL Transformations (XSLT):** a language for transforming XML;
- **XML Path Language (XPath):** an expression language used by XSLT to access or refer to parts of an XML document. XPath is also used by the XML Linking specification; and
- **XSL Formatting Objects (XSL-FO):** an XML vocabulary for specifying formatting semantics.

An XSLT stylesheet specifies the presentation of a class of XML documents by describing how an instance of the class is transformed into an XML document that uses a formatting vocabulary, such as (X)HTML or XSL-FO.

XSL is a language for expressing style sheets. An XSL style sheet is, as with CSS, a file that describes how to display an XML document of a given type. XSL shares the functionality and is compatible with CSS2 (although it uses a different syntax). It also adds:

- **A transformation language for XML documents:** XSLT. Originally intended to perform complex styling operations, like the generation of tables of contents and indexes, it is now used as a general purpose XML processing language. XSLT is thus widely used for purposes other than XSL, such as generating HTML Web pages from XML data; and

- **Advanced styling features:** expressed by an XML document type, which defines a set of elements called *Formatting Objects*, and attributes (in part borrowed from CSS2 properties and adding more complex ones).

Styling requires a source, XML documents, containing the information that the style sheet would display and the style sheet itself, which describes how to display a document of a given type. Figure 4.26 shows a XML version of an IPV results file (Appendix F lists a portion of the actual file used to produce this example screen shot).

This XML file does not contain any presentational information, which is contained in the stylesheet. Separating the document's content from its styling information allows the same document to be displayed on different media (like screen, paper, immersed VR). It also enables users to view the document according to their preferences and abilities, just by modifying the style sheet.

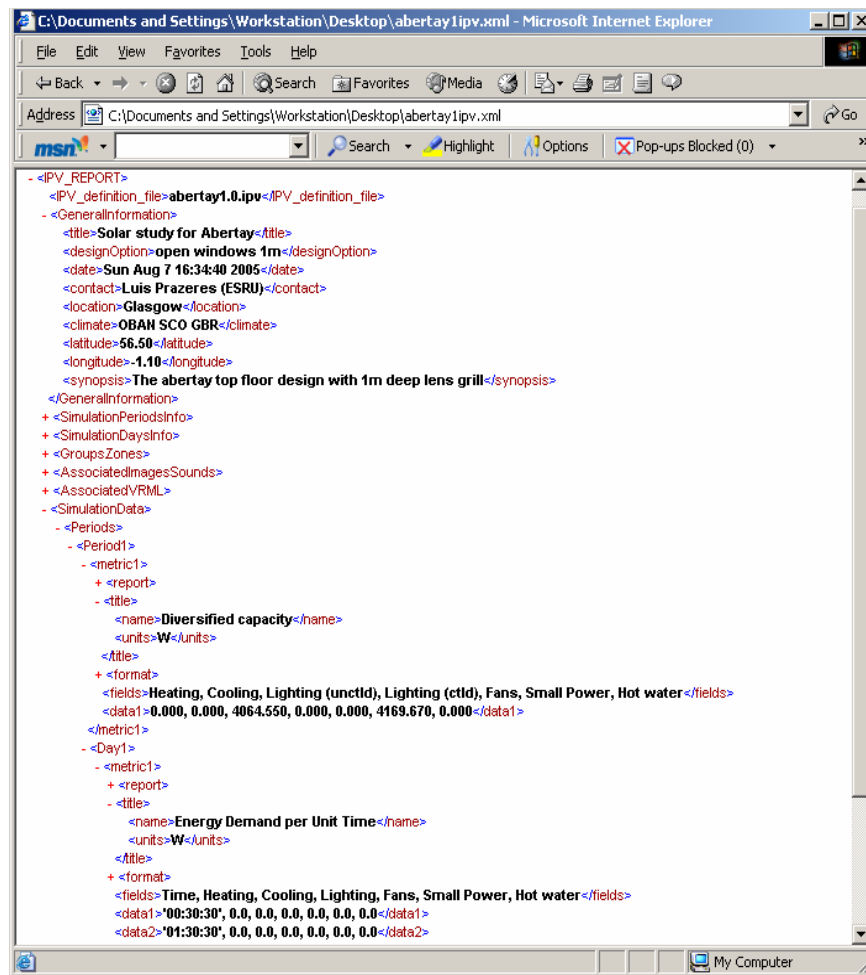


Figure 4.26: XML format of IPV-results.

The stylesheet could be used to transform any instance of the Document Type Definition (DTD) for which it was designed. The Formatting Objects, which are generated by the XML file, and the stylesheet could be rendered. The XSL-FO vocabulary is designed to be displayed on a wide variety of media: screen, paper, immersed VR or even voice.

In the context of BS, the use of the XML and XSL technologies bring many advantages. XML could store design option information in a structured way, which may be readily parsed and transformed by existing Java APIs. In addition, the displays could be targeted to the different BS user types through adequate media with XSL technology.

4.3 Summary

This chapter has described a new tool that embeds perceptualisation techniques and rules that facilitate the better communication of BS information.

This tool employs many combinations of formats and attributes to alert users about illicit actions, inform them about values above critical or assist in assessments of comfort. These combinations support users with visual or audio disabilities by displaying clues in both modalities.

In order to prove that such perceptualisation techniques/rules do indeed improve BS display effectiveness, during the different stages of the BS process and against the requirements of the different BS user types, the tool requires to be tested in the field. This is the topic of the next chapter.

Currently, the I²PV tool is being tested by a few consultancy firms and research institutes. The source code of this tool and installation/use instructions may be downloaded from ‘www.esru.strath.ac.uk’.

This chapter describes the methodology adopted to evaluate the techniques and rules described in Chapter 3 and implemented in Chapter 4. For some information formats and attributes hypotheses are postulated for user evaluation.

Three organisations were involved in this study (comprising 5 different user groups) in order to identify the different user preferences. Each user was asked to complete an evaluation form, and their comments and suggestions for tool improvements were recorded for later qualitative analysis (see Appendix G). This was the main driving force for post field trial enhancement of the tool.

The methodology applied for the user testing and the main findings gathered are presented in the following sections.

5.1 Methodology

Each focus group received an introduction to the prototype tool's functionality prior to the interview and a real consultancy project was selected to ensure that the trial was relevant. The focus group members were then requested to perform certain tasks, which followed the flow of the tool's normal usage.

An evaluation sheet was used to record the user's level of satisfaction for each task against a five-point scale: *Very Dissatisfied* (VD), *Dissatisfied* (D), *Neutral* (N), *Satisfied* (S), and *Very Satisfied* (VS).

The qualitative evaluation was carried out against three criteria: effectiveness, flexibility and efficiency defined as follows.

- *Effectiveness* at communicating the messages inherent in the predicted data;
- *Flexibility* in dealing with the different requirements of the members of the design team and others; and
- *Efficiency* in terms of how quickly the task is performed.

In order to exemplify the potential benefits, some tasks were accompanied by mock-ups. Furthermore, each interview, which took an average of 2.5 hours (42.5 hours in total), was recorded, transcribed and analysed.

Table 5.1 summarises the activities of the three organisations involved in the trial, while Table 5.2 lists the different groups (and related characteristics) referenced throughout this chapter (and in Appendix G).

Table 5.1: Organisations consulted.

Hulley and Kirkwood Consulting Engineers (H&K)	Established in 1953, this consulting 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, this consulting 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 (ESRU)	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 5.2: Focus groups and related characteristics.

Group	Number of Users	Years of experience in Building Simulation (years)	Organisation
A	3	10 – 20	ESRU
B	3	2.5 – 6	H&K
C	3	1	HLM
D	4	3 – 6	ESRU
E	4	1	ESRU

The organisations involved in this study were chosen mainly because they all use, among other tools, ESP-r in their daily work. ESP-r is the simulator used as a test-bed in this study. Due to user's familiarity with the outputs being shown, the testing process was facilitated. The three organisations are currently using the I²PV tool in

their daily work, and reporting bugs or providing suggestion for enhancements back to the researcher.

In regards to the user groups, they were formed to capture the different user types that utilise BS tools. Such differentiators mainly include: experience level, technical level and academic or industry focus. More often than not, engineers and scientists are more technical than architects; however, experience in the BS field can make an architect very technical. In order to achieve the best results, the researcher created groups with different experience levels / background to assess their preferences. The number of users per group, three or four, might be seen as a limitation; however, in order to compensate that, in-depth interviews were conducted.

5.2 Evaluation of Attributes

For each of the three attributes evaluated (interactivity, dynamicity and colour), one predominant hypothesis was evaluated. However, each attribute was also used in a non-predominant manner in other hypotheses (attributes and formats sections) which ultimately contributed to the overall assessment of each attribute.

5.2.1 Interactivity

One hypothesis was developed to study the level of display effectiveness/flexibility and the task efficiency of information interactivity in the BS context. This hypothesis was named IT1 for easier referencing. Table 5.3 shows the hypothesis and results (see Appendix G for more details).

Table 5.3: Hypothesis and results summary for the interactive attribute.

Hypotheses (see Figure 4.7-4.14 in Chapter 4)		% VS	% S	% N	% D	% VD
IT1	An interactive IPV could support exploration and presentation of information to users.	50	50	-	-	-

No user group patterns were recognised against the above hypothesis. However, it was noticed that as the user level increased (e.g. from a simulation specialist to an energy manager) the need for detailed results decreased, which allowed the

researcher to conclude that the degree of interactivity in the displays should also decrease to avoid confusion or user errors by displaying appropriate defaults.

The overall effectiveness of an IPV is due to the fact that it is integrated. It was also noted that the information interactivity increased the flexibility of the display and the efficiency of the task at hand (all users were either *Very Satisfied* or *Satisfied*). This is mainly because one is able to:

- Start and stop animations (e.g. a loop of air movement continuous images or dynamic line graph);
- Resize internal cells (e.g. a default internal cell size to a larger one);
- *Save As* or *Print* (e.g. overall IPV-page or individual internal cells);
- Retrieve information (e.g. graph tool-tips or hyperlink);
- Directly manipulate graphical features (e.g. graph or geometry zoom);
- Toggle graphical features (e.g. change from graph to alphanumeric format, off the internal cell top to save screen space, off graph grid to reduce clutter, *etc.*); and
- Suppress unwanted information (e.g. minimize an internal cell to its top frame, move a suppression bar, *etc.*).

The session provided some suggestions of improving information exploration, which included the following:

- a global-IPV zoom functionality is required to allow drill-down into a small detail on an image or graph without compromising the overall quality of the display; and
- an IPV link to a VR model is required to allow intuitive model enquiries about performance metrics, material properties, dimensions, occupancy schedules, *etc.*

The session suggested a few improvements to information presentation, which included the following:

- Informal report generation: on the click-of-a-button each individual graph and image should be printed in the A4 size where the alphanumeric information

(on the *General Information*) becomes the cover page and the integrated IPV the last page. This would allow discussions within the design team or with clients, including short scribbles at the sides of the pages for future reference; and

- Auto-rearrange and layout manager: to facilitate the display of the internal cell to accelerate the process of information presentation. The auto-rearrange would work in a way that when the user resizes (or deletes) an internal cell, the other cells would accommodate that by becoming smaller or larger accordingly. The layout manager would work in a way that the user could save the dimensions and locations of the internal cells for future displays.

The researcher initially believed that interactivity would be far more beneficial in exploration and analysis than presentation of information, but the results indicated that it was also very useful during information presentation. When presenting information, interactivity is particularly important to stop an animated GIF or a dynamic graph at a certain point (i.e. time/date, location or weather condition) to initiate a save or print after internal cell rearrangement. It would allow the user to include notes in an IPV (general information area) so that, for example, in a client meeting or design team discussion those issues are not forgotten. In summary, to explore, analyse and present BS information one needs to interact with it – by controlling, retrieving or manipulating directly the information.

5.2.2 Dynamicity

A hypothesis was developed to study the level of display effectiveness, flexibility and task efficiency of information dynamicity in the BS context. This hypothesis was named D1 for ease of referencing. Table 5.4 shows the results (see also Appendix G for more details).

Table 5.4: Hypothesis and results summary for the dynamicity attribute.

Hypothesis (see Figure 4.20 in Chapter 4)		% VS	% S	% N	% D	% VD
D1	<p>The comparison of time-varying metrics (e.g. the energy demands of different design options) is enhanced when controlled data dynamicity is available through:</p> <ul style="list-style-type: none"> ▪ clear labelling of axis and data; ▪ provision of chart focus (i.e. when/where) below chart title; ▪ applying grid lines to improve readability; ▪ applying a label colour perception match (e.g. red for heating); ▪ applying differentiation of lines with hatching; ▪ chart interactivity (i.e. zoom, tool-tips, resizable window and chart properties); ▪ warning messages for charts with more than 4 lines (non-staked); ▪ applying toggles to chart features (e.g. stacked/non-stacked); ▪ cumulative amounts information; ▪ critical value indicated with line, sound alerts and chart background colour change; and ▪ information on the exact critical values and dates/times. 	25	50	-	25	-

A user group pattern was recognised from the above hypothesis as documented below:

- Group B were the most enthusiastic (all *Very Satisfied*) group about the available functionality, such as zoom and speed control to allow a snap-shot of an area of interest to be imported into a report, critical value alerts (with visual and audio clues) and cumulative and critical value recording to support information exploration. In addition, these users appreciated the ability to directly compare design options and saw the potential benefits of an energy breakdown display and its link to CO₂ and energy costs (with further breakdown for gas and electricity).

The effectiveness/flexibility and task efficiency mainly depend on the following (75% of the users were either *Very Satisfied* or *Satisfied*):

- The manner in which the data is presented (dynamic mode) to allow absorption of information at an adequate user rate;

- Being able to compare all design options in one graph;
- Having a fully interactive display;
- Having animated alphanumeric information to complement the dynamic line graph, for example in energy demand, information about the breakdown values (including the associated CO₂ emissions and costs), accumulative amounts over time, peak values and critical values record; and
- Alerts with audio and visual clues.

The reasons provided by the 25% of users *Dissatisfied* were because:

- The static graph would provide the same information and quicker: this might be true, but the researcher believes that for better insight the data should be displayed dynamically, however less efficient;
- The dynamic lines made the display too confusing: the researcher concluded that the maximum number of lines in dynamic mode should be less than 4 (recommended maximum in static mode) to guarantee an effective display (Note: unless the *Intelligence* component is included in the tool to identify the level of overlapping – see *Future Work* section in Chapter 6 for more details); and
- The information displayed was too technical: the users were right here, it indeed affected the less technical/experienced users.

It was also discussed that task efficiency would increase if different audio alerts are applied for different situations. For example, one type of audio for the overall critical value and another for the breakdown critical values. With experience, it is likely that users would get to know the audio language (different alerts) and, therefore, allow the dynamic lines to run on in the background while doing other tasks and only paying attention when the audio they were interested in occurred.

In summary, dynamicity in general is very appropriate within the BS context because BS data is transient, changes over time within a space. Therefore, it should be commonly used to explore, analyse and present information.

5.2.3 Colouration

One hypothesis was developed to study the level of display effectiveness/flexibility and task efficiency of coloured information in the BS context. This hypothesis was named C1 for ease of referencing. Table 5.5 shows the hypothesis and results (see Appendix G for more details).

Table 5.5: Hypothesis and results summary for the colour attribute.

Hypotheses (see Figure 4.1 in Chapter 4)		% VS	% S	% N	% D	% VD
C1	Colour is useful to separate design options in terms of performance focus.	47	47	6	-	-

No user group patterns were recognised from the above hypothesis, which indicates that this technique applies regardless of the user type.

The effectiveness and flexibility of a display and the overall task efficiency increased when colour is applied appropriately. The objective of this colour functionality was to allow the user to assess in seconds (at a glance) all design options of a given project and for a given performance metric. To achieve that, the key elements of the display were (94% of the users were either *Very Satisfied* or *Satisfied*):

- Provide the ‘traffic light’ concept which is familiar to users;
- Provide a feedback area with the actual values to complement the colour;
- Provide a feedback area with general information about the design options or project; and
- Provide a fully interactive display.

The session suggested a few improvements to coloured information in this context, which included the following:

- Provide ready definition of the yellow band even with allowed customisation;
- Within each colour (green, red and yellow), reorder the design options in descending/ascending order, according to the performance focus defined by the user (e.g. energy demand, thermal comfort, visual comfort, acoustics comfort, emissions, *etc.*); and

- In addition to a record of all performance focus enquiries (including actual values for each design option), the tool should provide the % of improvement (or deterioration) against a reference design option chosen by the user (e.g. base case).

In summary, the perception label-colour match technique increased display effectiveness and task efficiency exponentially because the user's brain automatically related the colour to one label out of all possibilities: for example red with *Stop*, green with *Go ahead* and yellow *Go ahead with caution* (just like traffic lights). Other examples are, red for *Heating* or *Maximum*, blue for *Cooling* or *Minimum*, yellow for *Lighting* and green for *Renewable*. In addition, colour is effective to group data that belong together and makes the display better to look at.

5.3 Evaluation of Formats

Five formats were evaluated - geometry, graphical, image, alphanumeric and sound. An average of 3.2 hypotheses per format was created. However, each format was also used in a non-predominant manner in other hypotheses (attributes and formats sections) which ultimately contributed to the overall assessment of each format.

5.3.1 Geometry

One hypothesis was developed to study the level of display effectiveness/flexibility and task efficiency of geometrical information in the BS context. This hypothesis was named GM1 for ease of referencing. Table 5.6 shows the hypothesis and results (see Appendix G for more details).

Table 5.6: Hypothesis and results summary for the geometry format.

Hypothesis (see Figures 4.15-4.18 in Chapter 4)		% VS	% S	% N	% D	% VD
GM1	Geometry should be displayed with the following features: <ul style="list-style-type: none"> ▪ Available in two formats (i.e. wire-frame and solid); ▪ Origin reference, north indication and ground layer (toggled); ▪ Colour to distinguish different zone groups; ▪ Zoom, pan and rotation (direct manipulation with mouse); ▪ List of zones where user is able to build combinations and clear; ▪ Save/print functionality; ▪ Information retrieval; ▪ Viewpoint accelerators; ▪ Colour to distinguish different metric variables (solid only); and ▪ Depth-colour perception (wire-frame only). 	88	12	-	-	-

No user group patterns were recognised in the above hypothesis, which demonstrates that such preferences do not depend on user type.

The display effectiveness/flexibility and task efficiency of geometrical information depended mainly on (all users were either *Very Satisfied* or *Satisfied*):

- how interactive is the display: to directly manipulate the model to allow performance enquiries and results presentation to the design team/clients; and
- how much flexibility is available: to display any combination of zones (using the explosion technique), to switch between solid (including transparent) and wire-frame formats, and to be able to *Print / Save As* the geometry display.

All users, including architects who were not easily impressed with geometry displays due to their daily job of dealing with powerful geometrical packages, believed that the future of BS is in the information acquisition mechanism. The concept of acquiring information/simulation results of a model as one goes along (internally or externally), in particular for less technical or less experienced users, where intuition is most needed, was very effective. However, it is important to be aware that VR cannot be compared to photorealistic packages because its purpose is to render 3D

models in real time. That said VR brings many benefits to BS. Apart from exploration, it is possible to create backgrounds such as rainy, foggy, sunny, *etc.* and apply these to each design option to check the visual (and the other senses) impact.

In addition, the use of data dynamicity (e.g. in CFD results display) and the inclusion of images on the VR scene (e.g. glare sources) increased effectiveness. All agreed that immersed VR would be the ultimate experience because it would be possible to feel, see, hear and smell the actual building (see *Future Work* section in Chapter 6 for more details).

5.3.2 Graphical

Five hypotheses were developed to study the level of display effectiveness/flexibility and task efficiency of graphical information in the BS context. These hypotheses were named G1-5 for ease of referencing. Table 5.7 shows the hypotheses and results (see Appendix G for more details).

Table 5.7: Hypotheses and results summary for the graphical format.

Hypotheses (see Figures 4.7-4.14 & 4.19 in Chapter 4)		% VS	% S	% N	% D	% VD
G1	<p>Bar graph to compare data with the following features:</p> <ul style="list-style-type: none"> ▪ clear labelling of axis and data; ▪ provision of chart focus (i.e. when/where) below chart title; ▪ application of grid lines to improve readability; ▪ application of a colour-label perception match (e.g. red for heating); ▪ spacing between adjacent bars should typically be less than the bar width to facilitate comparisons; ▪ application of toggles to chart features (e.g. stacked/non-stacked); and ▪ chart interactivity (i.e. zoom, tool-tips, resizable window and chart properties). 	-	75	17	8	-
G2	<p>Line graph to show how two continuous variables are related, with the following features:</p> <ul style="list-style-type: none"> ▪ clear labelling of axis and data; ▪ provision of chart focus (i.e. when/where) below chart title; ▪ application of grid lines to improve readability; ▪ application of a colour-label perception match (e.g. red for heating); ▪ differentiation of lines with hatching; ▪ chart interactivity (i.e. zoom, tool-tips, resizable window and chart properties); ▪ warning message for charts with more than 4 lines (non-staked); and ▪ application of toggles to chart features (e.g. stacked/non-stacked). 	8	92	-	-	-
G3	Counter graph superimposed in a 3D representation to show spatial data, with user interactivity for location focus.	50	50	-	-	-
G4	Star graph superimposed in a 3D representation to show Visual comfort information (Guth index), with user interactivity for location focus, detail information and associated glare images.	59	41	-	-	-
G5	The bubble graph is very useful for comparison of design options when weightings and individual metric evaluation are available.	29	53	6	12	-

A user group pattern was recognised from the hypotheses (G1-4) testing as follows:

- Group B preferred default stacked bars and lines because they were looking for single numbers to pass the building regulations. In addition, less

experienced and less technical users were keener on intuitive interfaces (e.g. visual comfort) to show and interact with information.

Regarding the bubble chart (G5), the following was observed:

- Group A were the most enthusiastic (all *Very Satisfied*). They found it effective with the possibility of assessing all design options at once including objective performance targets and subjective weightings set by the users (increases flexibility); and
- Group B were the least enthusiastic (all *Neutral* or *Dissatisfied*) because the results could not be trusted due to its subjectivity and, therefore, the direct comparison of performance metrics values was preferred.

The display effectiveness/flexibility and task efficiency of graphical information depended mainly on (G1-5) the following (75-100% of the users were either *Very Satisfied* or *Satisfied*):

- The degree of flexibility in the display: usage of toggles for graphical features (e.g. stacked (default) or non-stacked; with or without values/percentages on top of bars/data points; with or without log-scales; with or without graph grid, *etc.*), allowed users to customise the graph for their immediate need. Also, being allowed to change the general graphical properties and to *Print / Save As* the graphs was deemed useful;
- The use of alert messages: audio and visual clues to inform the user about potentially confusing issues and for example, offer ‘ignore’ or other displaying options as alternatives. Line graphs with a maximum of four series (static mode). (Note: From the literature, the maximum number of series in a bar/column graph is three; however, the researcher believes that because no major issues will arise when one increases the number of series – e.g. no overlapping – no specific limit was recommended in the related hypothesis – but as always, common sense applies);
- The degree of interactivity available: usage of zoom, tool-tips and intuitive interfaces for focus selection to allow extra information retrieval and quick focus display;

- The usage of the right type to display the information: bar charts to compare data; line charts to show how two continuous variables are related; counter/star charts superimposed on 3D representations to show spatial data; and bubble graph to show the relationships and correlations between data sets;
- The usage of colour: the label-match technique is effective/efficient because users make automatic links; and
- The usage of clear and informative messages: the display of short alphanumeric information sequences near to (or on) the graphs provided explanations and put information into context.

The session highlighted a few ideas of improvements to the line graph, such as the inclusion of the *Intelligence* component in the tool (see *Future Work* section in Chapter 6 for more details):

- By ‘remembering’ users’ past activities when displaying line graphs and acting accordingly, either ‘ignore’ the rule or present it in the most popular alternative option for that user type; and
- By calculating the degree of overlapping the line graph might have and alert/advise the user accordingly.

On bubble graph display (G5), the following point is pertinent (82% of the users were either *Very Satisfied* or *Satisfied*):

- The advantage of the bubble chart in comparison to the scattered graph was that a third dimension could be integrated in the display. A particularly effective display was the annual energy cost of the design options on the Y-axis, the capital costs for the design options on the X-axis, while the bubble radius were the benefits achieved by each design option. The method was favourable because the costs were actual values and the benefits were just a relative number that depend on the project targets and weightings provided by the user. In addition, the bubble tool-tips could also inform the user of project targets and weightings.

From the session two ideas for improvement of the bubble graph were provided:

- The setting of the project targets should be set at the project level rather than at the IPV-level. The purpose was that the I²PV tool would automatically apply the same targets to all design options (i.e. avoid repetition by giving the same importance to the same metrics and, therefore, increasing efficiency); and
- To avoid confusion, further help should be available on the graph itself to provide clarity about the way the benefits were calculated.

5.3.3 Image

Three hypotheses were developed to study the level of display effectiveness/flexibility and task efficiency of image information in the BS context. These hypotheses were named I1-3 for ease of referencing. Table 5.8 shows the hypotheses and results (see Appendix G for more details).

Table 5.8: Hypotheses and results summary for the image format.

Hypotheses (see Figure 4.2, 4.5, 4.7, 4.10-4.11 & 4.13 in Chapter 4)		% VS	% S	% N	% D	% VD
I1	Help system should have images to guide user.	24	76	-	-	-
I2	Background information delivery should also be through images (e.g. site, preliminary results, <i>etc.</i>).	47	53	-	-	-
I3	IPV integration of third party software image results should be supported (e.g. CDF analysis).	86	14	-	-	-

The following user group pattern was recognised from the results.

- Group B was the most enthusiastic group on the use of images to display background information due to the fact that they considered it crucial to have an integrated mechanism to present information to the design team and client.

The display effectiveness/flexibility and task efficiency of images information depended mainly on the following factors (all users were either *Very Satisfied* or *Satisfied*):

- The degree of control the users had over the display: controlling the display in terms of speed, play/stop/still animation, resize image, *etc.*, increases

flexibility. In addition, providing context and focus to the user through thumbnails increased efficiency;

- Whether the image is linked to other information formats: to alphanumeric data, sound, *etc.* (synchronised when appropriate) in order to be more effective; and
- How integrated the system was: to have one check point rather than several (which is what the background information and integration of third party results achieves). This was deemed an excellent mechanism to support project briefings and for practitioners to more effectively handle project management at a distance.

During the session, an idea for improvement that stands out was provided:

- Being able to print all images, so that they could be brought to a design team / client meeting and allow scribbles for future reference would be very practical and would increase flexibility / efficiency.

All users found the use of images with dynamicity/colour very appealing because it made issues visual and increased intuition, in particular when dealing with transient data. The less experienced and less technical users were the ones that benefited the most from these techniques.

5.3.4 Alphanumeric

Four hypotheses were developed to study the level of display effectiveness/flexibility and task efficiency of alphanumeric information in the BS context. These hypotheses were named A1-4 for ease of referencing. Table 5.9 shows the hypotheses and results (see Appendix G for more details).

Table 5.9: Hypotheses and results summary for the alphanumeric format.

Hypotheses (see mainly Figure 4.1-4.6, 4.18-4.20 & 4.23 in Chapter 4)		% VS	% S	% N	% D	% VD
A1	Text should be in non-capital letters, Serif font and not underlined (except hyper-link) for ease of reading.	73	27	-	-	-
A2	The treatment of time should be via a calendar.	24	41	29	6	-
A3	Search time decreases and flexibility increases when a projects manager is embedded in the tool. In addition, message alerts avoids user errors.	35	47	12	6	-
A4	Alphanumeric data should be grouped, structured, spaced and aligned to decrease search times.	65	35	-	-	-

No user group pattern was identified from the above results, which means that the results are applicable across the range of user types.

The display effectiveness/flexibility and task efficiency of alphanumeric information depended mainly on the following factors (65-100% of the users were either *Very Satisfied* or *Satisfied*):

- The use of organised and structured displays, by techniques such as data-trees, tables, lists, drop-down menus or calendars that group information that belong together would decrease search times;
- The use of flexible displays, by interaction to provide the ability to control the display allow quick selections to explore/analyse information;
- The use of easy-to-read displays, such as user friendly fonts like *Arial*, no capital letters, non-underlined text unless it is an hyperlink and other features, would speed up communication (e.g. bold to highlight information);
- The use of colour to increase effectiveness because it separates the information and increases efficiency as information is quickly located;
- The use of hyperlinks to obtain more detailed information and tool-tips to retrieve short pieces of information (e.g. definitions). Also, the inter-links of information (e.g. *Help* interface) would increase efficiency;
- The use of complementary visual/audio aids such as images/sound respectively would increase effectiveness because they help users put results into context; and
- The use of clear and informative message alerts would prevent user errors.

The reasons provided by the 35% of users *Neutral* or *Dissatisfied* in A2 were mainly the following:

- The calendar showed unnecessary information, and therefore, took crucial screen space: the researcher disagrees, because on the other hand the extra information brings unforeseen benefits to the analysis (e.g. by knowing where the weekends are which might affect the energy consumption). Also, the inclusion of interactivity / colour attributes on a calendar interface can be extremely effective; and
- The calendar was distracting, messy and not to the point, and therefore, preferred a more concise display such as alphanumeric information: the researcher agrees that alphanumeric information should probably be the default display to treat time for more experienced / technical users because less intuition is needed, but, at the same time being able to display the calendar if required. On the other hand, the calendar should be the default display to users on the other side of the spectrum.

From the session a few ideas for improvement were provided and discussed:

- In *Projects Manager* interface one could integrate visually other information for each design option: general information, images, voice annotations, VR, *etc*;
- Avoid long text to facilitate reading; and
- Apply string-search functionality to increase efficiency.

Generally speaking, alphanumeric information was useful to complement other information or put ‘things’ into context. This applied to graphs, images, geometry or sound formats. Attributes like colour (to group information), interactivity (through hyperlinks or tool-tips) and dynamicity (value update) supported the effectiveness/flexibility of the display and efficiency of the tasks.

5.3.5 Sound

Three hypotheses were developed to study the level of display effectiveness/flexibility and task efficiency of sound information in the BS context.

These hypotheses were named S1-3 for ease of referencing. Table 5.10 shows the hypotheses and results (see Appendix G for more details).

Table 5.10: Hypotheses and results summary for the sound format.

Hypotheses (see Figure 4.5-4.7 & 4.14) in Chapter 4)		% VS	% S	% N	% D	% VD
S1	Experiential appraisal for acoustics assessment.	70	24	6	-	-
S2	Sound alert to flag a performance metric above a critical value.	25	31	25	19	-
S3	Voice annotation to deliver general information.	43	38	13	6	-

Some user group patterns were recognised from the above hypotheses as follows.

- Group A was the least enthusiastic on the critical value alert (44% of the users were *Neutral* or *Dissatisfied*), claiming that the sound flag was not well applied; it should have been a Boolean value (NO/YES) in combination with a message informing the user about the number of failed metrics and their names. As an aside, the issue of users with hearing difficulties would be overcome with this solution;
- Group B was the only group concerned (qualitative analysis) about the technical part of the experiential sound technique because engineering firms are more practical and to the point (prefer pass or fail values for performance metrics); and
- Group C was the only consistent group across the three hypotheses where the level of satisfaction was between *Satisfied* and *Very Satisfied*. This was perhaps due to fact that architecture firms are more open to cutting-edge techniques to explore and present information; examples of this are the advanced walkthrough packages that the other user groups are less inclined towards.

The displays effectiveness/flexibility and tasks efficiency of sound information depends mainly on the following factors (56-94% of the users were either *Very Satisfied* or *Satisfied*):

- How integrated the tool was with other formats: the sound format is normally effective in combination (or synchronised) with other formats - alphanumeric (messages), images; and attributes: colour; plus other visual cues; and

- How well targeted was the technique to the user: different user technical modes should be applied, for example the experiential sound technique (along with reverberation versus frequency) should only be applied if a high user technical mode is chosen.

Advanced sound techniques (i.e. voice annotation to provide background information) is perfectly achievable with simple PDA/mobile phone devices which have huge data storage, advanced cameras, are portable and have embedded data transfer technology (Bluetooth and Infrared). Advanced sound techniques (e.g. for acoustic assessments) are exciting future prospects. However, future research must be undertaken to make it work; this is beyond the scope of this PhD research project.

Generally speaking, sounds should be an important way to communicate BS information to users. Usually, sound assists/complements (or is assisted/complemented by) other formats/attributes. Sound could provide information (e.g. alerts and voice annotations or acoustics assessment) in parallel with the user doing other tasks (by freeing the visual channel) for the following reasons:

- Voice annotation is powerful because it allows client meeting memos to be recorded, project briefing to be broadcast to the design team or support for distance project management. Also, a practitioner could record site noise at different times so that acoustics isolation could be better tackled by the design team; and
- Different audio alerts are useful so that with time users know instinctively what type of issue is being alerted.

The experiential assessment for acoustics is an exciting possibility, which would change the way acoustic environments are appraised because the user can choose a source location and play the original audio, then apply design modifications to hear the effect. Another important consideration in regards to audio is that it could assist users with visual disabilities (e.g. the colour blind).

5.4 Summary

This chapter explained the methodology for user testing in terms of hypotheses created for each attribute and format (i.e. techniques that had a predominant attribute/format). User preferences were reported along with suggestions for tool enhancements.

The main user patterns found were as follows:

- Intuitive displays benefit inexperienced users;
- Experienced users were more likely to trade-off intuitive displays if these sacrifice too much screen space or need too much computer resources (decrease efficiency);
- Industry users (engineering) preferred overall figures, fail/pass feedback instead of breakdowns. They also appreciated the integration of information (background information technique or IPVs);
- Industry users (architects) accepted the sound format more than the other users;
- The combination of visual/audio formats helped people with disabilities; and
- All users appreciated flexible displays (toggles, *etc.*).

The VR (Desktop) was the technique that was most appreciated by all users and regarded as a benefit to BS. The final chapter summarises the beneficial outcomes from this PhD study, the research limitation and suggestions for future work.

The objective of this PhD research was to identify techniques and rules from the field of information perceptualisation theory that could be usefully applied in the BS context while taking cognisance of the fact that BS users are technically diverse and possess different skill levels and technical know-how.

A software tool, I²PV, was developed to encapsulate and deliver relevant perceptualisation techniques and rules. This tool was built with technology that delivers multimedia features through the Internet.

The tool was tested by several user types and the outcomes recorded and evaluated to provide an overall pointer of satisfaction in regards to an individual attribute/format related to a particular display/task. This qualitative analysis was crucial to later efforts to enhance the tool. A few user group preferences were clearly identified, which allowed the development of targeted user-oriented displays.

This chapter highlights the main conclusions from the PhD study, its limitations, and the future research needed to overcome these limitations and further refine the I²PV tool.

6.1 Summary

In this thesis, the BS information was divided into seven formats: geometry, graphics, images, alphanumeric, sound, haptic and smell. Each format might then have a combination of attributes applied: interactivity, dynamicity, colour and type.

Techniques refer to the ways of displaying information and were usually a combination of attributes and formats. Rules (as identified from this research) were sets of conventions linked to an attribute or format. Such techniques might give rise to greater effectiveness or flexibility and the task that employs such a technique would be performed more efficiently. An effective technique was one that allowed

greater information insight while a flexible technique is one that allows better communication with a targeted user type (or strictly speaking, user type preference). An efficient task was one that performed more rapidly than would otherwise be the case.

Cognition science is not a precise subject and, therefore, the outcomes from this research should be considered as guidelines only because they depended on subjective user preferences. That said, the research demonstrated that generalisations could be made for specific user types.

6.1.1 Stages of the BS Process

Within the BS process, there are four main stages: exploration, analysis, informal presentation and external reporting. Each stage is unique and therefore specific techniques/rules could provide maximum display effectiveness/flexibility in order to improve overall task efficiency.

6.1.2 Techniques and Rules

Usually, intuitive displays favoured inexperienced users because they provided a better insight into the underlying message. However, such displays tended to require more screen space and/or computing power. For this reason, experienced users sometimes prefer simpler (less intuitive) displays. Combinations of formats and attributes improve the effectiveness/flexibility of displays and hence overall task efficiency because they tended to complement each other.

The hypotheses in Chapter 5 were chosen because the percentages of the respective attribute/format being evaluated were high. However, they all had a combination of other attributes/formats applied to them, which contributed to the overall evaluation of the respective attributes/formats. In addition, Chapter 4 provided extra screenshots and mock-ups, which were shown to the users and discussed during interviews – this additional feedback was also taken into account when evaluating the attributes/formats.

It was more likely for an attribute to be effective on its own than for a format. This was because formats depend more on being complemented by attributes (or other formats) to be effective. This is in line with the definition of a *Attribute*. The attributes considered in this study were: interactivity, dynamicity, colour and type.

Formats were completely dependent on the context of use in order to be effective in comparison to the above attributes. This is in line with the definition of a *Format*. The formats considered in this study were: geometry, graphical, image, alphanumeric, sound and haptic/smell.

6.2 Research Contribution to Academia and Industry

This PhD study benefits:

- **Academia** because it extends perceptualisation techniques and rules to the BS field; and
- **Industry** because it developed a tool that supported BS information exploration, analysis and presentation.

The I²PV tool is currently being used by practitioners and students, which provides continuous feedback for ongoing enhancements.

The objectives of this PhD study were to investigate the applicability and usefulness of perceptualisation techniques and rules within a computational approach to design. For that the researcher investigated the following issues.

- The effect of intuitive and interactive techniques when **exploring** BS information.

This was achieved by identifying techniques that were intuitive and interactive. These included the geometry format as a foundation with information superimposed. Examples were: the contour graph for air movement or daylight availability, a star graph for visual comfort and sound

decay visual traces plus audio (experiential appraisal) for acoustic assessment.

➤ Comparison techniques to **analyse** BS information.

Five design option comparison techniques were identified to support analyses: a *Costs vs. Benefits* for a high-level analysis and to allow objective and subjective inputs; a *Dynamic Line Graph* to analyse time-based metrics in detail supported by flagged warnings with audio and visual clues; *Tab-switching* to create an update effect for each performance metric (reduced space used in comparison to side-by-side graphs); a *Matrix* that allowed side-by-side comparison by positioning all design options as columns and the performance metrics (or other information) as rows; and colour coding design options on *Projects Manager* interface with red (fail), green (pass) and yellow (borderline) against a specific performance focus.

➤ Techniques to organise, structure and group BS information (i.e. support **internal presentation** and **external reporting**).

Three ways were identified of presenting information informally to the design team: *Background Information* to provide a quick project briefing or support distance project management through images, audio and alphanumeric information; an *A4-sized Hardcopy* to print the individual cell information and allow user comments at the sides; and *Desktop VR* to present information through interactive, dynamic and other visual information clues. Distance project management is greatly enhanced with the Internet and collaborative / concurrent communication (MS Live concept plus voice).

There were two ways of formally reporting information. One was the *PDF Reporting* where a standard technical report was defined by the user and automatically customised using XML/XSL technology with ‘click of a button’ emailing to the client. The *Online Report* has a similar content but is

sent to the client as a web-link for viewing through a Java Applet that allows some degree of interaction (exploration). The content of both reports included details on the chosen design option with comparisons made to other options.

- The benefits of **targeted displays** to addresses the needs of the different user types.

The research identified a few user patterns as summarised below.

- The inexperienced user benefited from intuitive displays because it helped them to understand what was actually going on and where the information were derived.
- Experienced users were more likely to trade-off intuitive displays for screen-space and computer power resource saving.
- Higher level users (e.g. energy manager) should have less display interactivity to avoid confusion and assessment errors – default displays recommended.
- Experienced users preferred the flexibility of having both objective and subjective elements when comparing design options (e.g. Costs vs. Benefits).
- Industry users (architects) appreciated more the audio benefits than the other user groups. Examples included experiential appraisals for acoustics assessment and voice annotations for project briefings or providing essential supplementary information.
- Industry users (engineers) preferred overall values or pass/fail results rather than detailed breakdowns because they were more objective. Example: they did not appreciate the subjectivity element when comparing design options in a *Costs vs. Benefits* analysis.
- Industry users (engineers) appreciated one location to encompass all design option and project-related information with multimedia techniques. Examples: *Background information* and IPV concept.

All users appreciated the following features.

- The display of information within the main windows (with scroll and context & focus techniques) instead of within a separate window. This avoided window overlap and saves screen space.
- The existence of toggles to allow the change to a more preferable information format (e.g. from bar graph to a table) or features to un-clutter the display (e.g. to turn off a graphical grid or to include values on top of the bars on a bar graph).
- The existence of suppression techniques to un-clutter displays. Examples: minimise internal windows in an IPV display.
- The combinations of audio and visual clues benefited users with disabilities. Example: colour blind or hearing impairment.

The following section discusses the research limitations encountered in this study.

6.3 Research Limitations

This research had some limitations that should be looked at in future research in order to further improve results reliability:

- the user base should be increased;
- differentiation should be applied within each user type (e.g. engineers with basic, medium and advanced knowledge of BS); and
- the number of hypotheses per attribute/format should be increased.

The use of mock-ups for user testing was not ideal as the users could not interact with the display or see it in dynamic mode. Instead they had to imagine it. Therefore, real implementations of all techniques would improve the reliability of some test findings because it would provide to more insightful user suggestions. In addition, the use of mock-up data was sometimes provided for user testing instead of real data, which was not ideal for display evaluation. The advantage of real data was its consistency of linkage with other information.

If technology such as sensitised data gloves and helmets becomes available then immersed VR could be tested in more detail.

These issues notwithstanding, the researcher believes that the research outcomes are not unacceptably diminished.

6.4 Future Work

The user testing provided several suggestions for enhancements and an enhancement program is underway in response. Furthermore, the I²PV tool is currently being used by the organisations who participated in the PhD study so that further suggestions for improvement are expected. The impact in practice of the tool's evolution would be monitored and an optimisation cycle followed (i.e. user testing – qualitative analysis – implementation – further user testing).

Further developments are also planned in relation to the mock-ups evaluated in Chapter 4. This includes small enhancements to the functionality of all displays. The main aspects of future development relate to the following.

- The **Costs vs. Benefits** comparison functionality to allow effective high-level analysis.
- The **Desktop VR** geometry to allow more information retrieval in other formats.
- The **External Reporting** generation in PDF or Java Applet format on a click of a button.
- The creation of an **IPV layout manger** to allow users to define convenient templates.

From this PhD study, a few user patterns were identified, so targeting the displays to user types would be an effective way to increase analysis efficiency. This could be achieved by setting three different technical modes which users may select at the start of tool usage. Corresponding details on the technical modes will also be made available in the *Help* interface for user clarity. Alternatively, the user could provide

information on BS experience and the tool could choose the technical mode automatically (but allow the mode to be changed as appropriate).

The researcher intends to incorporate some *Intelligence* into the tool's functionality. This tool would be called *I³PV – Integrated, Interactive and Intelligent Performance View*. This tool would include the following additional features.

- Keeping a record of **users' activities** while using the tool, and based on that information to apply display defaults. This could be done through an individual password.
- The level of **overlapping** in a line graph could be identified in order to avoid confusing displays (e.g. show a warning message with the overlapping index, present alternative options, and activate an element toggle, *etc.*).
- The level of **irregularity** on a stacked line graph could be identified to avoid confusing displays (e.g. show a warning message with the irregularity index of the elements, activate an element toggle, and display the elements by the irregularity level ranking, *etc.*).

A more advanced enhancement is the immersed VR. The experiential technique, above all, offers most potential because it could provide a true experience to the user, through haptic, smell, audio and vision senses. The amazing benefit is that it integrates all formats and attributes within the core format (geometry). The user would use virtual buttons and select from virtual menus to 'experience' a design option. The senses involved are:

- the **haptic** format through data gloves/suit to experience the building's temperature for example;
- the **smell** format through a data helmet to experience the building's odours.
- **3D sound** format through a data helmet to hear acoustics environments as well as other sound information; and
- **3D visual** formats (i.e. geometry, graphical, image, alphanumeric) through a data helmet to see the building geometry itself, as well as information in graphs (i.e. performance metrics), images (e.g. glare sources or different

weather condition landscapes) or alphanumeric (i.e. definitions, explanations or summaries).

In addition, the researcher intends to fully incorporate the *Internet-based* component into the tool, becoming *I⁴PV – Integrated, Interactive, Intelligent and Internet-based Performance View*. It would support distance project management (internal presentation) with collaborative / concurrent communication (MS Live concept plus voice).

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Fri 4 Apr 1980,Thu 10 Apr 1980,abertay spring run
Wed 23 Jul 1980,Thu 31 Jul 1980,abertay summer run
Fri 3 Oct 1980,Thu 9 Oct 1980,abertay autumn run
Fri 14 Nov 1980,Thu 20 Nov 1980,abertay 2nd winter run

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Thu 24 Jul 1980
Sat 4 Oct 1980
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'-1350--1250',7,0.83,40,4.76
'-1250--1150',7,0.83,47,5.60
'-1150--1050',1,0.12,48,5.71
'-1050--950',5,0.60,53,6.31
'-950--850',8,0.95,61,7.26
'-850--750',7,0.83,68,8.10
'-750--650',9,1.07,77,9.17
'-650--550',24,2.86,101,12.02
'-550--450',34,4.05,135,16.07
'-450--350',35,4.17,170,20.24
'-350--250',51,6.07,221,26.31
'-250--150',25,2.98,246,29.29
'-150--50',37,4.40,283,33.69
'-50-50',557,66.31,840,100.00
'50-150',0,0.00,840,100.00
'>150',0,0.0,0.0,0.0
*end_report

*report,11,stats,Infil,infil_zones
*title,Infiltration load,W
*format,table,1,7
*fields,maximum,minimum,average,diversified_max,distributed_max,diversified_min,distributed_min
n
*data,67.577,-2473.471,-207.609,5.115,67.577,-3006.443,-3464.280
*end_report

*day_to_display,Fri 8 Feb 1980

```

```

*report,70,demand,per_unit_time,lens
*title,Energy Demand per Unit Time,W
*format,tabular,24,7
*fields,Time,Heating,Cooling,Lighting,Fans,Small Power,Hot water
*data
'00:30:30',0.0,0.0,0.0,0.0,0.0,0.0
'01:30:30',0.0,0.0,0.0,0.0,0.0,0.0
'02:30:30',0.0,0.0,0.0,0.0,0.0,0.0
'03:30:30',0.0,0.0,0.0,0.0,0.0,0.0
'04:30:30',0.0,0.0,0.0,0.0,0.0,0.0
'05:30:30',0.0,0.0,0.0,0.0,0.0,0.0
'06:30:30',0.0,0.0,0.0,0.0,0.0,0.0
'07:30:30',0.0,0.0,211.0,0.0,260.6,0.0
'08:30:30',0.0,0.0,3164.5,0.0,3909.1,0.0
'09:30:30',0.0,0.0,3375.5,0.0,4169.7,0.0
'10:30:30',0.0,0.0,3375.5,0.0,4169.7,0.0
'11:30:30',0.0,0.0,3375.5,0.0,4169.7,0.0
'12:30:30',0.0,0.0,3375.5,0.0,4169.7,0.0
'13:30:30',0.0,0.0,3375.5,0.0,4169.7,0.0
'14:30:30',0.0,0.0,3375.5,0.0,4169.7,0.0
'15:30:30',0.0,0.0,3375.5,0.0,4169.7,0.0
'16:30:30',0.0,0.0,3375.5,0.0,4169.7,0.0
'17:30:30',0.0,0.0,3375.5,0.0,4169.7,0.0
'18:30:30',0.0,0.0,3375.5,0.0,4169.7,0.0
'19:30:30',0.0,0.0,3164.5,0.0,3909.1,0.0
'20:30:30',0.0,0.0,211.0,0.0,260.6,0.0
'21:30:30',0.0,0.0,0.0,0.0,0.0,0.0
'22:30:30',0.0,0.0,0.0,0.0,0.0,0.0
'23:30:30',0.0,0.0,0.0,0.0,0.0,0.0
*end_report

```

```

*report,70,demand,per_unit_time,other
*title,Energy Demand per Unit Time,W
*format,tabular,24,7
*fields,Time,Heating,Cooling,Lighting,Fans,Small Power,Hot water
*data
'00:30:30',0.0,0.0,0.0,0.0,0.0,0.0
'01:30:30',0.0,0.0,0.0,0.0,0.0,0.0
'02:30:30',0.0,0.0,0.0,0.0,0.0,0.0
'03:30:30',0.0,0.0,0.0,0.0,0.0,0.0
'04:30:30',0.0,0.0,0.0,0.0,0.0,0.0
'05:30:30',0.0,0.0,0.0,0.0,0.0,0.0
'06:30:30',0.0,0.0,0.0,0.0,0.0,0.0
'07:30:30',0.0,0.0,128.8,0.0,159.6,0.0
'08:30:30',0.0,0.0,1931.7,0.0,2393.5,0.0
'09:30:30',0.0,0.0,2060.5,0.0,2553.1,0.0
'10:30:30',0.0,0.0,2060.5,0.0,2553.1,0.0
'11:30:30',0.0,0.0,2060.5,0.0,2553.1,0.0
'12:30:30',0.0,0.0,2060.5,0.0,2553.1,0.0
'13:30:30',0.0,0.0,2060.5,0.0,2553.1,0.0
'14:30:30',0.0,0.0,2060.5,0.0,2553.1,0.0
'15:30:30',0.0,0.0,2060.5,0.0,2553.1,0.0
'16:30:30',0.0,0.0,2060.5,0.0,2553.1,0.0
'17:30:30',0.0,0.0,2060.5,0.0,2553.1,0.0
'18:30:30',0.0,0.0,2060.5,0.0,2553.1,0.0
'19:30:30',0.0,0.0,1931.7,0.0,2393.5,0.0
'20:30:30',0.0,0.0,128.8,0.0,159.6,0.0

```

```

'21:30:30',0.0,0.0,0.0,0.0,0.0,0.0
'22:30:30',0.0,0.0,0.0,0.0,0.0,0.0
'23:30:30',0.0,0.0,0.0,0.0,0.0,0.0
*end_report
*report, 6,thermal_comfort,comfort,occup_lens
*title,Resultant temperature,degC
*format,tabular,24, 7
*fields,Time,lens_void,lens_5_a,lens_mez_a,lense_doub,lens_5_b,lens_mez_b
*data
'00:30:30',8.63,12.23,12.13,11.76,13.41,12.77
'01:30:30',8.46,12.06,11.90,11.56,13.20,12.51
'02:30:30',8.30,11.90,11.68,11.37,13.00,12.27
'03:30:30',8.12,11.73,11.47,11.19,12.80,12.04
'04:30:30',7.90,11.54,11.26,11.00,12.58,11.81
'05:30:30',7.67,11.34,11.04,10.79,12.35,11.58
'06:30:30',7.45,11.15,10.82,10.59,12.15,11.34
'07:30:30',7.28,11.00,10.63,10.40,12.03,11.14
'08:30:30',7.47,11.46,11.30,10.83,12.65,11.96
'09:30:30',8.75,12.26,12.05,11.51,13.62,12.72
'10:30:30',11.76,13.55,13.35,12.57,14.28,13.34
'11:30:30',15.53,15.40,15.49,14.36,14.62,14.10
'12:30:30',17.73,16.70,16.80,15.58,15.47,15.17
'13:30:30',18.33,17.39,17.57,16.31,16.38,16.16
'14:30:30',17.82,17.45,17.89,16.63,17.03,16.98
'15:30:30',16.06,17.00,17.49,16.51,17.36,17.37
'16:30:30',13.73,16.29,16.86,15.94,17.20,17.19
'17:30:30',11.88,15.45,15.98,15.07,16.47,16.42
'18:30:30',10.98,14.97,15.35,14.42,16.22,15.97
'19:30:30',10.40,14.61,14.96,14.04,15.93,15.69
'20:30:30',9.58,13.67,13.86,13.19,14.87,14.44
'21:30:30',8.70,13.02,13.04,12.43,14.28,13.67
'22:30:30',8.15,12.62,12.55,11.98,13.88,13.23
'23:30:30',7.69,12.27,12.16,11.61,13.53,12.87
*end_report

*report, 6,thermal_comfort,comfort,ocup_other
*title,Resultant temperature,degC
*format,tabular,24, 6
*fields,Time,cellular_a,analysis,gen_chem,gen_corid,break_corid
*data
'00:30:30',8.86,11.01,11.48,13.74,9.66
'01:30:30',8.62,10.81,11.26,13.59,9.45
'02:30:30',8.40,10.63,11.05,13.44,9.24
'03:30:30',8.17,10.44,10.84,13.30,9.04
'04:30:30',7.91,10.24,10.62,13.14,8.81
'05:30:30',7.65,10.04,10.39,12.98,8.58
'06:30:30',7.41,9.83,10.17,12.83,8.35
'07:30:30',7.22,9.61,10.01,12.74,8.13
'08:30:30',7.59,10.11,10.54,13.23,8.28
'09:30:30',8.50,10.28,11.21,14.03,8.79
'10:30:30',9.83,10.56,11.89,14.28,9.69
'11:30:30',11.69,11.23,12.70,14.47,11.28
'12:30:30',12.05,11.75,12.62,14.15,12.16
'13:30:30',12.22,11.92,12.98,14.45,12.07
'14:30:30',11.92,12.03,13.10,14.72,11.89
'15:30:30',11.44,12.12,13.05,14.82,11.67
'16:30:30',10.96,12.08,12.98,14.87,11.36
'17:30:30',10.25,11.89,12.74,14.71,10.86

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'18:30:30',9.82,11.61,12.64,14.64,10.43
'19:30:30',9.36,11.50,12.46,14.55,10.09
'20:30:30',8.47,10.76,11.49,13.99,9.49
'21:30:30',7.81,10.26,10.89,13.56,8.84
'22:30:30',7.32,9.91,10.50,13.30,8.37
'23:30:30',6.88,9.60,10.16,13.06,7.97
*end_report
```

```
*report,13,relative humidity,ZnRH,rh_lens
*title,Relative humidity,%
*format,tabular,24, 7
*fields,Time,lens_void,lens_5_a,lens_mez_a,lens_mez_b,lens_5_b,lense_doub
*data
'00:30:30',50.17,44.19,42.82,42.57,39.62,43.20
'01:30:30',47.48,41.84,41.22,41.10,37.41,41.26
'02:30:30',45.02,39.50,39.20,39.47,35.26,39.00
'03:30:30',42.31,37.31,37.15,37.58,33.31,36.91
'04:30:30',40.13,35.02,35.09,35.71,31.25,34.64
'05:30:30',38.06,33.24,33.05,33.71,29.74,32.76
'06:30:30',36.22,31.47,31.30,31.88,28.23,31.01
'07:30:30',34.62,30.01,29.66,30.16,27.03,29.52
'08:30:30',33.26,28.47,27.85,28.42,26.21,28.19
'09:30:30',32.60,29.11,28.81,30.67,27.86,28.95
'10:30:30',31.06,29.76,30.49,33.89,29.99,30.68
'11:30:30',26.37,28.17,31.52,37.13,31.23,30.48
'12:30:30',19.55,29.65,30.23,36.88,30.23,30.53
'13:30:30',17.03,27.82,27.53,34.27,30.57,31.52
'14:30:30',21.84,24.70,31.25,35.18,28.85,29.11
'15:30:30',29.95,27.93,29.95,37.93,28.80,28.51
'16:30:30',34.79,31.37,31.57,36.25,30.16,31.36
'17:30:30',39.43,34.46,33.27,35.81,31.38,33.94
'18:30:30',41.63,35.82,34.26,35.20,31.95,35.36
'19:30:30',42.74,36.60,34.84,35.17,32.66,36.09
'20:30:30',44.17,38.35,36.44,37.13,33.83,37.22
'21:30:30',44.49,37.99,36.30,36.39,33.16,37.01
'22:30:30',43.54,36.78,35.06,34.95,32.27,35.78
'23:30:30',42.50,35.54,33.84,33.56,31.31,34.55
*end_report
```

```
*report,13,relative humidity,ZnRH,rh_other
*title,Relative humidity,%
*format,tabular,24, 6
*fields,Time,cellular_a,analysis,gen_chem,gen_corid,break_corid
*data
'00:30:30',44.73,39.15,44.16,39.97,42.61
'01:30:30',41.97,37.58,41.10,37.24,40.59
'02:30:30',39.25,35.52,38.12,34.42,38.15
'03:30:30',36.91,33.51,35.51,31.94,35.96
'04:30:30',34.46,31.34,32.95,29.54,33.58
'05:30:30',33.14,29.65,30.97,27.50,31.98
'06:30:30',31.78,28.19,29.24,25.80,30.52
'07:30:30',30.96,27.14,27.91,24.32,29.53
'08:30:30',31.32,26.67,29.19,24.71,29.22
'09:30:30',37.42,30.19,35.92,32.39,31.98
'10:30:30',41.76,32.94,42.38,41.21,35.34
'11:30:30',38.78,35.19,45.60,44.02,37.08
'12:30:30',34.81,39.24,43.21,43.26,37.33
'13:30:30',32.47,40.81,40.31,39.33,36.43
```

```
'14:30:30',34.22,40.55,42.36,40.41,37.42
'15:30:30',36.56,40.17,45.23,42.92,38.73
'16:30:30',38.89,40.15,47.58,44.93,39.86
'17:30:30',39.56,39.67,48.73,45.82,40.61
'18:30:30',40.53,39.00,48.51,45.13,40.72
'19:30:30',41.38,38.34,48.72,45.08,40.77
'20:30:30',42.08,38.66,48.74,44.56,40.87
'21:30:30',41.52,36.81,43.94,39.72,39.78
'22:30:30',41.01,35.35,40.08,35.54,38.77
'23:30:30',40.60,34.30,37.35,32.64,38.01
*end_report
```

```
*report,11,infiltration load,Infil,infil_zones
*title,Infiltration load,W
*format,tabular,24,6
*fields,Time,lens_void,lens_5_a,lens_mez_a,cellular_a,lense_doub
*data
'00:30:30',-1368.40,0.00,0.00,-423.27,0.00
'01:30:30',-1320.63,0.00,0.00,-405.95,0.00
'02:30:30',-1273.40,0.00,0.00,-388.88,0.00
'03:30:30',-1266.91,0.00,0.00,-385.07,0.00
'04:30:30',-1287.54,0.00,0.00,-390.11,0.00
'05:30:30',-1305.15,0.00,0.00,-394.48,0.00
'06:30:30',-1295.87,0.00,0.00,-388.16,0.00
'07:30:30',-1240.79,0.00,0.00,-369.29,0.00
'08:30:30',-1404.50,0.00,0.00,-362.57,0.00
'09:30:30',-1244.39,0.00,0.00,-273.01,0.00
'10:30:30',-1411.69,0.00,0.00,-258.15,0.00
'11:30:30',-2188.79,0.00,0.00,-317.90,0.00
'12:30:30',-2345.44,0.00,0.00,-542.11,0.00
'13:30:30',-2473.47,0.00,0.00,-532.97,0.00
'14:30:30',-2428.76,0.00,0.00,-487.23,0.00
'15:30:30',-2340.60,0.00,0.00,-497.37,0.00
'16:30:30',-2244.58,0.00,0.00,-530.72,0.00
'17:30:30',-2190.98,0.00,0.00,-539.85,0.00
'18:30:30',-2079.28,0.00,0.00,-536.45,0.00
'19:30:30',-2203.26,0.00,0.00,-591.50,0.00
'20:30:30',-2202.27,0.00,0.00,-584.50,0.00
'21:30:30',-2117.93,0.00,0.00,-578.42,0.00
'22:30:30',-2137.17,0.00,0.00,-589.08,0.00
'23:30:30',-2180.95,0.00,0.00,-603.28,0.00
*end_report
```

```
*end_day_to_display
```

```
*end_assessment
```

```
*assessment, 2,abertay spring run
```

```
*report,70,diversified,capacity,lens
*title,Diversified capacity,W
*format,table,1,7
*fields,Heating,Cooling,Lighting (unctld),Lighting (ctld),Fans,Small Power,Hot water
*data,0.000,0.000,4064.550,0.000,0.000,4169.670,0.000
*end_report
```

```
*report,70,diffuse,capacity,lens
```

```

*title,Diffuse capacity,W
*format,table,1,7
*fields,Heating,Cooling,Lighting (unctlld),Lighting (ctlld),Fans,Small Power,Hot water
*data,0.000,0.000,4064.550,0.000,0.000,4169.670,0.000
*end_report

*report,70,in_one_zone,capacity,lens
*title,Maximum in any one zone capacity,W
*format,table,1,7
*fields,Heating,Cooling,Lighting (unctlld),Lighting (ctlld),Fans,Small Power,Hot water
*data,0.000,0.000,978.300,0.000,0.000,978.300,0.000
*end_report

*report,70,minimum,capacity,lens
*title,Minimum capacity (diversified),W
*format,table,1,7
*fields,Heating,Cooling,Lighting (unctlld),Lighting (ctlld),Fans,Small Power,Hot water
*data,0.000,0.000,0.000,0.000,0.000,0.000,0.000
*end_report

*report,70,demand,integrated,lens
*title,Integrated demand,kWhr
*format,table,1,7
*fields,Heating,Cooling,Lighting (unctlld),Lighting (ctlld),Fans,Small Power,Hot water
*data,0.000,0.000,252.430,0.000,0.000,257.749,0.000
*end_report

*report,70,diversified,capacity,other
*title,Diversified capacity,W
*format,table,1,7
*fields,Heating,Cooling,Lighting (unctlld),Lighting (ctlld),Fans,Small Power,Hot water
*data,0.000,0.000,2060.480,0.000,0.000,2553.100,0.000
*end_report

*report,70,diffuse,capacity,other
*title,Diffuse capacity,W
*format,table,1,7
*fields,Heating,Cooling,Lighting (unctlld),Lighting (ctlld),Fans,Small Power,Hot water
*data,0.000,0.000,2060.480,0.000,0.000,2553.100,0.000
*end_report

*report,70,in_one_zone,capacity,other
*title,Maximum in any one zone capacity,W
*format,table,1,7
*fields,Heating,Cooling,Lighting (unctlld),Lighting (ctlld),Fans,Small Power,Hot water
*data,0.000,0.000,1008.000,0.000,0.000,1260.000,0.000
*end_report

*report,70,minimum,capacity,other
*title,Minimum capacity (diversified),W
*format,table,1,7
*fields,Heating,Cooling,Lighting (unctlld),Lighting (ctlld),Fans,Small Power,Hot water
*data,0.000,0.000,0.000,0.000,0.000,0.000,0.000
*end_report

*report,70,demand,integrated,other
*title,Integrated demand,kWhr

```



```

*format,table,1,7
*fields,Heating,Cooling,Lighting (unctlld),Lighting (ctlld),Fans,Small Power,Hot water
*data,0.000,0.000,149.435,0.000,0.000,175.525,0.000
*end_report

*report, 6,distribution,comfort,occup_lens
*title,Resultant temperature,degC
*format,frequency,12,5,12.0,2.0,30.0
*fields,range,distribution,percent,cumulative_distrib,cumulative_percent
*data
'<12',0,0.0,0.0,0.0
'12-14',3,0.69,3,0.69
'14-16',7,1.62,10,2.31
'16-18',42,9.72,52,12.04
'18-20',158,36.57,210,48.61
'20-22',163,37.73,373,86.34
'22-24',55,12.73,428,99.07
'24-26',4,0.93,432,100.00
'26-28',0,0.00,432,100.00
'28-30',0,0.00,432,100.00
'30-32',0,0.00,432,100.00
'>32',0,0.0,0.0,0.0
*end_report

*report, 6,stats,comfort,occup_lens
*title,Resultant temperature,degC
*format,table,1,7
*fields,maximum,minimum,average,diversified_max,distributed_max,diversified_min,distributed_min
*data,141.680,12.311,20.004,136.110,141.680,0.000,95.990
*end_report

*report, 6,distribution,comfort,ocup_other
*title,Resultant temperature,degC
*format,frequency,12,5,12.0,2.0,30.0
*fields,range,distribution,percent,cumulative_distrib,cumulative_percent
*data
'<12',0,0.0,0.0,0.0
'12-14',0,0.00,0,0.00
'14-16',15,4.17,15,4.17
'16-18',99,27.50,114,31.67
'18-20',198,55.00,312,86.67
'20-22',48,13.33,360,100.00
'22-24',0,0.00,360,100.00
'24-26',0,0.00,360,100.00
'26-28',0,0.00,360,100.00
'28-30',0,0.00,360,100.00
'30-32',0,0.00,360,100.00
'>32',0,0.0,0.0,0.0
*end_report

*report, 6,stats,comfort,ocup_other
*title,Resultant temperature,degC
*format,table,1,7
*fields,maximum,minimum,average,diversified_max,distributed_max,diversified_min,distributed_min
*data,105.091,14.167,18.577,101.642,105.091,0.000,76.836
*end_report

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```

*report,13,distribution,ZnRH,rh_lens
*title,Relative humidity,%
*format,frequency,21,5,0.0,5.0,100.0
*fields,range,distribution,percent,cumulative_distrib,cumulative_percent
*data
'0-5',0,0.00,0,0.00
'5-10',0,0.00,0,0.00
'10-15',0,0.00,0,0.00
'15-20',28,2.78,28,2.78
'20-25',63,6.25,91,9.03
'25-30',77,7.64,168,16.67
'30-35',99,9.82,267,26.49
'35-40',216,21.43,483,47.92
'40-45',271,26.88,754,74.80
'45-50',180,17.86,934,92.66
'50-55',62,6.15,996,98.81
'55-60',11,1.09,1007,99.90
'60-65',0,0.00,1007,99.90
'65-70',1,0.10,1008,100.00
'70-75',0,0.00,1008,100.00
'75-80',0,0.00,1008,100.00
'80-85',0,0.00,1008,100.00
'85-90',0,0.00,1008,100.00
'90-95',0,0.00,1008,100.00
'95-100',0,0.00,1008,100.00
'100-105',0,0.00,1008,100.00
*end_report

```

```

*report,13,stats,ZnRH,rh_lens
*title,Relative humidity,%
*format,table,1,7
*fields,maximum,minimum,average,diversified_max,distributed_max,diversified_min,distributed_min
*data,347.292,16.769,39.005,301.188,347.292,0.000,97.152
*end_report

```

```

*report,13,distribution,ZnRH,rh_other
*title,Relative humidity,%
*format,frequency,21,5,0.0,5.0,100.0
*fields,range,distribution,percent,cumulative_distrib,cumulative_percent
*data
'0-5',0,0.00,0,0.00
'5-10',0,0.00,0,0.00
'10-15',0,0.00,0,0.00
'15-20',0,0.00,0,0.00
'20-25',34,4.05,34,4.05
'25-30',69,8.21,103,12.26
'30-35',62,7.38,165,19.64
'35-40',129,15.36,294,35.00
'40-45',254,30.24,548,65.24
'45-50',214,25.48,762,90.71
'50-55',73,8.69,835,99.40
'55-60',5,0.60,840,100.00
'60-65',0,0.00,840,100.00
'65-70',0,0.00,840,100.00
'70-75',0,0.00,840,100.00
'75-80',0,0.00,840,100.00

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'80-85',0,0.00,840,100.00
'85-90',0,0.00,840,100.00
'90-95',0,0.00,840,100.00
'95-100',0,0.00,840,100.00
'100-105',0,0.00,840,100.00
*end_report

*report,13,stats,ZnRH,rh_other
*title,Relative humidity,%
*format,table,1,7
*fields,maximum,minimum,average,diversified_max,distributed_max,diversified_min,distributed_min
n
*data,281.608,20.112,41.291,257.959,281.608,0.000,107.251
*end_report

*report,11,distribution,Infil,infil_zones
*title,Infiltration load,W
*format,frequency,65,5,-12400.0,200.0,0.0
*fields,range,distribution,percent,cumulative_distrib,cumulative_percent
*data
'<-12500',0,0.0,0.0,0.0
'-12500--12300',0,0.00,0,0.00
'-12300--12100',0,0.00,0,0.00
'-12100--11900',0,0.00,0,0.00
'-11900--11700',0,0.00,0,0.00
'-11700--11500',0,0.00,0,0.00
'-11500--11300',0,0.00,0,0.00
'-11300--11100',0,0.00,0,0.00
'-11100--10900',0,0.00,0,0.00
'-10900--10700',0,0.00,0,0.00
'-10700--10500',0,0.00,0,0.00
'-10500--10300',0,0.00,0,0.00
'-10300--10100',0,0.00,0,0.00
'-10100--9900',0,0.00,0,0.00
'-9900--9700',0,0.00,0,0.00
'-9700--9500',0,0.00,0,0.00
'-9500--9300',0,0.00,0,0.00
'-9300--9100',0,0.00,0,0.00
'-9100--8900',0,0.00,0,0.00
'-8900--8700',0,0.00,0,0.00
'-8700--8500',0,0.00,0,0.00
'-8500--8300',1,0.12,1,0.12
'-8300--8100',0,0.00,1,0.12
'-8100--7900',0,0.00,1,0.12
'-7900--7700',0,0.00,1,0.12
'-7700--7500',0,0.00,1,0.12
'-7500--7300',1,0.12,2,0.24
'-7300--7100',0,0.00,2,0.24
'-7100--6900',0,0.00,2,0.24
'-6900--6700',3,0.36,5,0.60
'-6700--6500',1,0.12,6,0.71
'-6500--6300',1,0.12,7,0.83
'-6300--6100',1,0.12,8,0.95
'-6100--5900',0,0.00,8,0.95
'-5900--5700',0,0.00,8,0.95
'-5700--5500',1,0.12,9,1.07
'-5500--5300',2,0.24,11,1.31
'-5300--5100',4,0.48,15,1.79

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```

'-5100--4900',0,0.00,15,1.79
'-4900--4700',0,0.00,15,1.79
'-4700--4500',2,0.24,17,2.02
'-4500--4300',3,0.36,20,2.38
'-4300--4100',1,0.12,21,2.50
'-4100--3900',5,0.60,26,3.10
'-3900--3700',2,0.24,28,3.33
'-3700--3500',3,0.36,31,3.69
'-3500--3300',6,0.71,37,4.40
'-3300--3100',2,0.24,39,4.64
'-3100--2900',6,0.71,45,5.36
'-2900--2700',6,0.71,51,6.07
'-2700--2500',15,1.79,66,7.86
'-2500--2300',12,1.43,78,9.29
'-2300--2100',12,1.43,90,10.71
'-2100--1900',11,1.31,101,12.02
'-1900--1700',5,0.60,106,12.62
'-1700--1500',4,0.48,110,13.10
'-1500--1300',7,0.83,117,13.93
'-1300--1100',11,1.31,128,15.24
'-1100--900',13,1.55,141,16.79
'-900--700',36,4.29,177,21.07
'-700--500',46,5.48,223,26.55
'-500--300',38,4.52,261,31.07
'-300--100',35,4.17,296,35.24
'-100-100',544,64.76,840,100.00
'>100',0,0.0,0.0,0.0
*end_report

*report,11,stats,Infil,infil_zones
*title,Infiltration load,W
*format,table,1,7
*fields,maximum,minimum,average,diversified_max,distributed_max,diversified_min,distributed_min
*data,0.000,-8384.598,-553.528,0.000,0.000,-8723.917,-13976.032
*end_report

*day_to_display,Sat 5 Apr 1980

*report,70,demand,per_unit_time,lens
*title,Energy Demand per Unit Time,W
*format,tabular,24,7
*fields,Time,Heating,Cooling,Lighting,Fans,Small Power,Hot water
*data
'00:30:30',0.0,0.0,0.0,0.0,0.0,0.0
'01:30:30',0.0,0.0,0.0,0.0,0.0,0.0
'02:30:30',0.0,0.0,0.0,0.0,0.0,0.0
'03:30:30',0.0,0.0,0.0,0.0,0.0,0.0
'04:30:30',0.0,0.0,0.0,0.0,0.0,0.0
'05:30:30',0.0,0.0,0.0,0.0,0.0,0.0
'06:30:30',0.0,0.0,0.0,0.0,0.0,0.0
'07:30:30',0.0,0.0,254.0,0.0,39.4,0.0
'08:30:30',0.0,0.0,3810.5,0.0,591.3,0.0
'09:30:30',0.0,0.0,4064.6,0.0,630.7,0.0
'10:30:30',0.0,0.0,4064.6,0.0,630.7,0.0
'11:30:30',0.0,0.0,4064.6,0.0,630.7,0.0
'12:30:30',0.0,0.0,4064.6,0.0,630.7,0.0
'13:30:30',0.0,0.0,4064.6,0.0,630.7,0.0

```

```
'14:30:30',0.0,0.0,4064.6,0.0,630.7,0.0
'15:30:30',0.0,0.0,4064.6,0.0,630.7,0.0
'16:30:30',0.0,0.0,4064.6,0.0,630.7,0.0
'17:30:30',0.0,0.0,4064.6,0.0,630.7,0.0
'18:30:30',0.0,0.0,4064.6,0.0,630.7,0.0
'19:30:30',0.0,0.0,3810.5,0.0,591.3,0.0
'20:30:30',0.0,0.0,254.0,0.0,39.4,0.0
'21:30:30',0.0,0.0,0.0,0.0,0.0,0.0
'22:30:30',0.0,0.0,0.0,0.0,0.0,0.0
'23:30:30',0.0,0.0,0.0,0.0,0.0,0.0
*end_report
```

```
*report,70,demand,per_unit_time,other
*title,Energy Demand per Unit Time,W
*format,tabular,24,7
*fields,Time,Heating,Cooling,Lighting,Fans,Small Power,Hot water
*data
```

```
'00:30:30',0.0,0.0,0.0,0.0,0.0,0.0
'01:30:30',0.0,0.0,0.0,0.0,0.0,0.0
'02:30:30',0.0,0.0,0.0,0.0,0.0,0.0
'03:30:30',0.0,0.0,0.0,0.0,0.0,0.0
'04:30:30',0.0,0.0,0.0,0.0,0.0,0.0
'05:30:30',0.0,0.0,0.0,0.0,0.0,0.0
'06:30:30',0.0,0.0,0.0,0.0,0.0,0.0
'07:30:30',0.0,0.0,128.8,0.0,116.3,0.0
'08:30:30',0.0,0.0,1931.7,0.0,1745.2,0.0
'09:30:30',0.0,0.0,2060.5,0.0,1861.6,0.0
'10:30:30',0.0,0.0,2060.5,0.0,1861.6,0.0
'11:30:30',0.0,0.0,2060.5,0.0,1861.6,0.0
'12:30:30',0.0,0.0,2060.5,0.0,1861.6,0.0
'13:30:30',0.0,0.0,2060.5,0.0,1861.6,0.0
'14:30:30',0.0,0.0,2060.5,0.0,1861.6,0.0
'15:30:30',0.0,0.0,2060.5,0.0,1861.6,0.0
'16:30:30',0.0,0.0,2060.5,0.0,1861.6,0.0
'17:30:30',0.0,0.0,2060.5,0.0,1861.6,0.0
'18:30:30',0.0,0.0,2060.5,0.0,1861.6,0.0
'19:30:30',0.0,0.0,1931.7,0.0,1745.2,0.0
'20:30:30',0.0,0.0,128.8,0.0,116.3,0.0
'21:30:30',0.0,0.0,0.0,0.0,0.0,0.0
'22:30:30',0.0,0.0,0.0,0.0,0.0,0.0
'23:30:30',0.0,0.0,0.0,0.0,0.0,0.0
*end_report
```

```
*report, 6,thermal_comfort,comfort,occup_lens
*title,Resultant temperature,degC
*format,tabular,24, 7
*fields,Time,lens_void,lens_5_a,lens_mez_a,lense_doub,lens_5_b,lens_mez_b
*data
'00:30:30',14.44,18.25,19.38,18.49,18.81,20.41
'01:30:30',14.11,18.02,19.09,18.32,18.51,19.62
'02:30:30',13.82,17.78,18.73,18.02,18.35,19.46
'03:30:30',13.52,17.60,18.49,17.76,18.19,19.53
'04:30:30',13.11,17.27,18.19,17.49,17.70,18.71
'05:30:30',12.72,16.93,17.78,17.16,17.30,17.89
'06:30:30',12.64,16.72,17.49,16.90,16.98,17.35
'07:30:30',14.30,17.11,17.63,17.06,17.36,17.76
'08:30:30',17.92,18.80,19.11,18.64,18.44,18.94
'09:30:30',19.34,19.41,20.34,20.23,18.99,19.41
'10:30:30',18.27,19.40,20.90,21.07,17.88,18.85
```

```
'11:30:30',21.25,20.77,21.11,22.00,19.05,19.35
'12:30:30',21.51,20.65,21.57,22.81,19.69,20.62
'13:30:30',20.38,20.63,21.55,23.06,20.21,20.47
'14:30:30',19.54,20.20,21.42,22.68,20.82,20.27
'15:30:30',18.83,19.91,21.44,22.57,20.41,20.44
'16:30:30',18.85,20.20,21.93,22.30,21.43,20.75
'17:30:30',18.88,20.13,21.61,21.94,21.35,21.03
'18:30:30',19.00,20.46,21.53,20.47,21.00,22.28
'19:30:30',18.48,20.12,21.03,18.64,21.49,21.49
'20:30:30',16.64,19.27,19.76,18.16,20.47,21.11
'21:30:30',16.51,19.07,20.11,19.11,20.09,20.93
'22:30:30',16.28,19.46,19.81,18.91,20.03,20.70
'23:30:30',16.24,19.11,19.85,19.13,19.74,20.63
*end_report
```

```
*report, 6,thermal_comfort,comfort,ocup_other
*title,Resultant temperature,degC
*format,tabular,24, 6
*fields,Time,cellular_a,analysis,gen_chem,gen_corid,break_corid
*data
'00:30:30',15.67,18.01,17.80,19.16,16.67
'01:30:30',15.37,17.94,17.41,18.97,16.52
'02:30:30',15.00,17.74,17.17,18.82,16.20
'03:30:30',14.50,17.33,16.97,18.71,15.67
'04:30:30',14.27,17.34,16.58,18.54,15.59
'05:30:30',14.08,17.27,16.20,18.33,15.59
'06:30:30',14.04,17.12,15.89,18.13,15.54
'07:30:30',14.47,16.99,16.09,18.08,15.64
'08:30:30',16.01,17.41,17.42,18.53,16.47
'09:30:30',17.85,18.06,18.39,19.04,17.77
'10:30:30',19.36,18.50,19.20,19.43,18.79
'11:30:30',19.80,18.90,19.38,19.59,19.47
'12:30:30',19.85,19.16,19.59,19.71,19.59
'13:30:30',19.74,19.44,20.57,19.57,19.66
'14:30:30',19.80,19.56,20.79,19.01,19.10
'15:30:30',19.92,19.59,21.06,19.31,19.60
'16:30:30',19.28,19.73,21.42,19.27,19.47
'17:30:30',19.34,19.77,21.55,19.19,19.41
'18:30:30',19.07,19.24,19.78,19.49,19.58
'19:30:30',18.09,18.78,18.81,18.84,18.38
'20:30:30',18.68,18.56,19.31,19.40,18.32
'21:30:30',18.52,18.41,19.10,19.42,18.61
'22:30:30',18.29,18.23,18.88,19.29,18.42
'23:30:30',17.51,18.23,18.99,19.36,17.86
*end_report
```

```
*report,13,relative humidity,ZnRH,rh_lens
*title,Relative humidity,%
*format,tabular,24, 7
*fields,Time,lens_void,lens_5_a,lens_mez_a,lens_mez_b,lens_5_b,lense_doub
*data
'00:30:30',47.81,41.10,36.39,34.32,38.55,38.65
'01:30:30',47.39,40.57,36.02,35.46,37.97,37.94
'02:30:30',46.83,40.18,35.72,34.08,37.22,37.66
'03:30:30',46.60,39.60,35.29,33.15,37.03,37.24
'04:30:30',46.75,39.65,35.08,34.59,37.41,36.97
'05:30:30',47.06,39.78,35.06,35.52,37.69,36.90
'06:30:30',47.30,39.99,35.04,36.59,38.98,36.95
```

```

'07:30:30',44.31,38.90,34.70,34.73,38.24,36.63
'08:30:30',39.59,35.01,31.79,31.27,36.44,33.89
'09:30:30',43.53,38.12,31.47,33.28,38.35,33.06
'10:30:30',56.11,42.67,33.23,39.73,47.27,35.01
'11:30:30',45.25,39.61,36.29,40.36,43.92,36.04
'12:30:30',44.18,40.84,36.04,36.95,41.66,35.41
'13:30:30',44.89,38.22,35.33,37.67,38.27,33.77
'14:30:30',44.80,39.23,35.22,39.04,36.47,33.81
'15:30:30',47.19,40.95,35.67,39.77,39.26,33.76
'16:30:30',47.25,40.55,34.59,40.15,36.68,34.73
'17:30:30',48.20,42.15,36.74,40.91,38.39,36.42
'18:30:30',47.35,42.33,37.75,35.38,42.37,44.07
'19:30:30',48.69,45.09,40.43,38.72,39.04,52.24
'20:30:30',56.36,48.81,46.13,40.43,44.19,53.32
'21:30:30',55.28,49.43,43.83,41.26,45.57,47.10
'22:30:30',55.18,46.76,44.61,41.78,45.22,47.41
'23:30:30',54.38,48.11,43.96,41.60,45.96,46.09
*end_report

```

```

*report,13,relative humidity,ZnRH,rh_other
*title,Relative humidity,%
*format,tabular,24, 6
*fields,Time,cellular_a,analysis,gen_chem,gen_corid,break_corid
*data
'00:30:30',45.38,39.36,40.34,37.13,42.66
'01:30:30',44.41,38.17,39.45,35.77,41.22
'02:30:30',44.73,37.75,38.51,34.64,41.33
'03:30:30',45.23,37.80,37.85,33.87,41.94
'04:30:30',44.47,36.48,37.90,33.39,40.50
'05:30:30',44.29,35.83,38.09,33.06,39.49
'06:30:30',44.37,35.63,38.87,33.23,39.24
'07:30:30',44.32,35.97,38.68,33.56,39.97
'08:30:30',43.51,36.54,38.01,34.05,40.13
'09:30:30',43.54,37.99,41.72,38.43,40.45
'10:30:30',42.97,40.78,44.30,42.81,41.79
'11:30:30',43.51,43.28,46.55,45.10,41.84
'12:30:30',42.01,44.86,44.69,45.39,42.72
'13:30:30',40.71,44.41,42.08,38.63,41.06
'14:30:30',40.15,42.68,39.99,38.43,42.08
'15:30:30',39.72,40.00,36.90,37.75,39.68
'16:30:30',42.79,39.80,36.99,39.21,40.88
'17:30:30',43.63,40.88,38.04,41.02,42.40
'18:30:30',46.09,45.29,46.60,42.44,42.77
'19:30:30',52.30,48.75,52.04,48.85,49.83
'20:30:30',47.55,49.62,48.47,44.53,49.52
'21:30:30',47.77,49.42,48.17,45.16,47.45
'22:30:30',48.41,49.49,48.11,45.90,47.90
'23:30:30',51.55,48.77,46.70,45.09,50.15
*end_report

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```

*report,11,infiltration load,Infil,infil_zones
*title,Infiltration load,W
*format,tabular,24, 6
*fields,Time,lens_void,lens_5_a,lens_mez_a,cellular_a,lense_doub
*data
'00:30:30',-2408.47,0.00,0.00,-685.29,0.00
'01:30:30',-2557.75,0.00,0.00,-594.39,0.00
'02:30:30',-2452.69,0.00,0.00,-660.33,0.00

```

```

'03:30:30',-2461.80,0.00,0.00,-686.50,0.00
'04:30:30',-2636.97,0.00,0.00,-611.14,0.00
'05:30:30',-2654.96,0.00,0.00,-595.34,0.00
'06:30:30',-2584.93,0.00,0.00,-532.17,0.00
'07:30:30',-1966.06,0.00,0.00,-492.00,0.00
'08:30:30',-1983.78,0.00,0.00,-479.05,0.00
'09:30:30',-3305.64,0.00,0.00,-494.07,0.00
'10:30:30',-5120.42,0.00,0.00,-533.50,0.00
'11:30:30',-3563.39,0.00,0.00,-721.91,0.00
'12:30:30',-3706.95,0.00,0.00,-698.62,0.00
'13:30:30',-4077.51,0.00,0.00,-735.98,0.00
'14:30:30',-3090.53,0.00,0.00,-298.46,0.00
'15:30:30',-2801.10,0.00,0.00,-450.93,0.00
'16:30:30',-2842.15,0.00,0.00,-598.16,0.00
'17:30:30',-1695.78,0.00,0.00,-421.75,0.00
'18:30:30',-3377.59,0.00,0.00,-591.92,0.00
'19:30:30',-2795.03,0.00,0.00,-490.86,0.00
'20:30:30',-2629.52,0.00,0.00,0.00,0.00
'21:30:30',-1320.64,0.00,0.00,-40.61,0.00
'22:30:30',-1082.92,0.00,0.00,-97.97,0.00
'23:30:30',-1571.93,0.00,0.00,-364.54,0.00
*end_report

*end_day_to_display

*end_assessment

*assessment, 3,abertay summer run

*report,70,diversified,capacity,lens
*title,Diversified capacity,W
*format,table,1,7
*fields,Heating,Cooling,Lighting (unctltd),Lighting (ctltd),Fans,Small Power,Hot water
*data,0.000,0.000,4064.550,0.000,0.000,4169.670,0.000
*end_report

*report,70,diffuse,capacity,lens
*title,Diffuse capacity,W
*format,table,1,7
*fields,Heating,Cooling,Lighting (unctltd),Lighting (ctltd),Fans,Small Power,Hot water
*data,0.000,0.000,4064.550,0.000,0.000,4169.670,0.000
*end_report

*report,70,in_one_zone,capacity,lens
*title,Maximum in any one zone capacity,W
*format,table,1,7
*fields,Heating,Cooling,Lighting (unctltd),Lighting (ctltd),Fans,Small Power,Hot water
*data,0.000,0.000,978.300,0.000,0.000,978.300,0.000
*end_report

*report,70,minimum,capacity,lens
*title,Minimum capacity (diversified),W
*format,table,1,7
*fields,Heating,Cooling,Lighting (unctltd),Lighting (ctltd),Fans,Small Power,Hot water
*data,0.000,0.000,0.000,0.000,0.000,0.000,0.000
*end_report

```



```

*report,70,demand,integrated,lens
*title,Integrated demand,kWhr
*format,table,1,7
*fields,Heating,Cooling,Lighting (unctlld),Lighting (ctlld),Fans,Small Power,Hot water
*data,0.000,0.000,333.442,0.000,0.000,357.821,0.000
*end_report

```

```

*report,70,diversified,capacity,other
*title,Diversified capacity,W
*format,table,1,7
*fields,Heating,Cooling,Lighting (unctlld),Lighting (ctlld),Fans,Small Power,Hot water
*data,0.000,0.000,2060.480,0.000,0.000,2553.100,0.000
*end_report

```

```

*report,70,diffuse,capacity,other
*title,Diffuse capacity,W
*format,table,1,7
*fields,Heating,Cooling,Lighting (unctlld),Lighting (ctlld),Fans,Small Power,Hot water
*data,0.000,0.000,2060.480,0.000,0.000,2553.100,0.000
*end_report

```

```

*report,70,in_one_zone,capacity,other
*title,Maximum in any one zone capacity,W
*format,table,1,7
*fields,Heating,Cooling,Lighting (unctlld),Lighting (ctlld),Fans,Small Power,Hot water
*data,0.000,0.000,1008.000,0.000,0.000,1260.000,0.000
*end_report

```

```

*report,70,minimum,capacity,other
*title,Minimum capacity (diversified),W
*format,table,1,7
*fields,Heating,Cooling,Lighting (unctlld),Lighting (ctlld),Fans,Small Power,Hot water
*data,0.000,0.000,0.000,0.000,0.000,0.000,0.000
*end_report

```

```

*report,70,demand,integrated,other
*title,Integrated demand,kWhr
*format,table,1,7
*fields,Heating,Cooling,Lighting (unctlld),Lighting (ctlld),Fans,Small Power,Hot water
*data,0.000,0.000,198.886,0.000,0.000,236.799,0.000
*end_report

```

```

*report, 6,distribution,comfort,occup_lens
*title,Resultant temperature,degC
*format,frequency,12,5,12.0,2.0,30.0
*fields,range,distribution,percent,cumulative_distrib,cumulative_percent
*data
'<12',0,0.0,0.0,0.0
'12-14',0,0.00,0.0,0.00
'14-16',0,0.00,0.0,0.00
'16-18',13,2.26,13,2.26
'18-20',98,17.01,111,19.27
'20-22',271,47.05,382,66.32
'22-24',154,26.74,536,93.06
'24-26',33,5.73,569,98.78
'26-28',7,1.22,576,100.00
'28-30',0,0.00,576,100.00

```

```

'30-32',0,0.00,576,100.00
'>32',0,0.0,0.0,0.0
*end_report

*report, 6,stats,comfort,occup_lens
*title,Resultant temperature,degC
*format,table,1,7
*fields,maximum,minimum,average,diversified_max,distributed_max,diversified_min,distributed_min
n
*data,153.752,16.750,21.377,151.932,153.752,0.000,112.773
*end_report

*report, 6,distribution,comfort,occup_other
*title,Resultant temperature,degC
*format,frequency,12,5,12.0,2.0,30.0
*fields,range,distribution,percent,cumulative_distrib,cumulative_percent
*data
'<12',0,0.0,0.0,0.0
'12-14',0,0.00,0,0.00
'14-16',0,0.00,0,0.00
'16-18',0,0.00,0,0.00
'18-20',144,30.00,144,30.00
'20-22',275,57.29,419,87.29
'22-24',42,8.75,461,96.04
'24-26',18,3.75,479,99.79
'26-28',1,0.21,480,100.00
'28-30',0,0.00,480,100.00
'30-32',0,0.00,480,100.00
'>32',0,0.0,0.0,0.0
*end_report

*report, 6,stats,comfort,occup_other
*title,Resultant temperature,degC
*format,table,1,7
*fields,maximum,minimum,average,diversified_max,distributed_max,diversified_min,distributed_min
n
*data,124.086,18.180,20.733,121.409,124.086,0.000,93.517
*end_report

*report,13,distribution,ZnRH,rh_lens
*title,Relative humidity,%
*format,frequency,21,5,0.0,5.0,100.0
*fields,range,distribution,percent,cumulative_distrib,cumulative_percent
*data
'0-5',0,0.00,0,0.00
'5-10',0,0.00,0,0.00
'10-15',0,0.00,0,0.00
'15-20',0,0.00,0,0.00
'20-25',0,0.00,0,0.00
'25-30',0,0.00,0,0.00
'30-35',3,0.23,3,0.23
'35-40',39,3.01,42,3.24
'40-45',120,9.26,162,12.50
'45-50',141,10.88,303,23.38
'50-55',153,11.81,456,35.19
'55-60',258,19.91,714,55.09
'60-65',259,19.98,973,75.08
'65-70',197,15.20,1170,90.28

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'70-75',80,6.17,1250,96.45
'75-80',34,2.62,1284,99.07
'80-85',12,0.93,1296,100.00
'85-90',0,0.00,1296,100.00
'90-95',0,0.00,1296,100.00
'95-100',0,0.00,1296,100.00
'100-105',0,0.00,1296,100.00
*end_report

*report,13,stats,ZnRH,rh_lens
*title,Relative humidity,%
*format,table,1,7
*fields,maximum,minimum,average,diversified_max,distributed_max,diversified_min,distributed_min
*data,488.729,33.698,57.983,434.886,488.729,0.000,212.791
*end_report

*report,13,distribution,ZnRH,rh_other
*title,Relative humidity,%
*format,frequency,21,5,0.0,5.0,100.0
*fields,range,distribution,percent,cumulative_distrib,cumulative_percent
*data
'0-5',0,0.00,0,0.00
'5-10',0,0.00,0,0.00
'10-15',0,0.00,0,0.00
'15-20',0,0.00,0,0.00
'20-25',0,0.00,0,0.00
'25-30',0,0.00,0,0.00
'30-35',0,0.00,0,0.00
'35-40',7,0.65,7,0.65
'40-45',99,9.17,106,9.81
'45-50',153,14.17,259,23.98
'50-55',121,11.20,380,35.19
'55-60',159,14.72,539,49.91
'60-65',288,26.67,827,76.57
'65-70',209,19.35,1036,95.93
'70-75',44,4.07,1080,100.00
'75-80',0,0.00,1080,100.00
'80-85',0,0.00,1080,100.00
'85-90',0,0.00,1080,100.00
'90-95',0,0.00,1080,100.00
'95-100',0,0.00,1080,100.00
'100-105',0,0.00,1080,100.00
*end_report

*report,13,stats,ZnRH,rh_other
*title,Relative humidity,%
*format,table,1,7
*fields,maximum,minimum,average,diversified_max,distributed_max,diversified_min,distributed_min
*data,387.554,38.763,57.949,355.466,387.554,0.000,188.429
*end_report

*report,11,distribution,Infil,infil_zones
*title,Infiltration load,W
*format,frequency,71,5,-13600.0,200.0,0.0
*fields,range,distribution,percent,cumulative_distrib,cumulative_percent
*data

```

'<-13700',0,0.0,0.0,0.0
 '-13700--13500',0,0.00,0,0.00
 '-13500--13300',0,0.00,0,0.00
 '-13300--13100',0,0.00,0,0.00
 '-13100--12900',0,0.00,0,0.00
 '-12900--12700',0,0.00,0,0.00
 '-12700--12500',0,0.00,0,0.00
 '-12500--12300',0,0.00,0,0.00
 '-12300--12100',0,0.00,0,0.00
 '-12100--11900',0,0.00,0,0.00
 '-11900--11700',0,0.00,0,0.00
 '-11700--11500',0,0.00,0,0.00
 '-11500--11300',0,0.00,0,0.00
 '-11300--11100',1,0.09,1,0.09
 '-11100--10900',0,0.00,1,0.09
 '-10900--10700',0,0.00,1,0.09
 '-10700--10500',1,0.09,2,0.19
 '-10500--10300',0,0.00,2,0.19
 '-10300--10100',0,0.00,2,0.19
 '-10100--9900',0,0.00,2,0.19
 '-9900--9700',0,0.00,2,0.19
 '-9700--9500',0,0.00,2,0.19
 '-9500--9300',0,0.00,2,0.19
 '-9300--9100',2,0.19,4,0.37
 '-9100--8900',0,0.00,4,0.37
 '-8900--8700',0,0.00,4,0.37
 '-8700--8500',0,0.00,4,0.37
 '-8500--8300',0,0.00,4,0.37
 '-8300--8100',2,0.19,6,0.56
 '-8100--7900',0,0.00,6,0.56
 '-7900--7700',1,0.09,7,0.65
 '-7700--7500',0,0.00,7,0.65
 '-7500--7300',0,0.00,7,0.65
 '-7300--7100',2,0.19,9,0.83
 '-7100--6900',2,0.19,11,1.02
 '-6900--6700',0,0.00,11,1.02
 '-6700--6500',3,0.28,14,1.30
 '-6500--6300',1,0.09,15,1.39
 '-6300--6100',2,0.19,17,1.57
 '-6100--5900',1,0.09,18,1.67
 '-5900--5700',1,0.09,19,1.76
 '-5700--5500',1,0.09,20,1.85
 '-5500--5300',3,0.28,23,2.13
 '-5300--5100',0,0.00,23,2.13
 '-5100--4900',0,0.00,23,2.13
 '-4900--4700',4,0.37,27,2.50
 '-4700--4500',3,0.28,30,2.78
 '-4500--4300',2,0.19,32,2.96
 '-4300--4100',1,0.09,33,3.06
 '-4100--3900',1,0.09,34,3.15
 '-3900--3700',5,0.46,39,3.61
 '-3700--3500',0,0.00,39,3.61
 '-3500--3300',2,0.19,41,3.80
 '-3300--3100',5,0.46,46,4.26
 '-3100--2900',3,0.28,49,4.54
 '-2900--2700',3,0.28,52,4.81
 '-2700--2500',4,0.37,56,5.19
 '-2500--2300',6,0.56,62,5.74

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'-2300--2100',5,0.46,67,6.20
'-2100--1900',9,0.83,76,7.04
'-1900--1700',8,0.74,84,7.78
'-1700--1500',20,1.85,104,9.63
'-1500--1300',22,2.04,126,11.67
'-1300--1100',14,1.30,140,12.96
'-1100--900',22,2.04,162,15.00
'-900--700',27,2.50,189,17.50
'-700--500',49,4.54,238,22.04
'-500--300',38,3.52,276,25.56
'-300--100',55,5.09,331,30.65
'-100-100',749,69.35,1080,100.00
'>100',0,0.0,0.0,0.0
*end_report

*report,11,stats,Infil,infil_zones
*title,Infiltration load,W
*format,table,1,7
*fields,maximum,minimum,average,diversified_max,distributed_max,diversified_min,distributed_min
*data,0.000,-11214.523,-482.348,0.000,0.000,-11279.871,-16850.971
*end_report

*day_to_display,Thu 24 Jul 1980

*report,70,demand,per_unit_time,lens
*title,Energy Demand per Unit Time,W
*format,tabular,24,7
*fields,Time,Heating,Cooling,Lighting,Fans,Small Power,Hot water
*data
'00:30:30',0.0,0.0,0.0,0.0,0.0,0.0,0.0
'01:30:30',0.0,0.0,0.0,0.0,0.0,0.0,0.0
'02:30:30',0.0,0.0,0.0,0.0,0.0,0.0,0.0
'03:30:30',0.0,0.0,0.0,0.0,0.0,0.0,0.0
'04:30:30',0.0,0.0,0.0,0.0,0.0,0.0,0.0
'05:30:30',0.0,0.0,0.0,0.0,0.0,0.0,0.0
'06:30:30',0.0,0.0,0.0,0.0,0.0,0.0,0.0
'07:30:30',0.0,0.0,211.0,0.0,260.6,0.0
'08:30:30',0.0,0.0,3164.5,0.0,3909.1,0.0
'09:30:30',0.0,0.0,3375.5,0.0,4169.7,0.0
'10:30:30',0.0,0.0,3375.5,0.0,4169.7,0.0
'11:30:30',0.0,0.0,3375.5,0.0,4169.7,0.0
'12:30:30',0.0,0.0,3375.5,0.0,4169.7,0.0
'13:30:30',0.0,0.0,3375.5,0.0,4169.7,0.0
'14:30:30',0.0,0.0,3375.5,0.0,4169.7,0.0
'15:30:30',0.0,0.0,3375.5,0.0,4169.7,0.0
'16:30:30',0.0,0.0,3375.5,0.0,4169.7,0.0
'17:30:30',0.0,0.0,3375.5,0.0,4169.7,0.0
'18:30:30',0.0,0.0,3375.5,0.0,4169.7,0.0
'19:30:30',0.0,0.0,3164.5,0.0,3909.1,0.0
'20:30:30',0.0,0.0,211.0,0.0,260.6,0.0
'21:30:30',0.0,0.0,0.0,0.0,0.0,0.0,0.0
'22:30:30',0.0,0.0,0.0,0.0,0.0,0.0,0.0
'23:30:30',0.0,0.0,0.0,0.0,0.0,0.0,0.0
*end_report

*report,70,demand,per_unit_time,other
*title,Energy Demand per Unit Time,W

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*format,tabular,24,7
*fields,Time,Heating,Cooling,Lighting,Fans,Small Power,Hot water
*data
'00:30:30',0.0,0.0,0.0,0.0,0.0,0.0
'01:30:30',0.0,0.0,0.0,0.0,0.0,0.0
'02:30:30',0.0,0.0,0.0,0.0,0.0,0.0
'03:30:30',0.0,0.0,0.0,0.0,0.0,0.0
'04:30:30',0.0,0.0,0.0,0.0,0.0,0.0
'05:30:30',0.0,0.0,0.0,0.0,0.0,0.0
'06:30:30',0.0,0.0,0.0,0.0,0.0,0.0
'07:30:30',0.0,0.0,128.8,0.0,159.6,0.0
'08:30:30',0.0,0.0,1931.7,0.0,2393.5,0.0
'09:30:30',0.0,0.0,2060.5,0.0,2553.1,0.0
'10:30:30',0.0,0.0,2060.5,0.0,2553.1,0.0
'11:30:30',0.0,0.0,2060.5,0.0,2553.1,0.0
'12:30:30',0.0,0.0,2060.5,0.0,2553.1,0.0
'13:30:30',0.0,0.0,2060.5,0.0,2553.1,0.0
'14:30:30',0.0,0.0,2060.5,0.0,2553.1,0.0
'15:30:30',0.0,0.0,2060.5,0.0,2553.1,0.0
'16:30:30',0.0,0.0,2060.5,0.0,2553.1,0.0
'17:30:30',0.0,0.0,2060.5,0.0,2553.1,0.0
'18:30:30',0.0,0.0,2060.5,0.0,2553.1,0.0
'19:30:30',0.0,0.0,1931.7,0.0,2393.5,0.0
'20:30:30',0.0,0.0,128.8,0.0,159.6,0.0
'21:30:30',0.0,0.0,0.0,0.0,0.0,0.0
'22:30:30',0.0,0.0,0.0,0.0,0.0,0.0
'23:30:30',0.0,0.0,0.0,0.0,0.0,0.0
*end_report
*report,6,thermal_comfort,comfort,occup_lens
*title,Resultant temperature,degC
*format,tabular,24,7
*fields,Time,lens_void,lens_5_a,lens_mez_a,lense_doub,lens_5_b,lens_mez_b
*data
'00:30:30',19.44,21.78,22.56,19.54,21.25,22.67
'01:30:30',18.94,21.37,22.36,19.33,22.25,22.24
'02:30:30',18.59,21.51,22.11,19.62,21.93,22.42
'03:30:30',19.02,21.04,21.46,18.39,21.74,22.25
'04:30:30',18.89,20.50,20.79,18.30,21.85,21.84
'05:30:30',19.11,20.16,20.70,17.88,21.82,22.01
'06:30:30',19.63,20.00,20.32,17.79,21.62,21.62
'07:30:30',21.06,20.31,20.62,18.41,21.67,21.56
'08:30:30',23.37,21.48,21.83,19.90,22.75,22.21
'09:30:30',24.58,22.15,22.51,20.95,23.14,22.78
'10:30:30',24.90,22.72,23.28,21.22,23.54,22.85
'11:30:30',24.17,22.78,23.26,20.75,22.66,22.74
'12:30:30',24.97,22.44,22.91,21.17,23.74,23.25
'13:30:30',24.64,22.32,22.57,21.33,23.69,23.22
'14:30:30',23.85,22.57,23.10,21.79,23.66,23.45
'15:30:30',22.30,22.97,23.52,21.29,22.48,22.92
'16:30:30',21.73,22.50,23.08,20.64,22.03,23.11
'17:30:30',22.59,22.07,22.33,20.23,24.07,23.55
'18:30:30',20.91,22.15,22.77,19.61,23.59,22.69
'19:30:30',19.48,21.83,22.86,19.33,22.83,22.88
'20:30:30',19.15,21.39,21.88,19.02,22.47,22.23
'21:30:30',19.98,21.19,21.26,18.78,22.96,22.26
'22:30:30',19.51,20.62,20.89,18.10,22.65,22.08
'23:30:30',19.02,20.03,20.20,17.32,22.18,21.55
*end_report

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*report, 6,thermal_comfort,comfort,ocup_other
*title,Resultant temperature,degC
*format,tabular,24, 6
*fields,Time,cellular_a,analysis,gen_chem,gen_corid,break_corid
*data
'00:30:30',20.97,20.53,21.37,22.49,20.65
'01:30:30',20.78,20.26,21.00,22.09,20.21
'02:30:30',20.69,20.31,20.96,22.25,20.23
'03:30:30',20.02,20.06,20.51,21.60,19.98
'04:30:30',20.15,20.13,20.90,21.29,19.76
'05:30:30',19.44,20.14,20.95,21.35,19.56
'06:30:30',19.37,20.11,20.81,21.18,19.52
'07:30:30',19.92,20.21,20.93,21.10,19.99
'08:30:30',21.01,20.19,20.74,21.02,20.63
'09:30:30',21.71,20.28,21.00,21.32,20.80
'10:30:30',22.37,20.45,20.90,21.25,20.93
'11:30:30',22.47,20.43,20.99,21.63,21.32
'12:30:30',21.75,20.29,20.93,21.13,21.15
'13:30:30',21.62,20.12,20.89,20.83,21.20
'14:30:30',21.96,20.36,21.16,21.10,21.33
'15:30:30',22.34,20.58,20.76,22.25,21.04
'16:30:30',21.96,20.20,20.72,21.99,20.93
'17:30:30',21.23,19.92,20.70,21.05,20.77
'18:30:30',21.02,19.96,20.47,21.65,20.37
'19:30:30',21.18,19.94,20.61,21.82,20.01
'20:30:30',20.74,19.50,20.30,21.52,19.78
'21:30:30',19.59,20.05,20.57,21.27,19.67
'22:30:30',19.95,20.02,20.39,20.94,20.02
'23:30:30',19.90,19.52,20.18,20.76,19.57
*end_report

*report,13,relative humidity,ZnRH,rh_lens
*title,Relative humidity,%
*format,tabular,24, 7
*fields,Time,lens_void,lens_5_a,lens_mez_a,lens_mez_b,lens_5_b,lense_doub
*data
'00:30:30',67.60,61.60,58.69,60.38,65.00,72.25
'01:30:30',67.16,61.15,56.58,59.37,55.99,69.58
'02:30:30',65.18,56.84,54.41,54.35,54.47,63.54
'03:30:30',58.93,56.18,54.42,51.45,52.76,66.18
'04:30:30',54.88,53.39,52.63,50.28,48.78,59.67
'05:30:30',50.17,51.46,49.23,45.27,44.73,58.92
'06:30:30',48.39,50.05,48.49,44.27,43.46,56.33
'07:30:30',43.31,44.31,43.80,41.36,40.17,48.74
'08:30:30',36.76,39.46,38.43,36.75,34.42,44.46
'09:30:30',37.74,40.51,38.95,36.67,35.55,44.46
'10:30:30',38.20,38.53,36.87,38.88,35.74,44.19
'11:30:30',41.35,41.53,40.38,42.14,42.04,50.36
'12:30:30',39.72,44.34,42.93,40.27,38.55,49.31
'13:30:30',41.71,45.65,44.94,42.21,40.37,48.65
'14:30:30',40.85,40.18,38.82,39.37,38.04,44.21
'15:30:30',49.25,42.73,41.49,46.16,47.94,52.14
'16:30:30',52.26,47.33,45.36,46.72,51.63,56.03
'17:30:30',46.95,49.02,48.13,43.64,41.17,57.20
'18:30:30',54.71,49.14,46.12,48.31,44.52,61.10
'19:30:30',60.58,51.23,46.20,48.15,48.82,61.97
'20:30:30',59.11,52.95,49.92,49.76,49.07,61.85

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'21:30:30',51.17,51.09,50.24,47.50,44.78,57.62
'22:30:30',48.65,48.65,47.70,44.98,42.59,55.21
'23:30:30',46.99,48.77,47.27,43.12,40.87,58.02
*end_report

*report,13,relative humidity,ZnRH,rh_other
*title,Relative humidity,%
*format,tabular,24, 6
*fields,Time,cellular_a,analysis,gen_chem,gen_corid,break_corid
*data
'00:30:30',64.61,66.09,63.65,55.79,64.49
'01:30:30',62.12,64.02,62.47,55.65,64.07
'02:30:30',58.82,59.33,58.38,52.13,59.90
'03:30:30',57.94,56.19,56.03,51.49,57.26
'04:30:30',51.30,50.59,48.74,47.05,52.08
'05:30:30',51.91,47.70,45.91,43.83,49.89
'06:30:30',49.43,45.08,43.79,42.46,48.42
'07:30:30',43.77,40.77,39.60,38.76,42.49
'08:30:30',41.06,42.80,42.58,39.07,40.15
'09:30:30',42.03,43.80,43.70,40.61,42.62
'10:30:30',39.52,44.74,45.03,39.47,42.10
'11:30:30',42.28,48.49,48.32,41.46,44.30
'12:30:30',47.45,49.90,49.55,45.94,46.35
'13:30:30',45.83,47.53,46.95,46.82,45.83
'14:30:30',42.81,45.61,44.97,41.08,41.27
'15:30:30',43.22,50.38,51.90,38.98,47.23
'16:30:30',47.81,53.72,53.35,44.46,50.19
'17:30:30',51.75,55.37,53.73,49.83,50.73
'18:30:30',53.08,56.21,56.09,46.71,53.29
'19:30:30',51.18,57.25,55.85,46.72,55.20
'20:30:30',53.07,58.30,55.76,48.57,56.64
'21:30:30',54.50,50.41,49.50,47.16,53.17
'22:30:30',47.99,47.13,45.46,43.89,47.03
'23:30:30',46.08,47.23,45.28,42.61,46.23
*end_report

*report,11,infiltration load,Infil,infil_zones
*title,Infiltration load,W
*format,tabular,24, 6
*fields,Time,lens_void,lens_5_a,lens_mez_a,cellular_a,lense_doub
*data
'00:30:30',-6596.45,0.00,0.00,-43.72,0.00
'01:30:30',-4365.69,0.00,0.00,-141.40,0.00
'02:30:30',-3345.97,0.00,0.00,0.00,0.00
'03:30:30',-2499.64,0.00,0.00,-911.99,0.00
'04:30:30',0.00,0.00,0.00,-410.50,0.00
'05:30:30',0.00,0.00,0.00,-1042.36,0.00
'06:30:30',0.00,0.00,0.00,-1254.25,0.00
'07:30:30',0.00,0.00,0.00,-1037.98,0.00
'08:30:30',0.00,0.00,0.00,-1203.30,0.00
'09:30:30',-1429.46,0.00,0.00,-1424.73,0.00
'10:30:30',-3220.18,0.00,0.00,-714.68,0.00
'11:30:30',-4640.05,0.00,0.00,-1313.74,0.00
'12:30:30',0.00,0.00,0.00,-2101.58,0.00
'13:30:30',0.00,0.00,0.00,-1813.80,0.00
'14:30:30',-1715.04,0.00,0.00,-1309.62,0.00
'15:30:30',-11214.52,0.00,0.00,-65.35,0.00
'16:30:30',-9256.75,0.00,0.00,-81.39,0.00

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'17:30:30',-397.75,0.00,0.00,-1513.93,0.00
'18:30:30',-7092.13,0.00,0.00,-1040.34,0.00
'19:30:30',-6181.19,0.00,0.00,-86.05,0.00
'20:30:30',-5411.50,0.00,0.00,-176.55,0.00
'21:30:30',-90.85,0.00,0.00,-880.50,0.00
'22:30:30',0.00,0.00,0.00,-481.17,0.00
'23:30:30',0.00,0.00,0.00,-441.71,0.00
*end_report

*end_day_to_display

*end_assessment

*assessment, 4,abertay autumn run

*report,70,diversified,capacity,lens
*title,Diversified capacity,W
*format,table,1,7
*fields,Heating,Cooling,Lighting (unctlD),Lighting (ctlD),Fans,Small Power,Hot water
*data,0.000,0.000,4064.550,0.000,0.000,4169.670,0.000
*end_report

*report,70,diffuse,capacity,lens
*title,Diffuse capacity,W
*format,table,1,7
*fields,Heating,Cooling,Lighting (unctlD),Lighting (ctlD),Fans,Small Power,Hot water
*data,0.000,0.000,4064.550,0.000,0.000,4169.670,0.000
*end_report

*report,70,in_one_zone,capacity,lens
*title,Maximum in any one zone capacity,W
*format,table,1,7
*fields,Heating,Cooling,Lighting (unctlD),Lighting (ctlD),Fans,Small Power,Hot water
*data,0.000,0.000,978.300,0.000,0.000,978.300,0.000
*end_report

*report,70,minimum,capacity,lens
*title,Minimum capacity (diversified),W
*format,table,1,7
*fields,Heating,Cooling,Lighting (unctlD),Lighting (ctlD),Fans,Small Power,Hot water
*data,0.000,0.000,0.000,0.000,0.000,0.000,0.000
*end_report

*report,70,demand,integrated,lens
*title,Integrated demand,kWhr
*format,table,1,7
*fields,Heating,Cooling,Lighting (unctlD),Lighting (ctlD),Fans,Small Power,Hot water
*data,0.000,0.000,252.430,0.000,0.000,257.749,0.000
*end_report

*report,70,diversified,capacity,other
*title,Diversified capacity,W
*format,table,1,7
*fields,Heating,Cooling,Lighting (unctlD),Lighting (ctlD),Fans,Small Power,Hot water
*data,0.000,0.000,2060.480,0.000,0.000,2553.100,0.000
*end_report

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```

*report,70,diffuse,capacity,other
*title,Diffuse capacity,W
*format,table,1,7
*fields,Heating,Cooling,Lighting (unctld),Lighting (ctld),Fans,Small Power,Hot water
*data,0.000,0.000,2060.480,0.000,0.000,2553.100,0.000
*end_report

```

```

*report,70,in_one_zone,capacity,other
*title,Maximum in any one zone capacity,W
*format,table,1,7
*fields,Heating,Cooling,Lighting (unctld),Lighting (ctld),Fans,Small Power,Hot water
*data,0.000,0.000,1008.000,0.000,0.000,1260.000,0.000
*end_report

```

```

*report,70,minimum,capacity,other
*title,Minimum capacity (diversified),W
*format,table,1,7
*fields,Heating,Cooling,Lighting (unctld),Lighting (ctld),Fans,Small Power,Hot water
*data,0.000,0.000,0.000,0.000,0.000,0.000,0.000
*end_report

```

```

*report,70,demand,integrated,other
*title,Integrated demand,kWhr
*format,table,1,7
*fields,Heating,Cooling,Lighting (unctld),Lighting (ctld),Fans,Small Power,Hot water
*data,0.000,0.000,149.435,0.000,0.000,175.525,0.000
*end_report

```

```

*report, 6,distribution,comfort,occup_lens
*title,Resultant temperature,degC
*format,frequency,12,5,12.0,2.0,30.0
*fields,range,distribution,percent,cumulative_distrib,cumulative_percent
*data
'<12',0,0.0,0.0,0.0
'12-14',0,0.00,0,0.00
'14-16',13,3.01,13,3.01
'16-18',85,19.68,98,22.69
'18-20',259,59.95,357,82.64
'20-22',74,17.13,431,99.77
'22-24',1,0.23,432,100.00
'24-26',0,0.00,432,100.00
'26-28',0,0.00,432,100.00
'28-30',0,0.00,432,100.00
'30-32',0,0.00,432,100.00
'>32',0,0.0,0.0,0.0
*end_report

```

```

*report, 6,stats,comfort,occup_lens
*title,Resultant temperature,degC
*format,table,1,7
*fields,maximum,minimum,average,diversified_max,distributed_max,diversified_min,distributed_min
*data,127.149,14.583,18.791,125.901,127.149,0.000,98.080
*end_report

```

```

*report, 6,distribution,comfort,ocup_other
*title,Resultant temperature,degC

```

```

*format,frequency,12,5,12.0,2.0,30.0
*fields,range,distribution,percent,cumulative_distrib,cumulative_percent
*data
'<12',0,0.0,0.0,0.0
'12-14',0,0.00,0,0.00
'14-16',27,7.50,27,7.50
'16-18',157,43.61,184,51.11
'18-20',168,46.67,352,97.78
'20-22',8,2.22,360,100.00
'22-24',0,0.00,360,100.00
'24-26',0,0.00,360,100.00
'26-28',0,0.00,360,100.00
'28-30',0,0.00,360,100.00
'30-32',0,0.00,360,100.00
'>32',0,0.0,0.0,0.0
*end_report

*report, 6,stats,comfort,ocup_other
*title,Resultant temperature,degC
*format,table,1,7
*fields,maximum,minimum,average,diversified_max,distributed_max,diversified_min,distributed_min
*data,98.754,14.193,17.878,98.237,98.754,0.000,75.000
*end_report

*report,13,distribution,ZnRH,rh_lens
*title,Relative humidity,%
*format,frequency,21,5,0.0,5.0,100.0
*fields,range,distribution,percent,cumulative_distrib,cumulative_percent
*data
'0-5',0,0.00,0,0.00
'5-10',0,0.00,0,0.00
'10-15',0,0.00,0,0.00
'15-20',0,0.00,0,0.00
'20-25',0,0.00,0,0.00
'25-30',0,0.00,0,0.00
'30-35',0,0.00,0,0.00
'35-40',0,0.00,0,0.00
'40-45',27,2.68,27,2.68
'45-50',164,16.27,191,18.95
'50-55',296,29.37,487,48.31
'55-60',208,20.63,695,68.95
'60-65',134,13.29,829,82.24
'65-70',98,9.72,927,91.96
'70-75',48,4.76,975,96.73
'75-80',31,3.08,1006,99.80
'80-85',2,0.20,1008,100.00
'85-90',0,0.00,1008,100.00
'90-95',0,0.00,1008,100.00
'95-100',0,0.00,1008,100.00
'100-105',0,0.00,1008,100.00
*end_report

*report,13,stats,ZnRH,rh_lens
*title,Relative humidity,%
*format,table,1,7
*fields,maximum,minimum,average,diversified_max,distributed_max,diversified_min,distributed_min
n

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*data,474.958,41.072,57.106,459.028,474.958,0.000,250.737
*end_report

*report,13,distribution,ZnRH,rh_other
*title,Relative humidity,%
*format,frequency,21,5,0.0,5.0,100.0
*fields,range,distribution,percent,cumulative_distrib,cumulative_percent
*data
'0-5',0,0.00,0,0.00
'5-10',0,0.00,0,0.00
'10-15',0,0.00,0,0.00
'15-20',0,0.00,0,0.00
'20-25',0,0.00,0,0.00
'25-30',0,0.00,0,0.00
'30-35',0,0.00,0,0.00
'35-40',0,0.00,0,0.00
'40-45',3,0.36,3,0.36
'45-50',68,8.10,71,8.45
'50-55',160,19.05,231,27.50
'55-60',193,22.98,424,50.48
'60-65',216,25.71,640,76.19
'65-70',93,11.07,733,87.26
'70-75',50,5.95,783,93.21
'75-80',30,3.57,813,96.79
'80-85',22,2.62,835,99.40
'85-90',5,0.60,840,100.00
'90-95',0,0.00,840,100.00
'95-100',0,0.00,840,100.00
'100-105',0,0.00,840,100.00
*end_report

*report,13,stats,ZnRH,rh_other
*title,Relative humidity,%
*format,table,1,7
*fields,maximum,minimum,average,diversified_max,distributed_max,diversified_min,distributed_min
*data,421.158,44.021,60.563,409.163,421.158,0.000,226.839
*end_report

*report,11,distribution,Infil,infil_zones
*title,Infiltration load,W
*format,frequency,88,5,-8500.0,100.0,0.0
*fields,range,distribution,percent,cumulative_distrib,cumulative_percent
*data
'<-8550',0,0.0,0.0,0.0
'-8550--8450',0,0.00,0,0.00
'-8450--8350',0,0.00,0,0.00
'-8350--8250',0,0.00,0,0.00
'-8250--8150',0,0.00,0,0.00
'-8150--8050',0,0.00,0,0.00
'-8050--7950',0,0.00,0,0.00
'-7950--7850',0,0.00,0,0.00
'-7850--7750',0,0.00,0,0.00
'-7750--7650',0,0.00,0,0.00
'-7650--7550',0,0.00,0,0.00
'-7550--7450',0,0.00,0,0.00
'-7450--7350',0,0.00,0,0.00
'-7350--7250',0,0.00,0,0.00

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'-7250--7150',0,0.00,0,0.00
 '-7150--7050',0,0.00,0,0.00
 '-7050--6950',0,0.00,0,0.00
 '-6950--6850',0,0.00,0,0.00
 '-6850--6750',0,0.00,0,0.00
 '-6750--6650',0,0.00,0,0.00
 '-6650--6550',0,0.00,0,0.00
 '-6550--6450',0,0.00,0,0.00
 '-6450--6350',0,0.00,0,0.00
 '-6350--6250',0,0.00,0,0.00
 '-6250--6150',0,0.00,0,0.00
 '-6150--6050',0,0.00,0,0.00
 '-6050--5950',0,0.00,0,0.00
 '-5950--5850',0,0.00,0,0.00
 '-5850--5750',0,0.00,0,0.00
 '-5750--5650',0,0.00,0,0.00
 '-5650--5550',0,0.00,0,0.00
 '-5550--5450',0,0.00,0,0.00
 '-5450--5350',0,0.00,0,0.00
 '-5350--5250',0,0.00,0,0.00
 '-5250--5150',0,0.00,0,0.00
 '-5150--5050',1,0.12,1,0.12
 '-5050--4950',0,0.00,1,0.12
 '-4950--4850',0,0.00,1,0.12
 '-4850--4750',0,0.00,1,0.12
 '-4750--4650',0,0.00,1,0.12
 '-4650--4550',0,0.00,1,0.12
 '-4550--4450',0,0.00,1,0.12
 '-4450--4350',0,0.00,1,0.12
 '-4350--4250',0,0.00,1,0.12
 '-4250--4150',0,0.00,1,0.12
 '-4150--4050',1,0.12,2,0.24
 '-4050--3950',1,0.12,3,0.36
 '-3950--3850',0,0.00,3,0.36
 '-3850--3750',2,0.24,5,0.60
 '-3750--3650',0,0.00,5,0.60
 '-3650--3550',1,0.12,6,0.71
 '-3550--3450',1,0.12,7,0.83
 '-3450--3350',2,0.24,9,1.07
 '-3350--3250',0,0.00,9,1.07
 '-3250--3150',0,0.00,9,1.07
 '-3150--3050',1,0.12,10,1.19
 '-3050--2950',0,0.00,10,1.19
 '-2950--2850',0,0.00,10,1.19
 '-2850--2750',2,0.24,12,1.43
 '-2750--2650',4,0.48,16,1.90
 '-2650--2550',1,0.12,17,2.02
 '-2550--2450',3,0.36,20,2.38
 '-2450--2350',3,0.36,23,2.74
 '-2350--2250',2,0.24,25,2.98
 '-2250--2150',1,0.12,26,3.10
 '-2150--2050',4,0.48,30,3.57
 '-2050--1950',5,0.60,35,4.17
 '-1950--1850',6,0.71,41,4.88
 '-1850--1750',2,0.24,43,5.12
 '-1750--1650',8,0.95,51,6.07
 '-1650--1550',6,0.71,57,6.79
 '-1550--1450',7,0.83,64,7.62

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'-1450--1350',5,0.60,69,8.21
'-1350--1250',3,0.36,72,8.57
'-1250--1150',7,0.83,79,9.40
'-1150--1050',9,1.07,88,10.48
'-1050--950',7,0.83,95,11.31
'-950--850',16,1.90,111,13.21
'-850--750',13,1.55,124,14.76
'-750--650',20,2.38,144,17.14
'-650--550',25,2.98,169,20.12
'-550--450',43,5.12,212,25.24
'-450--350',35,4.17,247,29.40
'-350--250',36,4.29,283,33.69
'-250--150',25,2.98,308,36.67
'-150--50',11,1.31,319,37.98
'-50-50',521,62.02,840,100.00
'>50',0,0.0,0.0,0.0
*end_report

*report,11,stats,Infil,infil_zones
*title,Infiltration load,W
*format,table,1,7
*fields,maximum,minimum,average,diversified_max,distributed_max,diversified_min,distributed_min
*data,0.000,-5063.545,-342.852,0.000,0.000,-6092.635,-9767.062
*end_report

*day_to_display,Sat 4 Oct 1980

*report,70,demand,per_unit_time,lens
*title,Energy Demand per Unit Time,W
*format,tabular,24,7
*fields,Time,Heating,Cooling,Lighting,Fans,Small Power,Hot water
*data
'00:30:30',0.0,0.0,0.0,0.0,0.0,0.0
'01:30:30',0.0,0.0,0.0,0.0,0.0,0.0
'02:30:30',0.0,0.0,0.0,0.0,0.0,0.0
'03:30:30',0.0,0.0,0.0,0.0,0.0,0.0
'04:30:30',0.0,0.0,0.0,0.0,0.0,0.0
'05:30:30',0.0,0.0,0.0,0.0,0.0,0.0
'06:30:30',0.0,0.0,0.0,0.0,0.0,0.0
'07:30:30',0.0,0.0,254.0,0.0,39.4,0.0
'08:30:30',0.0,0.0,3810.5,0.0,591.3,0.0
'09:30:30',0.0,0.0,4064.6,0.0,630.7,0.0
'10:30:30',0.0,0.0,4064.6,0.0,630.7,0.0
'11:30:30',0.0,0.0,4064.6,0.0,630.7,0.0
'12:30:30',0.0,0.0,4064.6,0.0,630.7,0.0
'13:30:30',0.0,0.0,4064.6,0.0,630.7,0.0
'14:30:30',0.0,0.0,4064.6,0.0,630.7,0.0
'15:30:30',0.0,0.0,4064.6,0.0,630.7,0.0
'16:30:30',0.0,0.0,4064.6,0.0,630.7,0.0
'17:30:30',0.0,0.0,4064.6,0.0,630.7,0.0
'18:30:30',0.0,0.0,4064.6,0.0,630.7,0.0
'19:30:30',0.0,0.0,3810.5,0.0,591.3,0.0
'20:30:30',0.0,0.0,254.0,0.0,39.4,0.0
'21:30:30',0.0,0.0,0.0,0.0,0.0,0.0
'22:30:30',0.0,0.0,0.0,0.0,0.0,0.0
'23:30:30',0.0,0.0,0.0,0.0,0.0,0.0
*end_report

```

```

*report,70,demand,per_unit_time,other
*title,Energy Demand per Unit Time,W
*format,tabular,24,7
*fields,Time,Heating,Cooling,Lighting,Fans,Small Power,Hot water
*data
'00:30:30',0.0,0.0,0.0,0.0,0.0,0.0
'01:30:30',0.0,0.0,0.0,0.0,0.0,0.0
'02:30:30',0.0,0.0,0.0,0.0,0.0,0.0
'03:30:30',0.0,0.0,0.0,0.0,0.0,0.0
'04:30:30',0.0,0.0,0.0,0.0,0.0,0.0
'05:30:30',0.0,0.0,0.0,0.0,0.0,0.0
'06:30:30',0.0,0.0,0.0,0.0,0.0,0.0
'07:30:30',0.0,0.0,128.8,0.0,116.3,0.0
'08:30:30',0.0,0.0,1931.7,0.0,1745.2,0.0
'09:30:30',0.0,0.0,2060.5,0.0,1861.6,0.0
'10:30:30',0.0,0.0,2060.5,0.0,1861.6,0.0
'11:30:30',0.0,0.0,2060.5,0.0,1861.6,0.0
'12:30:30',0.0,0.0,2060.5,0.0,1861.6,0.0
'13:30:30',0.0,0.0,2060.5,0.0,1861.6,0.0
'14:30:30',0.0,0.0,2060.5,0.0,1861.6,0.0
'15:30:30',0.0,0.0,2060.5,0.0,1861.6,0.0
'16:30:30',0.0,0.0,2060.5,0.0,1861.6,0.0
'17:30:30',0.0,0.0,2060.5,0.0,1861.6,0.0
'18:30:30',0.0,0.0,2060.5,0.0,1861.6,0.0
'19:30:30',0.0,0.0,1931.7,0.0,1745.2,0.0
'20:30:30',0.0,0.0,128.8,0.0,116.3,0.0
'21:30:30',0.0,0.0,0.0,0.0,0.0,0.0
'22:30:30',0.0,0.0,0.0,0.0,0.0,0.0
'23:30:30',0.0,0.0,0.0,0.0,0.0,0.0
*end_report
*report, 6,thermal_comfort,comfort,occup_lens
*title,Resultant temperature,degC
*format,tabular,24, 7
*fields,Time,lens_void,lens_5_a,lens_mez_a,lense_doub,lens_5_b,lens_mez_b
*data
'00:30:30',17.20,19.24,19.31,18.81,19.65,19.20
'01:30:30',16.94,19.02,19.09,18.58,19.45,18.98
'02:30:30',16.73,18.83,18.90,18.40,19.27,18.77
'03:30:30',16.52,18.61,18.70,18.20,19.05,18.53
'04:30:30',16.03,18.38,18.49,18.08,18.56,18.03
'05:30:30',15.67,18.14,18.20,17.90,18.14,17.58
'06:30:30',15.81,17.97,17.98,17.69,18.18,17.58
'07:30:30',16.26,18.23,18.09,17.79,18.58,18.00
'08:30:30',17.04,18.71,18.87,18.52,18.61,18.08
'09:30:30',19.22,19.54,19.84,19.50,19.05,18.60
'10:30:30',18.54,19.42,20.30,20.16,19.33,18.97
'11:30:30',18.95,19.42,20.13,20.15,19.37,19.00
'12:30:30',17.55,19.18,20.12,20.13,18.91,18.63
'13:30:30',16.24,18.50,19.31,19.33,18.20,17.87
'14:30:30',16.97,18.96,19.59,19.47,18.54,18.21
'15:30:30',17.11,19.06,19.72,19.56,18.65,18.35
'16:30:30',16.95,19.01,19.66,19.47,18.66,18.36
'17:30:30',16.61,18.82,19.44,19.24,18.53,18.21
'18:30:30',16.46,18.70,19.22,18.98,18.52,18.15
'19:30:30',16.08,18.65,19.17,18.99,18.37,17.99
'20:30:30',15.21,17.64,18.24,18.09,17.56,17.10
'21:30:30',14.92,17.53,17.78,17.69,17.26,16.71

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'22:30:30',14.31,16.90,17.39,17.30,16.93,16.34
 '23:30:30',14.60,17.02,17.23,17.06,16.96,16.33
 *end_report

*report, 6,thermal_comfort,comfort,ocup_other
 *title,Resultant temperature,degC
 *format,tabular,24, 6
 *fields,Time,cellular_a,analysis,gen_chem,gen_corid,break_corid
 *data
 '00:30:30',16.37,18.97,16.65,17.38,17.92
 '01:30:30',16.11,18.81,16.39,17.11,17.68
 '02:30:30',15.88,18.65,16.17,16.88,17.50
 '03:30:30',15.63,18.49,15.91,16.63,17.30
 '04:30:30',15.65,18.37,15.87,16.58,17.20
 '05:30:30',15.61,18.26,15.78,16.56,17.16
 '06:30:30',15.45,18.14,15.62,16.36,16.93
 '07:30:30',15.47,18.07,15.67,16.35,16.82
 '08:30:30',16.21,18.51,16.53,16.81,17.39
 '09:30:30',17.33,19.04,17.27,17.33,18.43
 '10:30:30',18.26,19.45,17.75,17.69,19.34
 '11:30:30',19.04,19.41,18.59,18.14,19.26
 '12:30:30',18.60,19.42,17.77,18.01,19.28
 '13:30:30',17.81,19.39,17.56,17.77,18.90
 '14:30:30',17.20,19.53,17.18,17.49,18.60
 '15:30:30',17.10,19.62,17.15,17.38,18.66
 '16:30:30',16.97,19.63,17.08,17.33,18.61
 '17:30:30',16.73,19.51,16.92,17.19,18.45
 '18:30:30',16.64,19.45,16.99,17.19,18.16
 '19:30:30',16.95,19.45,17.52,17.59,18.04
 '20:30:30',16.64,18.67,17.54,17.33,17.40
 '21:30:30',16.19,18.48,16.53,17.24,17.27
 '22:30:30',16.05,18.08,16.82,16.70,16.66
 '23:30:30',15.85,17.95,16.44,16.90,16.63
 *end_report

*report,13,relative humidity,ZnRH,rh_lens
 *title,Relative humidity,%
 *format,tabular,24, 7
 *fields,Time,lens_void,lens_5_a,lens_mez_a,lens_mez_b,lens_5_b,lense_doub
 *data
 '00:30:30',58.99,54.59,52.82,53.18,52.69,54.39
 '01:30:30',58.85,54.34,52.53,53.08,52.26,53.99
 '02:30:30',58.67,53.71,51.99,52.83,51.95,53.42
 '03:30:30',59.18,54.52,51.68,53.56,52.89,53.38
 '04:30:30',62.74,56.53,52.62,57.13,57.16,54.22
 '05:30:30',64.73,58.96,54.99,59.75,59.80,56.42
 '06:30:30',62.95,58.33,55.84,57.91,56.97,57.16
 '07:30:30',60.49,56.15,54.43,55.16,54.37,55.57
 '08:30:30',59.83,54.26,51.47,55.02,54.51,53.08
 '09:30:30',54.78,52.01,49.28,53.49,53.33,50.58
 '10:30:30',61.02,53.57,48.93,52.38,52.21,49.62
 '11:30:30',56.54,52.09,48.72,51.53,51.10,48.99
 '12:30:30',62.26,53.99,48.22,55.07,55.33,48.63
 '13:30:30',69.50,59.73,53.38,61.25,61.76,53.80
 '14:30:30',64.27,58.04,52.93,59.58,60.02,54.34
 '15:30:30',63.51,57.68,52.93,59.09,59.47,54.32
 '16:30:30',63.84,57.87,53.23,59.02,59.12,54.69
 '17:30:30',63.81,57.43,52.83,58.23,58.00,54.70


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'18:30:30',62.73,56.46,52.17,57.30,57.31,53.88
'19:30:30',66.45,57.69,52.53,59.80,60.42,53.68
'20:30:30',72.35,65.03,58.43,65.75,65.91,59.32
'21:30:30',71.78,63.76,59.71,65.83,65.25,60.70
'22:30:30',73.98,66.02,59.89,66.27,65.58,60.98
'23:30:30',71.00,63.83,59.47,65.16,64.45,60.87
*end_report

*report,13,relative humidity,ZnRH,rh_other
*title,Relative humidity,%
*format,tabular,24, 6
*fields,Time,cellular_a,analysis,gen_chem,gen_corid,break_corid
*data
'00:30:30',64.22,54.08,63.09,60.43,57.00
'01:30:30',64.01,53.84,62.89,60.46,56.78
'02:30:30',64.21,53.20,62.95,60.01,56.13
'03:30:30',66.39,52.74,65.61,62.30,56.24
'04:30:30',66.94,52.85,67.17,63.53,56.81
'05:30:30',66.82,53.80,67.56,64.74,57.88
'06:30:30',66.49,55.08,65.99,63.35,59.25
'07:30:30',66.08,54.99,65.44,62.85,58.85
'08:30:30',62.54,52.97,61.67,60.44,56.32
'09:30:30',59.26,51.90,59.71,59.12,53.37
'10:30:30',55.66,51.21,57.33,57.60,50.82
'11:30:30',52.53,51.39,53.71,53.54,51.55
'12:30:30',55.32,50.98,59.50,55.77,50.40
'13:30:30',60.01,50.64,61.88,59.56,52.81
'14:30:30',64.34,51.79,64.94,62.81,55.81
'15:30:30',64.73,52.94,64.77,63.15,56.11
'16:30:30',64.77,53.47,64.52,63.14,56.35
'17:30:30',64.16,53.61,63.43,62.29,56.31
'18:30:30',63.85,52.79,62.69,61.03,55.98
'19:30:30',62.54,52.17,61.60,59.85,56.47
'20:30:30',64.65,56.55,60.58,61.94,61.50
'21:30:30',66.15,56.91,65.10,61.68,61.24
'22:30:30',65.41,57.97,61.45,63.63,63.27
'23:30:30',65.39,57.06,63.02,61.11,61.52
*end_report

*report,11,infiltration load,Infil,infil_zones
*title,Infiltration load,W
*format,tabular,24, 6
*fields,Time,lens_void,lens_5_a,lens_mez_a,cellular_a,lense_doub
*data
'00:30:30',-629.92,0.00,0.00,-603.55,0.00
'01:30:30',-640.10,0.00,0.00,-613.52,0.00
'02:30:30',-656.38,0.00,0.00,-618.15,0.00
'03:30:30',-693.39,0.00,0.00,-646.49,0.00
'04:30:30',-1012.11,0.00,0.00,-522.61,0.00
'05:30:30',-1179.75,0.00,0.00,-528.93,0.00
'06:30:30',-842.86,0.00,0.00,-510.60,0.00
'07:30:30',-478.31,0.00,0.00,-414.13,0.00
'08:30:30',-1149.03,0.00,0.00,-436.58,0.00
'09:30:30',-1362.40,0.00,0.00,-534.35,0.00
'10:30:30',-3995.11,0.00,0.00,-549.02,0.00
'11:30:30',-1904.41,0.00,0.00,-299.20,0.00
'12:30:30',-2150.60,0.00,0.00,-458.19,0.00
'13:30:30',-2050.19,0.00,0.00,-723.26,0.00

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'14:30:30',-1790.87,0.00,0.00,-896.75,0.00
'15:30:30',-1743.46,0.00,0.00,-856.89,0.00
'16:30:30',-1727.95,0.00,0.00,-856.50,0.00
'17:30:30',-1658.78,0.00,0.00,-840.80,0.00
'18:30:30',-1433.12,0.00,0.00,-704.45,0.00
'19:30:30',-1562.34,0.00,0.00,-438.59,0.00
'20:30:30',-1546.49,0.00,0.00,-322.52,0.00
'21:30:30',-1409.16,0.00,0.00,-395.93,0.00
'22:30:30',-1244.61,0.00,0.00,-306.78,0.00
'23:30:30',-1057.80,0.00,0.00,-295.84,0.00
*end_report

*end_day_to_display

*end_assessment

*assessment, 5,abertay 2nd winter run

*report,70,diversified,capacity,lens
*title,Diversified capacity,W
*format,table,1,7
*fields,Heating,Cooling,Lighting (unctld),Lighting (ctld),Fans,Small Power,Hot water
*data,0.000,0.000,4064.550,0.000,0.000,4169.670,0.000
*end_report

*report,70,diffuse,capacity,lens
*title,Diffuse capacity,W
*format,table,1,7
*fields,Heating,Cooling,Lighting (unctld),Lighting (ctld),Fans,Small Power,Hot water
*data,0.000,0.000,4064.550,0.000,0.000,4169.670,0.000
*end_report

*report,70,in_one_zone,capacity,lens
*title,Maximum in any one zone capacity,W
*format,table,1,7
*fields,Heating,Cooling,Lighting (unctld),Lighting (ctld),Fans,Small Power,Hot water
*data,0.000,0.000,978.300,0.000,0.000,978.300,0.000
*end_report

*report,70,minimum,capacity,lens
*title,Minimum capacity (diversified),W
*format,table,1,7
*fields,Heating,Cooling,Lighting (unctld),Lighting (ctld),Fans,Small Power,Hot water
*data,0.000,0.000,0.000,0.000,0.000,0.000,0.000
*end_report

*report,70,demand,integrated,lens
*title,Integrated demand,kWhr
*format,table,1,7
*fields,Heating,Cooling,Lighting (unctld),Lighting (ctld),Fans,Small Power,Hot water
*data,0.000,0.000,252.430,0.000,0.000,257.749,0.000
*end_report

*report,70,diversified,capacity,other
*title,Diversified capacity,W
*format,table,1,7

```

```
*fields,Heating,Cooling,Lighting (unctld),Lighting (ctld),Fans,Small Power,Hot water
*data,0.000,0.000,2060.480,0.000,0.000,2553.100,0.000
*end_report
```

```
*report,70,diffuse,capacity,other
*title,Diffuse capacity,W
*format,table,1,7
*fields,Heating,Cooling,Lighting (unctld),Lighting (ctld),Fans,Small Power,Hot water
*data,0.000,0.000,2060.480,0.000,0.000,2553.100,0.000
*end_report
```

```
*report,70,in_one_zone,capacity,other
*title,Maximum in any one zone capacity,W
*format,table,1,7
*fields,Heating,Cooling,Lighting (unctld),Lighting (ctld),Fans,Small Power,Hot water
*data,0.000,0.000,1008.000,0.000,0.000,1260.000,0.000
*end_report
```

```
*report,70,minimum,capacity,other
*title,Minimum capacity (diversified),W
*format,table,1,7
*fields,Heating,Cooling,Lighting (unctld),Lighting (ctld),Fans,Small Power,Hot water
*data,0.000,0.000,0.000,0.000,0.000,0.000,0.000
*end_report
```

```
*report,70,demand,integrated,other
*title,Integrated demand,kWhr
*format,table,1,7
*fields,Heating,Cooling,Lighting (unctld),Lighting (ctld),Fans,Small Power,Hot water
*data,0.000,0.000,149.435,0.000,0.000,175.525,0.000
*end_report
```

```
*report, 6,distribution,comfort,occup_lens
*title,Resultant temperature,degC
*format,frequency,12,5,12.0,2.0,30.0
*fields,range,distribution,percent,cumulative_distrib,cumulative_percent
*data
'<12',144,0.0,0.0,0.0
'12-14',176,61.11,176,61.11
'14-16',49,17.01,225,78.12
'16-18',58,20.14,283,98.26
'18-20',5,1.74,288,100.00
'20-22',0,0.00,288,100.00
'22-24',0,0.00,288,100.00
'24-26',0,0.00,288,100.00
'26-28',0,0.00,288,100.00
'28-30',0,0.00,288,100.00
'30-32',0,0.00,288,100.00
'>32',0,0.0,0.0,0.0
*end_report
```

```
*report, 6,stats,comfort,occup_lens
*title,Resultant temperature,degC
*format,table,1,7
*fields,maximum,minimum,average,diversified_max,distributed_max,diversified_min,distributed_min
*data,103.693,7.785,13.027,101.321,103.693,0.000,59.021
*end_report
```

```

*report, 6,distribution,comfort,ocup_other
*title,Resultant temperature,degC
*format,frequency,12,5,12.0,2.0,30.0
*fields,range,distribution,percent,cumulative_distrib,cumulative_percent
*data
'<12',275,0.0,0.0,0.0
'12-14',43,50.59,43,50.59
'14-16',34,40.00,77,90.59
'16-18',8,9.41,85,100.00
'18-20',0,0.00,85,100.00
'20-22',0,0.00,85,100.00
'22-24',0,0.00,85,100.00
'24-26',0,0.00,85,100.00
'26-28',0,0.00,85,100.00
'28-30',0,0.00,85,100.00
'30-32',0,0.00,85,100.00
'>32',0,0.0,0.0,0.0
*end_report

*report, 6,stats,comfort,ocup_other
*title,Resultant temperature,degC
*format,table,1,7
*fields,maximum,minimum,average,diversified_max,distributed_max,diversified_min,distributed_min
*data,68.704,6.141,10.831,68.203,68.704,0.000,37.711
*end_report

*report,13,distribution,ZnRH,rh_lens
*title,Relative humidity,%
*format,frequency,21,5,0.0,5.0,100.0
*fields,range,distribution,percent,cumulative_distrib,cumulative_percent
*data
'0-5',0,0.00,0,0.00
'5-10',0,0.00,0,0.00
'10-15',0,0.00,0,0.00
'15-20',0,0.00,0,0.00
'20-25',0,0.00,0,0.00
'25-30',0,0.00,0,0.00
'30-35',10,0.99,10,0.99
'35-40',73,7.24,83,8.23
'40-45',156,15.48,239,23.71
'45-50',125,12.40,364,36.11
'50-55',112,11.11,476,47.22
'55-60',134,13.29,610,60.52
'60-65',140,13.89,750,74.40
'65-70',56,5.56,806,79.96
'70-75',47,4.66,853,84.62
'75-80',65,6.45,918,91.07
'80-85',51,5.06,969,96.13
'85-90',37,3.67,1006,99.80
'90-95',2,0.20,1008,100.00
'95-100',0,0.00,1008,100.00
'100-105',0,0.00,1008,100.00
*end_report

*report,13,stats,ZnRH,rh_lens
*title,Relative humidity,%

```

```

*format,table,1,7
*fields,maximum,minimum,average,diversified_max,distributed_max,diversified_min,distributed_min
n
*data,528.801,32.844,57.355,526.037,528.801,0.000,205.467
*end_report

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```

*report,13,distribution,ZnRH,rh_other
*title,Relative humidity,%
*format,frequency,21,5,0.0,5.0,100.0
*fields,range,distribution,percent,cumulative_distrib,cumulative_percent
*data
'0-5',0,0.00,0,0.00
'5-10',0,0.00,0,0.00
'10-15',0,0.00,0,0.00
'15-20',0,0.00,0,0.00
'20-25',0,0.00,0,0.00
'25-30',0,0.00,0,0.00
'30-35',0,0.00,0,0.00
'35-40',19,2.26,19,2.26
'40-45',32,3.81,51,6.07
'45-50',80,9.52,131,15.60
'50-55',136,16.19,267,31.79
'55-60',104,12.38,371,44.17
'60-65',107,12.74,478,56.90
'65-70',112,13.33,590,70.24
'70-75',64,7.62,654,77.86
'75-80',38,4.52,692,82.38
'80-85',36,4.29,728,86.67
'85-90',58,6.90,786,93.57
'90-95',34,4.05,820,97.62
'95-100',15,1.79,835,99.40
'100-105',5,0.60,840,100.00
*end_report

```

```

*report,13,stats,ZnRH,rh_other
*title,Relative humidity,%
*format,table,1,7
*fields,maximum,minimum,average,diversified_max,distributed_max,diversified_min,distributed_min
n
*data,476.908,35.226,64.264,471.302,476.908,0.000,217.546
*end_report

```

```

*report,11,distribution,Infil,infil_zones
*title,Infiltration load,W
*format,frequency,29,5,-2500.0,100.0,100.0
*fields,range,distribution,percent,cumulative_distrib,cumulative_percent
*data
'<-2550',0,0.0,0,0.0
'-2550--2450',0,0.00,0,0.00
'-2450--2350',1,0.12,1,0.12
'-2350--2250',2,0.24,3,0.36
'-2250--2150',1,0.12,4,0.48
'-2150--2050',1,0.12,5,0.60
'-2050--1950',2,0.24,7,0.83
'-1950--1850',2,0.24,9,1.07
'-1850--1750',1,0.12,10,1.19
'-1750--1650',2,0.24,12,1.43
'-1650--1550',2,0.24,14,1.67

```

```

'-1550--1450',5,0.60,19,2.26
'-1450--1350',9,1.07,28,3.33
'-1350--1250',3,0.36,31,3.69
'-1250--1150',5,0.60,36,4.29
'-1150--1050',10,1.19,46,5.48
'-1050--950',3,0.36,49,5.83
'-950--850',9,1.07,58,6.90
'-850--750',7,0.83,65,7.74
'-750--650',17,2.02,82,9.76
'-650--550',29,3.45,111,13.21
'-550--450',34,4.05,145,17.26
'-450--350',37,4.40,182,21.67
'-350--250',49,5.83,231,27.50
'-250--150',46,5.48,277,32.98
'-150--50',43,5.12,320,38.10
'-50-50',519,61.79,839,99.88
'50-150',1,0.12,840,100.00
'>150',0,0.0,0.0,0.0
*end_report

*report,11,stats,Infil,infil_zones
*title,Infiltration load,W
*format,table,1,7
*fields,maximum,minimum,average,diversified_max,distributed_max,diversified_min,distributed_min
*data,87.409,-2420.833,-208.648,77.751,87.409,-3153.317,-3258.249
*end_report

*day_to_display,Sat 15 Nov 1980

*report,70,demand,per_unit_time,lens
*title,Energy Demand per Unit Time,W
*format,tabular,24,7
*fields,Time,Heating,Cooling,Lighting,Fans,Small Power,Hot water
*data
'00:30:30',0.0,0.0,0.0,0.0,0.0,0.0,0.0
'01:30:30',0.0,0.0,0.0,0.0,0.0,0.0,0.0
'02:30:30',0.0,0.0,0.0,0.0,0.0,0.0,0.0
'03:30:30',0.0,0.0,0.0,0.0,0.0,0.0,0.0
'04:30:30',0.0,0.0,0.0,0.0,0.0,0.0,0.0
'05:30:30',0.0,0.0,0.0,0.0,0.0,0.0,0.0
'06:30:30',0.0,0.0,0.0,0.0,0.0,0.0,0.0
'07:30:30',0.0,0.0,0.254,0.0,0.0,39.4,0.0
'08:30:30',0.0,0.0,3810.5,0.0,591.3,0.0
'09:30:30',0.0,0.0,4064.6,0.0,630.7,0.0
'10:30:30',0.0,0.0,4064.6,0.0,630.7,0.0
'11:30:30',0.0,0.0,4064.6,0.0,630.7,0.0
'12:30:30',0.0,0.0,4064.6,0.0,630.7,0.0
'13:30:30',0.0,0.0,4064.6,0.0,630.7,0.0
'14:30:30',0.0,0.0,4064.6,0.0,630.7,0.0
'15:30:30',0.0,0.0,4064.6,0.0,630.7,0.0
'16:30:30',0.0,0.0,4064.6,0.0,630.7,0.0
'17:30:30',0.0,0.0,4064.6,0.0,630.7,0.0
'18:30:30',0.0,0.0,4064.6,0.0,630.7,0.0
'19:30:30',0.0,0.0,3810.5,0.0,591.3,0.0
'20:30:30',0.0,0.0,254.0,0.0,39.4,0.0
'21:30:30',0.0,0.0,0.0,0.0,0.0,0.0,0.0
'22:30:30',0.0,0.0,0.0,0.0,0.0,0.0,0.0

```

```

'23:30:30',0.0,0.0,0.0,0.0,0.0,0.0,0.0
*end_report

*report,70,demand,per_unit_time,other
*title,Energy Demand per Unit Time,W
*format,tabular,24,7
*fields,Time,Heating,Cooling,Lighting,Fans,Small Power,Hot water
*data
'00:30:30',0.0,0.0,0.0,0.0,0.0,0.0,0.0
'01:30:30',0.0,0.0,0.0,0.0,0.0,0.0,0.0
'02:30:30',0.0,0.0,0.0,0.0,0.0,0.0,0.0
'03:30:30',0.0,0.0,0.0,0.0,0.0,0.0,0.0
'04:30:30',0.0,0.0,0.0,0.0,0.0,0.0,0.0
'05:30:30',0.0,0.0,0.0,0.0,0.0,0.0,0.0
'06:30:30',0.0,0.0,0.0,0.0,0.0,0.0,0.0
'07:30:30',0.0,0.0,128.8,0.0,116.3,0.0
'08:30:30',0.0,0.0,1931.7,0.0,1745.2,0.0
'09:30:30',0.0,0.0,2060.5,0.0,1861.6,0.0
'10:30:30',0.0,0.0,2060.5,0.0,1861.6,0.0
'11:30:30',0.0,0.0,2060.5,0.0,1861.6,0.0
'12:30:30',0.0,0.0,2060.5,0.0,1861.6,0.0
'13:30:30',0.0,0.0,2060.5,0.0,1861.6,0.0
'14:30:30',0.0,0.0,2060.5,0.0,1861.6,0.0
'15:30:30',0.0,0.0,2060.5,0.0,1861.6,0.0
'16:30:30',0.0,0.0,2060.5,0.0,1861.6,0.0
'17:30:30',0.0,0.0,2060.5,0.0,1861.6,0.0
'18:30:30',0.0,0.0,2060.5,0.0,1861.6,0.0
'19:30:30',0.0,0.0,1931.7,0.0,1745.2,0.0
'20:30:30',0.0,0.0,128.8,0.0,116.3,0.0
'21:30:30',0.0,0.0,0.0,0.0,0.0,0.0,0.0
'22:30:30',0.0,0.0,0.0,0.0,0.0,0.0,0.0
'23:30:30',0.0,0.0,0.0,0.0,0.0,0.0,0.0
*end_report

*report,6,thermal_comfort,comfort,occup_lens
*title,Resultant temperature,degC
*format,tabular,24,7
*fields,Time,lens_void,lens_5_a,lens_mez_a,lense_doub,lens_5_b,lens_mez_b
*data
'00:30:30',11.38,14.42,13.80,13.39,15.65,14.28
'01:30:30',11.12,14.22,13.63,13.24,15.40,14.10
'02:30:30',10.84,14.00,13.44,13.07,15.14,13.91
'03:30:30',10.64,13.82,13.26,12.90,14.93,13.72
'04:30:30',10.59,13.70,13.10,12.77,14.78,13.54
'05:30:30',10.58,13.62,12.96,12.68,14.65,13.37
'06:30:30',10.64,13.54,12.82,12.58,14.60,13.21
'07:30:30',10.60,13.71,12.66,12.14,14.69,13.05
'08:30:30',10.56,13.86,12.82,11.94,15.09,13.39
'09:30:30',10.21,14.25,13.18,12.05,15.40,13.71
'10:30:30',13.24,14.57,13.85,12.60,15.61,14.00
'11:30:30',16.71,15.34,15.34,13.55,16.01,14.69
'12:30:30',18.06,16.11,16.41,14.42,16.62,15.49
'13:30:30',18.36,16.69,16.93,15.11,17.29,16.21
'14:30:30',17.62,16.97,16.91,15.43,17.76,16.62
'15:30:30',15.45,16.94,16.41,15.28,17.88,16.54
'16:30:30',13.06,16.79,15.84,14.66,17.71,16.05
'17:30:30',12.61,16.06,15.32,14.39,17.38,15.66
'18:30:30',12.50,15.68,15.10,14.37,17.11,15.44
'19:30:30',12.22,15.42,14.99,14.34,16.95,15.34

```

```
'20:30:30',11.70,14.81,14.35,13.80,16.04,14.66
'21:30:30',11.05,14.31,13.84,13.32,15.51,14.21
'22:30:30',10.60,14.02,13.55,13.08,15.17,13.95
'23:30:30',10.16,13.72,13.30,12.84,14.83,13.72
*end_report
```

```
*report,6,thermal_comfort,comfort,ocup_other
*title,Resultant temperature,degC
*format,tabular,24,6
*fields,Time,cellular_a,analysis,gen_chem,gen_corid,break_corid
*data
'00:30:30',10.45,11.68,12.64,14.91,10.93
'01:30:30',10.22,11.54,12.44,14.74,10.76
'02:30:30',9.98,11.39,12.25,14.59,10.56
'03:30:30',9.79,11.27,12.08,14.45,10.39
'04:30:30',9.70,11.18,11.95,14.35,10.30
'05:30:30',9.64,11.09,11.83,14.25,10.23
'06:30:30',9.62,10.95,11.72,14.29,10.16
'07:30:30',9.67,10.73,11.56,14.39,10.13
'08:30:30',9.78,10.84,12.13,14.37,9.98
'09:30:30',9.66,10.81,12.63,14.49,9.82
'10:30:30',10.43,10.91,13.15,14.56,10.29
'11:30:30',11.46,11.08,13.72,14.73,10.98
'12:30:30',11.93,11.24,14.11,15.10,11.35
'13:30:30',12.06,11.45,14.35,15.52,11.50
'14:30:30',11.90,11.64,14.45,15.84,11.51
'15:30:30',11.67,11.74,14.49,16.04,11.43
'16:30:30',11.36,11.73,14.49,16.16,11.22
'17:30:30',11.05,11.66,14.44,16.00,11.00
'18:30:30',10.86,11.62,14.40,15.80,10.86
'19:30:30',10.73,11.59,14.39,15.80,10.77
'20:30:30',10.23,11.14,13.51,15.53,10.54
'21:30:30',9.73,10.89,13.01,15.35,10.16
'22:30:30',9.37,10.71,12.58,14.87,9.90
'23:30:30',9.00,10.52,12.23,14.60,9.63
*end_report
```

```
*report,13,relative humidity,ZnRH,rh_lens
*title,Relative humidity,%
*format,tabular,24,7
*fields,Time,lens_void,lens_5_a,lens_mez_a,lens_mez_b,lens_5_b,lense_doub
*data
'00:30:30',57.21,50.11,49.82,48.56,45.90,50.96
'01:30:30',57.63,50.40,49.92,48.70,46.23,51.06
'02:30:30',58.00,50.61,50.03,48.85,46.44,51.13
'03:30:30',57.46,50.46,50.02,48.92,46.24,51.06
'04:30:30',56.20,49.58,49.72,48.85,45.42,50.41
'05:30:30',54.56,48.45,49.03,48.53,44.39,49.43
'06:30:30',53.02,47.20,48.12,47.96,43.16,48.26
'07:30:30',52.27,45.51,47.26,47.08,42.40,48.51
'08:30:30',50.84,43.35,45.67,44.36,39.99,48.28
'09:30:30',53.21,42.06,44.46,43.65,39.11,48.33
'10:30:30',46.50,42.43,43.19,43.54,39.41,47.26
'11:30:30',40.23,40.98,38.91,41.40,38.56,44.53
'12:30:30',37.35,38.48,35.88,38.52,36.51,41.51
'13:30:30',36.23,36.73,34.65,36.75,34.80,39.72
'14:30:30',37.30,36.43,35.25,36.71,34.39,39.59
'15:30:30',41.35,37.27,37.57,37.64,35.10,41.30
```



```
'16:30:30',47.40,38.69,40.34,39.90,36.75,44.73
'17:30:30',48.77,40.70,42.87,41.74,37.71,45.61
'18:30:30',49.08,41.79,42.95,42.19,37.62,44.70
'19:30:30',49.58,42.50,42.70,42.08,37.88,44.28
'20:30:30',51.12,44.42,44.25,44.08,40.53,45.44
'21:30:30',52.48,45.51,44.93,44.52,41.46,46.17
'22:30:30',52.79,45.78,44.82,44.26,41.58,45.99
'23:30:30',53.20,45.99,44.78,44.00,41.80,46.00
*end_report
```

```
*report,13,relative humidity,ZnRH,rh_other
*title,Relative humidity,%
*format,tabular,24, 6
*fields,Time,cellular_a,analysis,gen_chem,gen_corid,break_corid
*data
'00:30:30',60.95,55.93,54.46,48.25,58.81
'01:30:30',61.46,56.11,54.36,48.05,59.16
'02:30:30',61.66,56.10,54.16,47.78,59.29
'03:30:30',60.92,55.64,53.62,47.31,58.79
'04:30:30',58.89,54.51,52.52,46.46,57.28
'05:30:30',56.57,53.04,51.18,45.35,55.39
'06:30:30',54.43,51.60,49.82,43.48,53.54
'07:30:30',53.46,50.60,49.03,42.62,52.22
'08:30:30',53.75,50.15,47.89,41.94,52.56
'09:30:30',56.22,51.72,48.14,41.29,54.63
'10:30:30',54.51,51.85,47.50,41.63,54.01
'11:30:30',50.99,51.21,45.90,40.98,52.28
'12:30:30',48.93,50.23,44.28,39.09,50.82
'13:30:30',49.63,50.75,44.07,37.59,51.09
'14:30:30',51.81,52.12,45.30,37.51,52.71
'15:30:30',53.87,53.29,47.01,38.31,54.33
'16:30:30',55.34,53.83,48.52,39.64,55.43
'17:30:30',54.81,53.23,49.22,40.43,55.38
'18:30:30',53.95,52.13,49.12,40.51,54.53
'19:30:30',54.41,52.07,50.09,40.41,54.61
'20:30:30',55.70,53.19,53.71,41.14,55.21
'21:30:30',56.33,52.53,53.44,41.86,55.19
'22:30:30',56.29,51.85,52.96,46.81,54.65
'23:30:30',56.37,51.29,51.44,46.00,54.30
*end_report
```

```
*report,11,infiltration load,Infil,infil_zones
*title,Infiltration load,W
*format,tabular,24, 6
*fields,Time,lens_void,lens_5_a,lens_mez_a,cellular_a,lense_doub
*data
'00:30:30',-771.12,0.00,0.00,-192.29,0.00
'01:30:30',-851.95,0.00,0.00,-217.26,0.00
'02:30:30',-923.36,0.00,0.00,-239.74,0.00
'03:30:30',-875.92,0.00,0.00,-225.91,0.00
'04:30:30',-768.81,0.00,0.00,-193.58,0.00
'05:30:30',-675.54,0.00,0.00,-164.76,0.00
'06:30:30',-544.36,0.00,0.00,-123.62,0.00
'07:30:30',-345.36,0.00,0.00,-74.22,0.00
'08:30:30',-678.67,0.00,0.00,-243.46,0.00
'09:30:30',-863.43,0.00,0.00,-408.24,0.00
'10:30:30',-1351.74,0.00,0.00,-446.35,0.00
'11:30:30',-1887.35,0.00,0.00,-517.98,0.00
```

```

'12:30:30',-1961.90,0.00,0.00,-497.01,0.00
'13:30:30',-1778.01,0.00,0.00,-428.38,0.00
'14:30:30',-1482.41,0.00,0.00,-344.82,0.00
'15:30:30',-1181.08,0.00,0.00,-311.68,0.00
'16:30:30',-852.81,0.00,0.00,-302.21,0.00
'17:30:30',-840.62,0.00,0.00,-286.01,0.00
'18:30:30',-859.62,0.00,0.00,-274.18,0.00
'19:30:30',-1024.73,0.00,0.00,-261.98,0.00
'20:30:30',-1073.45,0.00,0.00,-218.66,0.00
'21:30:30',-1143.26,0.00,0.00,-272.81,0.00
'22:30:30',-1219.29,0.00,0.00,-302.74,0.00
'23:30:30',-1362.95,0.00,0.00,-350.59,0.00
*end_report

*end_day_to_display

*end_assessment

*end

*Seasonal_summary, abertay 1st winter run

*report,98,energy,performance,aggregate
*title,Integrated demand,kWh/m^2
*format,table,2,6
*fields,Heating,Cooling,Lighting,Fans,Small Power,Hot water
*data,6.177,8.127,4.947,0.000,3.627,0.000
*end_report

*report,98,energy,building_performance,aggregate
*title,Integrated building demand,kWh
*format,table,2,6
*fields,Heating,Cooling,Lighting,Fans,Small Power,Hot water
*data,13347.8,17561.5,10690.0,0.0,7838.7,0.0
*end_report

*End_seasonal_summary

*Seasonal_summary, abertay spring run

*report,98,energy,performance,aggregate
*title,Integrated demand,kWh/m^2
*format,table,2,6
*fields,Heating,Cooling,Lighting,Fans,Small Power,Hot water
*data,1.381,25.193,5.565,0.000,4.081,0.000
*end_report

*report,98,energy,building_performance,aggregate
*title,Integrated building demand,kWh
*format,table,2,6
*fields,Heating,Cooling,Lighting,Fans,Small Power,Hot water
*data,2984.0,54442.9,12026.2,0.0,8818.5,0.0
*end_report

*End_seasonal_summary

*Seasonal_summary, abertay summer run

```

```

*report,98,energy,performance,aggregate
*title,Integrated demand,kWh/m^2
*format,table,2,6
*fields,Heating,Cooling,Lighting,Fans,Small Power,Hot water
*data,0.077,138.351,13.604,0.000,9.975,0.000
*end_report

```

```

*report,98,energy,building_performance,aggregate
*title,Integrated building demand,kWh
*format,table,2,6
*fields,Heating,Cooling,Lighting,Fans,Small Power,Hot water
*data,166.6,298977.2,29397.4,0.0,21556.4,0.0
*end_report

```

*End_seasonal_summary

*Seasonal_summary, abertay autumn run

```

*report,98,energy,performance,aggregate
*title,Integrated demand,kWh/m^2
*format,table,2,6
*fields,Heating,Cooling,Lighting,Fans,Small Power,Hot water
*data,0.505,16.185,3.092,0.000,2.267,0.000
*end_report

```

```

*report,98,energy,building_performance,aggregate
*title,Integrated building demand,kWh
*format,table,2,6
*fields,Heating,Cooling,Lighting,Fans,Small Power,Hot water
*data,1090.3,34976.3,6681.2,0.0,4899.2,0.0
*end_report

```

*End_seasonal_summary

*Seasonal_summary, abertay 2nd winter run

```

*report,98,energy,performance,aggregate
*title,Integrated demand,kWh/m^2
*format,table,2,6
*fields,Heating,Cooling,Lighting,Fans,Small Power,Hot water
*data,5.727,22.073,4.947,0.000,3.627,0.000
*end_report

```

```

*report,98,energy,building_performance,aggregate
*title,Integrated building demand,kWh
*format,table,2,6
*fields,Heating,Cooling,Lighting,Fans,Small Power,Hot water
*data,12376.6,47699.7,10690.0,0.0,7838.7,0.0
*end_report

```

*End_seasonal_summary

*Summary

```

*report,98,energy,performance,aggregate
*title,Integrated demand,kWh/m^2.a
*format,table,1,6
*fields,Heating,Cooling,Lighting,Fans,Small Power,Hot water

```

```

*data,0.000,0.000,23.273,0.000,25.427,0.000
*end_report

*report,74,power,capacity,aggregate
*title,Maximum capacity,W/m^2
*format,table,1,6
*fields,Heating,Cooling,Lighting,Fans,Small Power,Hot water
*data,0.000,0.000,6.202,0.000,6.807,0.000
*end_report

*report,75,emissions,pollutant,aggregate
*title,Pollutant emissions,kg/m^2.a
*format,table,3,6
*fields,Pollutant,CO2,NOx,SOx,Heating,Cooling,Lighting,Fans,Small Power,Hot water
*data,0.000,0.000,20.510,0.000,56.021,0.000
*data,0.000,0.000,0.069,0.000,0.189,0.000
*data,0.000,0.000,0.254,0.000,0.693,0.000
*end_report

*report76,distribution,thermal_comfort,aggregate
*title,Resultant Temperature,degC
*format,frequency,9,6,16.0,2.0,30.0
*fields,range,winter_early,spring,summer,autumn,winter_late
*data
'<16',283,0,0,0,275
'16-18',50,0,0,0,43
'18-20',27,15,0,27,34
'20-22',0,99,0,157,8
'22-24',0,198,144,168,0
'24-26',0,48,275,8,0
'26-28',0,0,42,0,0
'28-30',0,0,18,0,0
'>30',0,0,1,0,0
*end_report
*end

```

Java: Write Once, Run Anywhere

Sun (2005; <http://java.sun.com/>) identifies "Write once, run anywhere" as the core value proposition of the Java platform. Translated from business jargon, this means that the most important promise of Java technology is that the user need only to write an application once in order for it to run on any platform. Anywhere, that is, that supports the Java platform. Fortunately, Java support is nearly ubiquitous. It is integrated, or being integrated, into practically all major operating systems. It is built into popular web browsers, which places it on virtually every Internet-connected PC in the world. It is even being built into consumer electronic devices, such as television set-top boxes, PDAs, and cell phones.

Java: Security

Another key benefit of Java is its security features. Both the language and the platform were designed from the ground up with security in mind. The Java platform allows users to download untrusted code over a network and run it in a secure environment where it cannot do any harm: it cannot infect the host system with a virus, cannot read or write files from the hard drive, and so forth. This capability alone makes the Java platform unique.

The Java 2 Platform takes the security model a step further. It makes security levels and restrictions highly configurable and extends them beyond applets. As of Java 1.2, any Java code, whether it is an applet, a servlet, a JavaBeans component, or a complete Java application, could be run with restricted permissions that prevent it from doing harm to the host system.

The security features of the Java language and platform have been subjected to intense scrutiny by security experts around the world. Security-related bugs, some of them potentially serious, have been found and promptly fixed. While Java's security

is not yet perfect, it has been proven strong enough for practical day-to-day use and is certainly better than any of the alternatives.

Java: Network-centric Programming

Sun's corporate motto has always been "The network is the computer." The designers of the Java platform believed in the importance of networking and designed the Java platform to be network-centric. From a programmer's point of view, Java makes it unbelievably easy to work with resources across a network and to create network-based applications using client/server or multi-tier architectures. This means that Java programmers have a serious head start in the emerging network economy.

Java: Dynamic, Extensible Programs

Java is both dynamic and extensible. Java code is organised in modular object-oriented units called classes. Classes are stored in separate files and are loaded into the Java interpreter only when needed. This means that an application can decide as it is running what classes it needs and can load them only when needed. It also means that a program can dynamically extend itself by loading the classes needed to expand functionality.

The network-centric design of the Java platform means that a Java application could dynamically extend itself by loading new classes over a network. An application that takes advantage of these features ceases to be a monolithic block of code. Instead, it becomes an interacting collection of independent software components. Thus, Java enables a powerful new metaphor of application design and development.

Java: Internationalisation

Java is the only commonly used programming language that has internationalisation features at its very core, rather than tacked on as an afterthought. While most programming languages use 8-bit characters that represent only the alphabets of English and Western European languages, Java uses 16-bit Unicode characters that

represent the phonetic alphabets and ideographic character sets of the entire world. Java's internationalisation features are not restricted to just low-level character representation, however. The features permeate the Java platform, making it easier to write internationalised programs with Java than it is with any other environment.

Java: Performance

Java programs are compiled to a portable intermediate form known as byte codes, rather than to native machine-language instructions. The Java Virtual Machine runs a Java program by interpreting these portable byte-code instructions. This architecture means that Java programs are faster than programs or scripts written in purely interpreted languages, but they are typically slower than C and C++ programs compiled to native machine language. Although Java programs are compiled to byte code, not all of the Java platform is implemented with interpreted byte codes. For efficiency, computationally intensive portions of the Java platform - such as string-manipulation methods - are implemented using native machine code.

Although early releases of Java suffered from performance problems, the speed of the Java VM has improved dramatically with each new release. The VM has been highly tuned and optimised in many significant ways. Furthermore, many implementations include a just-in-time (JIT) compiler, which converts Java byte codes to native machine instructions ‘on the fly’. Using sophisticated JIT compilers, Java programs can execute at speeds comparable to the speeds of native C and C++ applications.

Java 3D: Datasheet

The Java 3D application program interface (API) provides a set of object-oriented interfaces for applications that require high performance, interactive 3D graphics. With the Java 3D API, developers can take advantage of a simple, high-level programming model that enables them to build, render and control the behaviour of 3D objects and visual environments. By leveraging the inherent strengths of the Java language, Java 3D extends the concept of “write once, run anywhere” to developers

of 3D graphics applications. With the introduction of the Java 3D API, developers are able to incorporate high-quality, scalable and platform-independent 3D graphics into Java-based applications and applets.

The Java 3D API takes advantage of existing hardware accelerators via its use of low-level APIs such as OpenGL® and Direct3D®. This layering allows applications written using the Java 3D API to run on any platform with a Java virtual machine (JDK version 1.2 or higher) and an OpenGL or a Direct3D implementation. Support for run-time loaders is included to allow Java3D to accommodate a wide variety of file formats. The Java 3D API benefits developers in a diverse set of application areas including scientific visualisation, animation, web site design, virtual world construction, simulations, training, games, and design automation.

The Java 3D API is an integral part of the Java Media APIs, providing developers the ability to better integrate 2D & 3D graphics, video, audio, image processing, and other multimedia and visualisation.

Java 3D: Simplification of 3D Graphics Application Development

The Java 3D API incorporates a high-level scene-graph model that allows developers to focus on the objects and the scene composition. This allows for rapid application development by freeing the programmer from spending time and effort designing specific geometric shapes and writing rendering code for the scene display.

Java 3D: Ideal for Intranet & Internet Visualisation Applications

The Java platform was designed from the ground up to be a network-centric computing environment. The Java platform includes a full suite of Java enterprise APIs and technologies such as the JavaBeans component, which enables objects to be exchanged over the network. The Java 3D API builds on this by giving developers the ability to do high-end 3D visualisation over the network regardless of the target platform. Java 3D incorporates geometry compression as part of its specification. This allows very large 3D models to be rapidly downloaded over the network for

remote viewing and manipulation, reducing the impact of potential bottlenecks in network bandwidth.

Java 3D: High Performance

The Java 3D API simplifies the application developer's job by allowing the API to perform many mundane tasks such as scene graph traversal or attribute state management. This allows Java 3D implementations to tune and scale the application's scene graph to the underlying hardware for maximum performance. Java 3D also provides three different rendering modes for optimizing an applications execution: immediate mode, retained mode, and compiled-retained mode. In addition, implementations of the Java 3D API are layered to take full advantage of the most appropriate rendering API for a given platform, namely OpenGL or Direct3D, delivering native graphics acceleration. The Java 3D API delivers the performance needed for visualisation and manipulation of very large 3D models through features such as view-frustum culling, execution culling, and multi-threading (MT-hot).

Java 3D: Other Advanced Features

Flexible Viewing Model: An application or applet written using the Java 3D API view model can render images to a broad range of display devices including flat screen displays, stereo displays, portals/caves, and head-mounted displays, all without modification to the code.

Integrated 3D Sound and Graphics: The Java 3D API supports spatial sound as an integral part of the API, providing an immersive experience to the viewer.

Level of Detail (LOD): The Java 3D API includes support for multiple levels of detail, enabling the end-user to view the nearest or most important objects at increased resolutions, thereby, improving both application performance and the user experience.

Support for continuous action devices: The Java 3D API can accept input from continuous action devices, such as trackers used in immersive caves and portals, increasing the interactive capabilities of Java 3D applications.

Java 3D: Programmer Efficiency and Time-to-Market

Java is an elegant language combined with a powerful and well-designed set of APIs. Studies have consistently shown that switching to Java increases programmer efficiency. Because Java is a simple and elegant language with a well-designed, intuitive set of APIs, programmers write better code with fewer bugs than for other platforms, again reducing development time.

Java 3D: Competitive Advantage

Since the Java 3D API is written for the Java platform allowing developers to mix Java 3D and other Java APIs in a single application, developers can take maximum advantage of the Java programming language. Early feedback from application developers indicated that the use of the Java programming language significantly increases the productivity of their programming staff. This results in reduced time to market which, when combined with the advanced feature set of the Java 3D API, provides developers a considerable advantage in the marketplace.

The explanations/definitions below are based on Ames (1997) and Web3D Consortium Web-site (2006).

PointLight Node

PointLight {			
on	TRUE	# exposedField	SFBool
location	0 0 0	# exposedField	SFVec3f
radius	100	# exposedField	SFFloat
intensity	1.0	# exposedField	SFFloat
ambientIntensity	0.0	# exposedField	SFFloat
color	1 1 1	# exposedField	SFColor
attenuation	1 0 0	# exposedField	SFVec3f
}			

Fields.

on

Controls whether the light is on or off. TRUE is on; FALSE is off.

location

The position of the source.

radius

This is the radius of the point light's sphere of illumination. Only shapes inside the sphere of illumination would be affected by the point light.

intensity

Intensity of the light, in the range 0 to 1.

ambientIntensity

The extent to which the light contributes to the level of ambient light. It is only effective for shapes inside the sphere of illumination. 0 means no contribution. 1 means maximum contribution.

color

The colour of the source (given by RGB values as usual).

attenuation

The rate at which the light produced by the source falls off with distance. The brightness of the light at distance d from the source would be inversely proportional to

$$a_0 + a_1 * d + a_2 * d^2$$

where a_0 , a_1 and a_2 are the three values of the attenuation field. The idea is that one juggles around with the values a_0 , a_1 and a_2 until the scene looks ok.

DirectionalLight Node

```
DirectionalLight {  
    on                TRUE          # exposedField  SFBool  
    intensity         1.0           # exposedField  SFFloat  
    ambientIntensity  0.0           # exposedField  SFFloat  
    color             1 1 1         # exposedField  SFColor  
    direction         0 0 -1        # exposedField  SFVec3f  
}
```

Fields.

The on, intensity, ambientIntensity and colour fields are the same as for a PointLight node.

direction

The direction of the light.

The value of this field is a 3-element vector. If the values are x, y, z then the direction of the light is from (0,0,0) to (x,y,z).

For example, the default value of this field specifies a light shining along the z-axis, from the $z > 0$ half towards the $z < 0$ half.

SpotLight Node

SpotLight {			
on	TRUE	# exposedField	SFBool
location	0 0 0	# exposedField	SFVec3f
direction	0 0 -1	# exposedField	SFVec3f
radius	100	# exposedField	SFFloat
intensity	1.0	# exposedField	SFFloat
ambientIntensity	0.0	# exposedField	SFFloat
color	1 1 1	# exposedField	SFColor
attenuation	1 0 0	# exposedField	SFVec3f
beamWidth	1.5708	# exposedField	SFFloat
cutOffAngle	0.7854	# exposedField	SFFloat
}			

Fields.

The fields have the same effect as described for the last two nodes, except for cutOffAngle and beamWidth.

cutOffAngle

This field specifies the maximum angular spread of the cone of light produced by the spot light. It is measured in radians, from the axis of the cone. A small angle describes a narrow beam of light. An angle close to 90° describes a wide beam. The default value is 45°.

beamWidth

This field is the angular spread of the central, brightest part of the beam. It is also measured in radians, from the axis of the cone. The default value is 90°. If the beam width is greater than the cut-off angle, all the beam (as specified by the cut-off angle) is at maximum intensity.

To get the full effect from the lighting nodes described above, one might want to specify that the viewer's headlight is switched off. This could be done by including a

NavigationInfo node with its headlight field set to FALSE.

NavigationInfo Node

```
NavigationInfo {  
    type                "WALK"                # exposedField  MFString  
    speed               1.0                   # exposedField  SFFloat  
    avatarSize          [ 0.25 1.6 0.75 ]      # exposedField  MFFloat  
    headlight           TRUE                  # exposedField  SFBool  
    visibilityLimit     0                     # exposedField  SFBool  
}
```

Fields.

type

The type of viewer navigation.

Standard values are "WALK", "FLY", "EXAMINE" and "NONE".
(More than one type could be given in case the browser does not recognise the first one specified.)

speed

Speed the viewer could move through the world, in units (meters per second).

avatarSize

The width, height and step size of the imaginary figure that represents the viewer (the avatar).

headlight

Controls the headlight. TRUE Is on; FALSE is off.

visibilityLimit

The limit on how far the viewer could see.

If the value is 0, then there is no limit on how far the viewer could see.

By default, the browser would start by displaying the view of the world as it appears from the position (0,0,10), looking back towards the origin.

If one wants the browser to start somewhere else, then one needs to define a Viewpoint node.

This enables one to move the initial viewpoint, to change the direction of view, and to widen or narrow the field of view.

One could give several alternative viewpoints, each with its own name. Most browsers would allow the viewer to change from one viewpoint to another.

Viewpoint Node

```
Viewpoint {  
    position      0 0 10      # exposedField      SFVec3f  
    orientation   0 0 1 0     # exposedField      SFRotation  
    fieldOfView   0.785398    # exposedField      SFFloat  
    description   ""          # field            SFString  
}
```

Fields.

position

Position from which the viewer would see the scene.

orientation

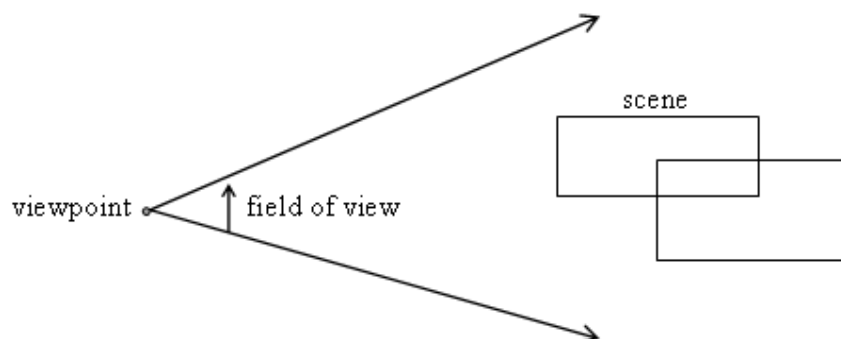
This consists of a direction vector and an angle.

Imagine that initially the viewer is looking in the opposite direction to the z-axis (i.e. in the direction from (0,0,1) to (0,0,0)).

Then the field of view (or ‘camera’) is rotated about the given direction by the given angle.

fieldOfView

The field of view is the angle (in radians) that measures how wide the field of view is. The Figure below illustrates that.



The default angle is 45°.

If one increases the fieldOfView angle, objects in the scene would appear smaller.

This gives a 'wide angle' view.

If one decreases the angle, they would appear larger - like looking through a telescope.

description

This is a name or phrase that would identify this viewpoint when the browser displays a list of the available viewpoints to the viewer.

It is possible to add a distant background to a scene using a Background node. This background would be a part of the world the viewer could see, but never get close to.

The simplest form of background is a single colour.

To give a world a horizon, we could specify a background divided into sky and ground.

The colours of both could be varied as they approach the horizon. More elaborate backgrounds could be produced by providing images of distant scenery in the form of JPEG, GIF or PNG files.

Up to six of these images could be specified. If they are all provided, they form a box that totally encloses the viewer.

Background Node

```
Background {  
    skyColor          [ 0 0 0 ]    # exposedField  MFCOLOR  
    skyAngle          [ ]          # exposedField  MFFloat  
    groundColor       [ ]          # exposedField  MFCOLOR  
    groundAngle       [ ]          # exposedField  MFFloat  
    backUrl           [ ]          # exposedField  MFString  
    frontUrl          [ ]          # exposedField  MFString  
    leftUrl           [ ]          # exposedField  MFString  
    rightUrl          [ ]          # exposedField  MFString  
    topUrl            [ ]          # exposedField  MFString  
    bottomUrl         [ ]          # exposedField  MFString  
}
```

Fields.

skyColor

This specifies a list of colours used for painting a background sphere that encloses the world. Typically this sphere is used to provide a sky for the world. (See the skyAngle field.)

skyAngle

This specifies a list of angles that determines how the sky colours are used to produce horizontal bands of colour.

groundColor

A list of colours used for painting the ground.

groundAngle

A list of angles to be used with the ground colours.

backUrl, frontUrl, leftUrl, rightUrl, topUrl, bottomUrl

If specified, these would be the URLs of files that provide background images. The names `backUrl`, `frontUrl`, *etc.* indicate where the images are located, assuming one is standing at the default initial viewpoint at (0,0,10), facing the origin. So, for example, one would be looking directly at `frontUrl`.

If one turns around and looks along the positive z-axis (with the origin behind one), one would be looking at `backUrl`.

The sky angles and ground angles are measured from the vertical, and should be in increasing order of size.

Suppose for example, two angles are specified, `a1` and `a2`. The list of colours supplied by the `skyColor` field should contain three colours, `c0`, `c1` and `c2`. (The number of colours is always one more than the number of angles.) These colours would be used as follows.

The colour `c0` is used at the angle 0, i.e. directly overhead, and the colour `c1` is used at the angle `a1`. Between the angles 0 and `a1`, the colour changes steadily from `c0` to `c1`.

Similarly, colour `c2` is used at the angle `a2`, and between the angles `a1` and `a2` the colour changes steadily from `c1` to `c2`.

After the angle `a2`, the last colour `c2` is used over the rest of the sphere.

The ground colours and ground angles are used just like the sky colours and sky angles.

However, the ground angles are measured upwards from the direction vertically downwards (which equals 0).

Also, an important difference between the use of ground colours and sky colours is that, after the last of the ground angles, no further ground colours are painted. So sky colours completely cover the sphere, but ground colours normally cover just part of it.

As one would expect, ground colours are always painted on top of the sky colours whenever they overlap.

The mood of a scene could sometimes be enhanced by the addition of a little mist. This is done using a fog node.

The effect of fog is to change the colours of objects.

The further away an object is, the more the browser would change its colour towards the colour of the fog.

Fog Node

```
Fog {  
    color          1 1 1      # exposedField  SColor  
    visibilityRange 0          # exposedField  SFloat  
    fogType        "LINEAR"   # exposedField  SString  
}
```

Fields.

color

The colour of the fog.

visibilityRange

This specifies how thick the fog is. It is the distance at which an object's colour changes completely to that of the fog.

A value of 0 would disable the fog.

fogType

Determines how quickly the effect of the fog increases with distance. Possible values are "LINEAR" and "EXPONENTIAL". The effect of linear fog increases more slowly with distance.

Fog does not effect the appearance of any background that has been provided for a scene.

This means that normally when one uses fog, it is necessary to provide a special background that matches the fog.

Appendix D: *HTML Technology*

The explanations/definitions below are based on Willard (2002).

HTML (HyperText Markup Language) is the document format used on the Web. Web pages are built with HTML tags (codes) embedded in the text. HTML defines the page layout, fonts and graphic elements as well as the hypertext links to other documents on the Web. Each link contains the URL (address) of a Web page residing on the same server or any server worldwide, hence "World Wide" Web.

HTML 2.0 was defined by the Internet Engineering Task Force (IETF) with a basic set of features, including interactive forms capability. Subsequent versions added more features such as blinking text, custom backgrounds and tables of contents. However, each new version requires agreement on the tags used, and browsers must be modified to implement those tags.

HTML is not a programming language, it is a markup language that uses a fixed set of markup tags. A markup language could also be thought of as a presentation language but it is not a programming language. Actions such as 'if this, do that' cannot be initiated as with languages such as Java, JavaScript or C++. However, in order to make pages interactive, programming code could be embedded in an HTML page. For example, JavaScript is widely interspersed in Web pages (HTML pages) for that purpose.

HTML was conceived as a simple markup language to render research documents. It was not envisaged that Web pages would turn into multimedia extravaganzas. HTML pages have been reworked, jury-rigged and extended into full-blown applications. As a result, the source code behind contemporary Web pages is often a hideous concoction of tags and scripting.

Accessing a Web document requires typing in the address, or URL (Uniform Resource Locator), of the home page in your Web browser. The home page is an HTML document, which contains hypertext links to other HTML documents that could be stored on the same server or on a server anywhere in the world.

Web browsers communicate with Web servers via the TCP/IP protocol. The browser sends HTTP requests to the server, which responds with HTML pages and possibly additional programs in the form of ActiveX controls or Java applets.

Standard IPV Metrics

#ESRU, December 2005

#Metrics for Standard IPV

#Max. = 12 metrics

#In where[0], whenDay[0] and whenPeriod[0]

#means group/day/period - [nb] element in array

*standardItems,10,6

Information,'-','-','-','-',Alphanumeric,'-'

Maximum capacity,Aggregated year,Aggregated model,W,Table,'0.0'

Pollutant emissions,Aggregated year,Aggregated model,kg/m².a,Table,'0.0'

Thermal comfort Resultant temperature,Aggregated year,Aggregated model,degC,Frequency,'0.0'

Energy demand per unit time,whenDay[0],where[0],W,Tabular,'0.0'

Energy demand per unit time,whenDay[1],where[0],W,Tabular,'0.0'

Energy demand per unit time,whenDay[2],where[0],W,Tabular,'0.0'

Energy demand per unit time,whenDay[3],where[0],W,Tabular,'0.0'

Energy demand per unit time,whenDay[4],where[0],W,Tabular,'0.0'

Integrated demand,Aggregated year,Aggregated mode,kWh/m².a,Table,'0.0'

Graphical Elements' Colour

#ESRU, December 2005

#Color – RGB

*nbSeries,22,3

Lighting (unctld), 255,255,0

Lighting (ctld), 255,255,102

Fans, 255,255,255

Pumps, 0,0,0

Lifts, 153,153,153

Small Power, 204,204,204

Hot water, 255,102,102

Heating, 255,0,0

Cooling, 0,0,255

Lighting, 255,255,0

Occup,102, 102,102

Too dark, 102,102,102

Poor contrast, 255,153,153,153,153,153

Too bright, 255,0,204

Overall, 255,255,255

maximum, 255,0,51

minimum, 0,51,255

average, 102,255,51

diversified_max, 255,102,102

distributed_max, 255,204,204

diversified_min, 102,102,255

distributed_min, 204,204,255

#yellow

#light yellow

#white

#black

#gray

#light gray

#light red

#red

#blue

#yellow

#dark gray

#dark gray

#contrast pink/grey

#magenta

#white

#red(ish)

#blue(ish)

#green(light)

#pink (light)

#pink (very light)

#blue (light)

#blue (very light)

<IPV_REPORT>

<IPV_definition_file>abertay1.0.ipv</IPV_definition_file>

<GeneralInformation>

<title>Solar study for Abertay</title>

<designOption>open windows 1m</designOption>

<date>Sun Aug 7 16:34:40 2005</date>

<contact>Luis Prazeres (ESRU)</contact>

<location>Glasgow</location>

<climate>OBAN SCO GBR</climate>

<latitude>56.50</latitude>

<longitude>-1.10</longitude>

<synopsis>The abertay top floor design with 1m deep lens grill</synopsis>

</GeneralInformation>

<SimulationPeriodsInfo>

<number>5</number>

<period1>

<name>abertay 1st winter run</name>

<startDate>Thu 7 Feb 1980</startDate>

<endDate>Wed 13 Feb 1980</endDate>

</period1>

<period2>

```

        <name>abertay spring run</name>
        <startDate>Fri 4 Apr 1980</startDate>
        <endDate>Thu 10 Apr 1980</endDate>
    </period2>
    <period3>
        <name>abertay summer run</name>
        <startDate>Wed 23 Jul 1980</startDate>
        <endDate>Thu 31 Jul 1980</endDate>
    </period3>
    <period4>
        <name>abertay autumn run</name>
        <startDate>Fri 3 Oct 1980</startDate>
        <endDate>Thu 9 Oct 1980</endDate>
    </period4>
    <period5>
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    </period5>
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    <day2>Sat 5 Apr 1980</day2>
    <day3>Thu 24 Jul 1980</day3>
    <day4>Sat 4 Oct 1980</day4>
    <day5>Sat 15 Nov 1980</day5>
</SimulationDaysInfo>

```

```

<GroupsZones>
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  <group1>
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    <number>7</number>
    <zones>lens_void, lens_5_a, mezanine, lens_mez_a, lense_doub, lens_5_b, lens_mez_b</zones>
  </group1>
  <group2>
    <name>other</name>
    <number>6</number>
    <zones>cellular_a, analysis, skylight, gen_chem, gen_corid, break_corid</zones>
  </group2>
  <group3>
    <name>occup_lens</name>
    <number>6</number>
    <zones>lens_void, ens_5_a, lens_mez_a, lense_doub, lens_5_b, lens_mez_b</zones>
  </group3>
  <group4>
    <name>ocup_other</name>
    <number>5</number>
    <zones>cellular_a, analysis, gen_chem, gen_corid, break_corid</zones>
  </group4>
  <group5>
    <name>rh_lens</name>
    <number>6</number>
    <zones>lens_void, lens_5_a, lens_mez_a, lens_mez_b, lens_5_b, lense_doub</zones>
  </group5>
  <group6>

```

```

        <name>rh_other</name>
        <number>5</number>
        <zones>cellular_a, analysis, gen_chem, gen_corid, break_corid</zones>
    </group6>
    <group7>
        <name>infil_zones</name>
        <number>5</number>
        <zones>lens_void, lens_5_a, lens_mez_a, cellular_a, lense_doub</zones>
    </group7>
</GroupsZones>

<AssociatedImagesSounds>
    <number>3</number>
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</AssociatedImagesSounds>

<AssociatedVRML>
    <number>1</number>
    <fileNames>abertay1.vrml</fileNames>
</AssociatedVRML>

<SimulationData>
    <Periods>
        <Period1>
            <metric1>
                <report>
                    <id>70</id>
                    <type>diversified</type>
                    <category>capacity</category>

```

```

        <where>lens</where>
    </report>
    <title>
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Interactivity

Hypothesis IT1		An interactive IPV could support exploration and presentation of information to users.
Test		The users interacted with the tool's <i>Content Definition</i> interface and the internal windows of the IPVs to test the hypothesis above (see Figures 4.7-4.14 in Chapter 4).
Results		50% of the users were <i>Very Satisfied</i> and 50% were <i>Satisfied</i> .
Feedback	Against	- one user mentioned that the I ² PV tool was not good for presentation purposes: the default window sizes were too small so the resolution was not good for a professional report. However, the user also said that if the window sizes were increased, some of the graphs could be pasted in a report, but in order to obtain high quality printed material one should take the alphanumeric data and use a graphing package where the best fonts, <i>etc.</i> are available.

	<p>Improvement</p> <ul style="list-style-type: none"> - a user after viewing the graph properties suggested that a button should exist so the best fonts, <i>etc.</i> could be applied (Note: the researcher tried to apply the most effective default fonts, <i>etc.</i>); - users suggested that a layout manager (with the save option) would improve efficiency by avoiding the resizing of the internal cells for presentation; - a user suggested a toggle for the header of the internal cell frame to avoid title repetition, but most importantly to save screen space; - a user recommended that when exploring an IPV display with more than 12 internal cells (3 rows x 4 columns - which need more than 1 tab to display) the tabs and its contents should be automatically rearranged by topics (e.g. energy, thermal, <i>etc.</i>); - user comment: <p><i>“For presentation it would be nice to click a button and all the graphs/images could be printed in A4 size pages (useful to discuss with clients/colleagues and to scribble some notes at the side)...this could actually be a report where the information window could be the content page plus some introduction to the chart results...for presentation the IPV display is a bit too small to present to a client.”</i></p> <p style="text-align: right;">User from Group B</p> <p>(Note: The researcher believes that the user is concerned with rushing to meetings and showing something meaningful to the client)</p> <ul style="list-style-type: none"> - a suggestion by a user was the auto-rearrange functionality: this functionality would work like the icons in the <i>Windows</i> OS – when a graph was deleted the rest would auto-rearrange themselves; and - another suggestion by a user was the functionality to export data to CSV format for further analysis in another package.
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	In favour	<ul style="list-style-type: none"> - users appreciated the different tabs to compare design options, referring to it as being ‘visually effective’; - a user recognised the effectiveness of the speed rate control for dynamic data, because without it would be distracting; - users mentioned that the I²PV tool was optimised for data exploration, where one could drill down into issues by making the internal cells larger for a clearer look; - users said that the I²PV tool was effective to present BS information, because before save or print, one could prepare the display by making some internal cells larger to any rectangular shape, deleting others, <i>etc.</i>; - user comment: <ul style="list-style-type: none"> <i>“The great thing about this tool is that it brings all the issues together in a integrated view not like other programs that are very specific to one issue only...the interaction is great because it allows you to explore the data and drill-down further...the charts are great and clear, therefore, the presentation of results is very good, it looks very professional (much more then in Excel which we use!)...it can hold lots of information (a bit crowded!) but we can go through it with a client/colleague and explain it...in my view the presentation is probably the greatest benefit of using this tool.”</i> <p style="text-align: right;">User from Group B</p> <ul style="list-style-type: none"> - users appreciated the integration of results with interactive and the dynamic functionality was highly effective to explore and present BS information; - users mentioned that when comparing design options (analysis) the interactive and dynamic functionality was also effective; - users said that IPV displays were effective in a client meeting where one could show the status of the project – in addition, the save functionality was useful to paste graphs in a report; - a user mentioned that interactive and dynamic IPV displays were a huge advancement from the original static ones; - a user said that the ability to keep notes inside IPVs (general information internal cell) was useful to remind us to explain critical issues in the client report; and - user comment: <ul style="list-style-type: none"> <i>“Exploration is good, powerful because a lot of information is held in a page...presentation is also good, it can be used to present to clients without using PowerPoint (you even have the text for some notes).”</i> <p style="text-align: right;">User from Group D</p>
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Dynamicity

Hypothesis D1		<p>The comparison of time-varying metrics (e.g. the energy demands of different design options) is enhanced when controlled data dynamicity is available through:</p> <ul style="list-style-type: none"> ▪ clear labelling of axis and data; ▪ provision of chart focus (i.e. when/where) below chart title; ▪ applying grid lines to improve readability; ▪ applying a label colour perception match (e.g. red for heating); ▪ applying differentiation of lines with hatching; ▪ chart interactivity (i.e. zoom, tool-tips, resizable window and chart properties); ▪ warning messages for charts with more than 4 lines (non-staked); ▪ applying toggles to chart features (e.g. stacked/non-stacked); ▪ cumulative amounts information; ▪ critical value indicated with line, sound alerts and chart background colour change; and ▪ information on the exact critical values and dates/times.
Test		The users were shown the <i>Dynamic Comparison</i> interface with the ‘Energy Demand per Unit Time’ (i.e. Power) displayed to test the above hypothesis (see Figure 4.20 in Chapter 4).
Results		25% of the users were <i>Very Satisfied</i> , 50% were <i>Satisfied</i> and 25% were <i>Dissatisfied</i> .
Feedback	Against	<ul style="list-style-type: none"> - a user did not like the dynamic graph claiming that one could obtain the same information with the static one and that it would be easier to understand; - a user found the dynamic graph slightly too technical; and - a user found three lines in dynamic mode too confusing and, therefore, recommended a maximum of two – also, warning clues should be used when above two to advice users of potential confusing graphs;
	Improvement	--

	<p>In favour</p> <ul style="list-style-type: none"> - uses agreed that more than four lines would be very confusing; - user comment: <ul style="list-style-type: none"> <i>“Effective when it is available in the standard view (dynamic display of individual days broken down into individual items - heating, cooling, etc.).”</i> <p style="text-align: right;">User from Group A</p> - a user mentioned that apart from colour, the design options names included in the accumulated amounts area were effective; - a user found it very effective to show the associated CO₂ emissions and costs (electricity/gas usage), and it was equally effective to show temperatures and pointing out the peaks; - users found it effective to compare all design options in one chart; - user comment: <ul style="list-style-type: none"> <i>“The cumulative amount for energy is very good because you know the energy spent up to that time which you could relate to cost or CO₂ emission, etc.”</i> <p style="text-align: right;">User from Group B</p> - user comment: <ul style="list-style-type: none"> <i>“Flexible because you can control the speed and even stop it to take a snap shot, manipulation is good!”</i> <p style="text-align: right;">User from Group B</p> - users found the critical value line, background colour change and sound alerts effective to identify issues; - user comment: <ul style="list-style-type: none"> <i>“All the functions are useful: warnings, cumulative amounts and speed control. The good thing about this is that it is as if you are seeing the simulation results in real time. At each given time you can compare the values for all design options and zoom into an area to investigate issues.”</i> <p style="text-align: right;">User from Group B</p> - a user found the dynamic graph effective because it showed the simulation data in a different way; and
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		<p>-user comment:</p> <p><i>“The dynamic graph helps in understanding the data, like a story line, your attention is drawn to the details of the graph (with the warnings as it goes along)...in comfort assessment the dynamic bit could be used to display the all-year (where a few seconds corresponds to a month). This would make the user memorise certain problematic temperature/month, so they could look into it further!”</i></p> <p>User from Group D</p>
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Colour

Hypothesis C1		Colour is useful to separate design options in terms of performance focus.
Test		The users interacted with the tool's <i>Projects Manager</i> interface to test the hypothesis above (see Figure 4.1 in Chapter 4).
Results		47% of the users were <i>Very Satisfied</i> , 47% were <i>Satisfied</i> and 6% <i>Neutral</i> .
Feedback	Against	- a user was unsure about the need for this feature and its location.
	Improvement	<ul style="list-style-type: none"> - users mentioned that colour definitions should be readily available (Note: available in Help); - a user rightly said the tool must take into consideration that in some performance metrics the larger the value the better (e.g. energy supply by a solar PV panel); - a user found the yellow colour not 100% intuitive and suggested shads of green and red as replacements; - a user suggested further evaluation of design options with numbers within each colour (e.g. 1, 2, 3, <i>etc.</i>); and - user comment: <i>"Is a good idea but a default critical value should already be there so that when you load a project the design options are automatically coloured and if you need to change the critical value you could do it later."</i> <p style="text-align: right;">User from Group C</p>

	<p>In favour</p> <ul style="list-style-type: none"> - users said that the concept was effective because it allowed high level analysis and efficient because one could see at a glance which performance metrics were passing or failing on the criteria; - user comment: <i>“No need to look for numbers, only a straight answer: YES or NO.”</i> <p style="text-align: right;">User from Group E</p> - user comment: <i>“Colour is very useful (traffic light colours) because design options could be ruled out immediately or investigated further where needed to make a decision..”</i> <p style="text-align: right;">User from Group C</p> - users mentioned that the feedback area, which holds detailed information for each performance focus analysis performed previously, was useful because it complemented the colour; - user comment: <i>“Useful that the actual values are on the feedback space (for example I’m rushing into a meeting and through the tool I can see that the initial design was yellow and the new design went to green by a certain percentage.”</i> <p style="text-align: right;">User from Group B</p> - users appreciated the customisation of the yellow band (Note: the default is $\pm 5\%$ the critical value); and - a user found effective that when one clicks on a design option, information showed up on the right feedback area (or if desirable, on a separate interface).
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Geometry

Hypothesis GM1		<p>Geometry should be displayed with the following features:</p> <ul style="list-style-type: none"> ▪ Available in two formats (i.e. wire-frame and solid); ▪ Origin reference, north indication and ground layer (toggled); ▪ Colour to distinguish different zone groups; ▪ Zoom, pan and rotation (direct manipulation with mouse); ▪ List of zones where user is able to build combinations and clear; ▪ Save/print functionality; ▪ Information retrieval; ▪ Viewpoint accelerators; ▪ Colour to distinguish different metric variables (solid only); and ▪ Depth-colour perception (wire-frame only).
Test		The users interacted with the tool's <i>Wire-frame Geometry</i> and <i>Solid Geometry</i> interfaces as well as mock-ups to test the above hypothesis (see mainly Figures 4.15-4.18 in Chapter 4).
Results		88% of the users were <i>Very Satisfied</i> and 12% were <i>Satisfied</i> .
Feedback	Against	<p>Regarding Solid:</p> <ul style="list-style-type: none"> - a user mentioned that VR display should not be used as a lighting simulator (Note: this feature was not intended to be used that way); - a user mentioned that some VR properties, such as fog, were not needed; and - a user found that the amount of data needed to support the VR display was excessive.

	<p>Improvement</p> <p>Regarding wire-frame (WF):</p> <ul style="list-style-type: none"> - a user said that the default position of the WF should be on the ground; - users mentioned that WF and solid displays should be integrated in the same interface and toggled (Note: this also applied to the ‘Regarding Solid’ part); - a user said that a button was needed to bring the model back to a default position and orientation to avoid users getting lost in the WF view; <p>Regarding Solid:</p> <ul style="list-style-type: none"> - users said that in VR properties, directional light should be called sunlight for clarity; - a user suggested that along with the VR display, a sketchy drawing geometry format like the one used in <i>Ecotec</i> (a BS package) would increase effectiveness and, therefore, intuition – needed for architects; - user comment: <ul style="list-style-type: none"> <i>“CFD data could be also analysed here, you could be inside a model and see the arrows floating around you (speed and direction), because this data is available (xyz positions and properties of air flow).”</i> <p style="text-align: right;">User from Group A</p> - a user suggested functionality to display the solid model with different levels of transparency so that the benefits of solid plus being able to see inside are combined; and - a user suggested the advanced use of VR where one changes the composition, send back to the simulation engine and bring the results back.
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	<p>In favour</p> <p>Regarding WF:</p> <ul style="list-style-type: none"> - users said that interactivity and the display of zone combinations (or all model) were crucial in WF; - users mentioned that direct manipulation (rotate, pan and zoom) was a very effective way to interact with geometry; - users said that being able to take a snap-shot (i.e. <i>Save As</i>) or <i>Print</i> a WF display was useful; - users mentioned that light-grey on the back of WF lines increased effectiveness by providing depth perception; - users found that reference point, north indication and ground location increased effectiveness; - users mentioned that WF was useful to check geometry errors; <p>Regarding Solid:</p> <ul style="list-style-type: none"> - a user mentioned that VR properties such as spot and point lights were useful for models with lighting where the tool fed their location, intensity and direction (Note: the researcher believes that this enhances the intuition and, therefore, effectiveness of the display even though VR is not a lighting simulator like Radiance); - a user mentioned that the VR display would be useful to show clients the weather conditions; - users appreciated the technique of exploding the model into different zones, as it showed which zones were adjacent to each other, and therefore, users could explore inside a specific zone and seek detailed information; - users found it useful to investigate glare issues, including natural and artificial lighting (Note: the researcher knows that this is impossible because VR is not a lighting simulator – what it can do is to create the lighting perception and include glare image, from a lighting simulator like Radiance, in the VR scene to increase intuition); - users mentioned that in VR properties, it was effective that the directional light (sunlight) location was provided through a calendar (date and time) plus location on earth (latitude/longitude); - users appreciated that the default VR properties were initially applied and that the user was then able to ‘call’ them from the interface when change was needed; - users appreciated the ground, origin and north direction indicators in VR scene because it increased intuition; - users said that viewpoint accelerator (including one from the sun) increased efficiency; - users found that colour was effective in differentiating surface temperatures of a time step in dynamic mode; - a user mentioned that VR was an effective way to present results and geometry to clients, building controllers, <i>etc.</i>;
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		<ul style="list-style-type: none"> - users said that VR was a powerful way to interrogate the model in terms of performance metrics, occupancy schedules, compositions, <i>etc.</i> – more intuitive and therefore effective (Note: the researcher believes that all information can be retrieved this manner – zone information and surface information – through graphs, images and alphanumeric information with dynamic and interactive functionality); - a user mentioned that VR was effective in relation to sunlight issues linked to the thermal analysis (Note: VR is not a lighting or thermal simulator, it is simply a visualisation tool and therefore it can display third party software data in virtually any format / attribute combination); - user comment: <p style="text-align: center;"><i>“VR could be used as a record of information about the design option.”</i> User from Group B</p> - a user mentioned that VR would be more useful to architects then to engineers (in particular the fog and landscape functionality), however the user also added that natural and artificial lighting might also be useful to engineers. - a user mentioned that VR would be effective for a client meeting under pressure where one could go inside a design option and check its composition; -a user said that VR was useful to pass information to a colleague that did not know about the model (exploration); -a user mentioned that VR provided a better feeling of the building then WF (Note: The researcher also agrees but WF was useful for geometry error check); -users found the use of colour effective in VR to group zones; -users mentioned that VR was the way forward in BS to make it more accessible to people; -users said that dynamic functionality within VR (data over time) was very effective; -users found the integration of glare images in the VR scene very effective; and -user comment: <p style="text-align: center;"><i>“Nowadays walk-through software does not have this functionality (you can’t interrogate!)”</i> User from Group C</p>
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Graphical

Hypothesis G1	Bar graph to compare data with the following features: <ul style="list-style-type: none"> ▪ clear labelling of axis and data; ▪ provision of chart focus (i.e. when/where) below chart title; ▪ application of grid lines to improve readability; ▪ application of a colour-label perception match (e.g. red for heating); ▪ spacing between adjacent bars should typically be less than the bar width to facilitate comparisons; ▪ application of toggles to chart features (e.g. stacked/non-stacked); and ▪ chart interactivity (i.e. zoom, tool-tips, resizable window and chart properties).
Test	The users compared the bar chart with other charts (e.g. pie, star, <i>etc.</i>) and alphanumeric data to test the above hypothesis. The features were tested qualitatively (see Figures 4.7-4.9 & 4.13 in Chapter 4).
Results	75% of the users were <i>Satisfied</i> , 17% were <i>Neutral</i> and 8% were <i>Dissatisfied</i> .
Feedback	Against <p>Regarding the best graph for data comparison:</p> <ul style="list-style-type: none"> - a user mentioned that the star chart was best to compare data because it provided a pattern as well as a comparison (Note: all other users had difficulties understanding the star chart in this context); <p>Regarding the features:</p> <ul style="list-style-type: none"> - a user said that the zoom functionality was not needed in bar charts; and - a user mentioned that a toggle between stacked and non-stacked was not needed because what was important was the benchmark.

	<p>Improvement</p> <p>Regarding the best graph for data comparison:</p> <ul style="list-style-type: none"> - a user mentioned that the bar graph was best to compare absolute values but the pie chart was better when comparing relative values (%). <p>Regarding the features:</p> <ul style="list-style-type: none"> - a user mentioned that the tool-tips should have values with the same precision as the data within the chart's axis for consistency; - a user suggested that for clarity, the focus of the chart should have actual dates instead of the period names; - a user recommended a multi-scale graph for technical people; - a user suggested a degree of intelligence to the tool where for example it would create the optimum default sizes by communicating to the other internal cells – in addition, it should provide appropriate default chart-properties and feature options (Note: the researcher agrees with the user that the next level should include the intelligent component in the tool – I³PV, Integrated, Interactive and Intelligent Performance View); - a user suggested that when using a stacked bar, ranking and displaying the elements from the largest to the smallest value would be more effective; and - user comment: <p><i>“As default the stacked bar is the best because as engineers we are after numbers to present to clients, so in the accumulated chart we can see how much CO₂ and which one is the biggest contributor (tool-tips), so we can work on that to improve the overall number! The reason for that is that the client wants building regs passed, and as far as we reach that goal they are happy with it (does not matter how we do it!).”</i></p> <p style="text-align: right;">User from Group D</p>
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	<p>In favour</p> <p>Regarding the features:</p> <ul style="list-style-type: none"> - users said that toggles allowed flexibility, for example: off grid to avoid clutter, display numbers on top of bars to provide detail data at a glance, collapse an internal cell to a top frame to save space; - users appreciated in particular the toggle to stack and non-stack the bars (when data was stackable); - a user mentioned that the zoom mitigates the issue of wide data ranges; - users appreciated the zoom functionality because it allowed one to take a snap shot of an interesting section of the chart; - users said that colour was effective on the label-match perception (e.g. red for Heating); - users mentioned that the primary colours help differentiate elements and, therefore, would help colour blind users (Note: the researcher can confirm that because a user was indeed partial colour blind); - users appreciated the toggle to switch between different data formats, such as alphanumeric, to determine actual values; - users appreciated the zoom and tool-tips functionalities because it improved the effectiveness of a stacked bar chart; and - users found very useful the stacked bar because it provided an overview at a glance.
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Hypothesis G2		<p>Line graph to show how two continuous variables are related, with the following features:</p> <ul style="list-style-type: none"> ▪ clear labelling of axis and data; ▪ provision of chart focus (i.e. when/where) below chart title; ▪ application of grid lines to improve readability; ▪ application of a colour-label perception match (e.g. red for heating); ▪ differentiation of lines with hatching; ▪ chart interactivity (i.e. zoom, tool-tips, resizable window and chart properties); ▪ warning message for charts with more than 4 lines (non-staked); and ▪ application of toggles to chart features (e.g. stacked/non-stacked).
Test		The users compared the line chart with other charts and alphanumeric data to test the above hypothesis. The features were tested qualitatively (see Figures 4.7-4.9 & 4.14 in Chapter 4).
Results		8% of the users were <i>Very Satisfied</i> and 92% were <i>Satisfied</i> .
Feedback	Against	<p>Regarding the features:</p> <ul style="list-style-type: none"> - a user said that a warning message to indicate that the number of lines was above four was not necessary because the zoom mitigated the overlapping; - a user mentioned that the four line limit rule should be changed to six (Note: the researcher believes that the ideal solution would be an intelligent tool to calculate the level of overlapping and act accordingly); - a user said that the line graph was not useful to find the exact values because they are like ‘images’ to find patterns, therefore, for exact values the alphanumeric data should be used instead (Note: that is why a toggle to change the format exists); and - a user said that the stacked line was enough because one could see the totals as well as the individual values with the tool-tips.

	<p>Improvement</p> <p>Regarding the features:</p> <ul style="list-style-type: none"> - a user suggested a toggle to grey or delete out unimportant lines in order to overcome the overlapping issue; - a user suggested an intelligent tool that ‘remembers’ the choices made by previous users of the same type – this means, recommend to continue with the graph with more than four lines (i.e. ignore rule) or to display the alternative option most chosen; - a user suggested that when the lines were stacked, the hatching should be converted to a point only to reduce clutter; - a user mentioned that an improvement to the stacked line would be to highlight the individual maximums; - a user suggested that when using tool-tips, a vertical and a horizontal line should indicate the values being referred to in the X and Y axis; - a use suggested that it would be useful to have the stacked and non-stacked values over time (e.g. Overall: 0-12 hour = 12 kWhr); - a user suggested that in the stacked line graph one should be allowed to change the order of the bands (i.e. elements) so that the lower one could be read easily, just like a line graph (Note: the researcher believes that an intelligent tool could be used to identify the irregularity level of each element, rank them and put the most irregular on top); and - users suggested the stacked line as default display (Note: this was the preferred opinion for the great majority of users).
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	In favour	<p>Regarding the features:</p> <ul style="list-style-type: none"> - users mentioned that the toggle to change to other formats increased flexibility; - users mentioned that the warning message was clear and informative by providing the metric's name and number of lines to be displayed; - users appreciated the zoom and tool-tips features because it mitigated the overlapping issue; - users appreciated the message to warns users in situations where a line chart would be potentially confusing and thus providing the user with the option to select an alternative format; - users appreciated the zoom feature to capture sections of the chart that were important; - users appreciated the combination of codes (i.e. hatching and colours) for each element as an effective differentiation mechanism; and - users appreciated the toggle to switch from stacked to non-stacked line.
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Hypothesis G3		Counter graph superimposed in a 3D representation to show spatial data, with user interactivity for location focus.
Test		The users were shown mock-ups to demonstrate the above hypothesis. CFD data and daylight availability were used in the tests (see Figures 4.7-4.9 but mainly 4.12 in Chapter 4).
Results		50% of the users were <i>Very Satisfied</i> and 50% were <i>Satisfied</i> .
Feedback	Against	--
	Improvement	<ul style="list-style-type: none"> - a user suggested that for daylight availability, the use of a Virtual Reality world with <i>Radiance</i> images on critical locations would be very effective (Note: the researcher believes that it is an excellent idea, specially in combination with viewpoint accelerators); - a user suggested that an interface should be available prior to the IPV display so that the user could select the desirable location, but once displayed, the user should be able to change the focus by going back to the interface (Note: the researcher believes that the main choices should be made in the normal <i>Content Definition</i> interface where a graphical and interactive pop-up permits location focus selection); - a user suggested that the animation of the data plan should be available in several directions including at an angle; - a user suggested that the counter graph should have smooth lines and not steps; and - a user mentioned that was important to link geometry and results because it was intuitive which would help non-simulation specialists, however, the option of a drop-down menu for BS specialist would increase flexibility.

	In favour	<ul style="list-style-type: none"> - users appreciated the animation attribute making the display effective (e.g. <i>Ecotec</i> simulator); - users appreciated the tool-tips on the counter graph to find detailed values; - users found it effective for client presentations, in particular to non-technical users; - users appreciated the link of the counter graph to the geometry because one could immediately see the location of the critical slice (Note: the researcher collected a report where this technique was applied by the user on a consultancy project); - users mentioned that it was effective to have the focus information (i.e. when and where) on the contour graph in the IPV-page context; - users appreciated the interaction attribute in locating the critical data plans within the geometry interface; and - user comment: <i>“With this method you know where is the data coming from rather than imagining it!”</i> <p style="text-align: right;">User from Group E</p>
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Hypothesis G4		Star graph superimposed in a 3D representation to show Visual comfort information (Guth index), with user interactivity for location focus, detail information and associated glare images.
Test		The users were shown mock-ups to demonstrate the above hypothesis (see Figures 4.7-4.9 but mainly 4.13 in Chapter 4).
Results		59% of the users were <i>Very Satisfied</i> and 41% were <i>Satisfied</i> .
Feedback	Against	<ul style="list-style-type: none"> - a user found a problem with the efficiency because there was a lot of information to go over; and - users found it initially hard in understanding the star graph.
	Improvement	<ul style="list-style-type: none"> - a user suggested that in regards to colour in the detail information bar graph, the ‘overall’ should be more prominent, a rendered colour – in addition, different shades should be applied for different luminance levels and yellow for ‘too bright’; and - a user suggested that an IPV cell should show the plan and the viewpoint next to the graph (instead of having alphanumeric information explaining the location and direction focus on the graph itself) as it would make the display more effective (Note: this researcher believes this idea would sacrifice too much space).
	In favour	<ul style="list-style-type: none"> - users appreciated being able to go back (from the IPV-page) to the interface to change the location and direction focus; - users appreciated the star graph on top of a geometry plan and the availability of detailed information (bar graph and glare images) through interaction on specific angles and for different times of the year or climates; - users appreciated this technique because it allowed one to understand where data origins; - users appreciated the animated and interactive attributes because it made the displays more effective; - a user had applied this technique in a consultancy project, so to have it integrated in the IPV-page was very effective; - a user found that in the detail information bar graph, the dark and bright colour were intuitive; - users appreciated the glare images because they link the results to reality; - users found it a useful manner to discuss results with the design team or clients; and - a user found it very visual and, therefore, architects would find it useful.

Hypothesis G5		The bubble graph is very useful for comparison of design options when weightings and individual metric evaluation are available.
Test		The users were shown a <i>Cost-Benefits Comparison</i> interface to test the above hypothesis (see Figures 4.7-4.9 but mainly 4.19 in Chapter 4).
Results		29% of the users were <i>Very Satisfied</i> , 53% were <i>Satisfied</i> , 6% were <i>Neutral</i> and 12% were <i>Dissatisfied</i> .
Feedback	Against	<ul style="list-style-type: none"> - a user found it too subjective and the graph was difficult to understand in terms of what was being compared, therefore, a table with the individual values for each design option would be more effective; - users found it a bit confusing; and - user comment: <i>"Higher level analysis is something that I would not use because it depends a lot on the user's input...I would rather have direct comparisons of specific performance metrics."</i> <p style="text-align: right;">User from Group B</p>
	Improvement	<ul style="list-style-type: none"> - user comment: <i>"The metric evaluation should be made immediately on the IPV as you look at it, and the ones you do provide evaluation on are the ones that would count for the cost/benefit analysis...the weightings should be asked before the display."</i> <p style="text-align: right;">User from Group A</p> - user comment: <i>"The critical values should be set at a higher level, so the 'meet the goal', 'just meets the goal', etc. would be done automatically, so you only need to provide the weightings. A transparent way on how to calculate the benefit values, using the weightings and the 'meeting the goal', etc. (i.e. is it 0, 1 or 2), is key for the effectiveness of the results."</i> <p style="text-align: right;">User from Group A</p> - a user suggested a 3D display because it would add an extra dimension; - users suggested readily available help here because they did not understand the function initially; - a user suggested the application of a financial model (cost/benefits); and - a user suggested the use of 'benchmark' instead of 'goal'.

	<p>In favour</p> <ul style="list-style-type: none"> - user comment: <i>“Our clients give a lot of importance to consider capital cost, so a bubble chart with the capital cost in X-axis and the energy cost in Y-axis with the benefits dimension as a bubble radius would be very appropriate.”</i> User from Group C - users appreciated having three dimensions (capital, energy costs and benefits) which made the bubble graph an effective display; - users appreciated the concept because it allowed high level manipulation through weightings (flexibility) which was needed to find the best design option; - user comment: <i>“Very, very good, I like it very much, the best I have seen in this IPV, because you can assess the design options not only quantitative analysis but also some designers’ objectives for the design...compares the design options in terms of money and design requirements...is a combination of objective and subjective analysis.”</i> User from Group A - users found it useful to present to clients (cost/benefit analysis); and - user comment: <i>“It compares all design options in an easy way (instant picture of all cases)...gives a task for others to do ... improvements here or there.”</i> User from Group C
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Image

Hypothesis H1		Help system should have images to guide user.
Test		The users compared the tool's <i>Help</i> interface (with images) and a help system with the same information but no images to test the above hypothesis (see Figure 4.2 in Chapter 4).
Results		24% of the users were <i>Very Satisfied</i> and 76% were <i>Satisfied</i> .
Feedback	Against	- a user found that the help interface occupied too much space on the screen, and that maybe a manual would be more effective/efficient (Note: the researcher believes that this option could be made available in the print functionality as <i>Print Manual</i> , but if that was the only option then the interactive features within the Help interface would be lost).
	Improvement	- a user suggested that the text should be linked to specific parts of the images through arrows to increase effectiveness of the explanation.
	In favour	<ul style="list-style-type: none"> - users found that the multimedia techniques applied to images improved effectiveness (Note: the researcher believes that animated tasks to explain to the user how to use certain functionality would be effective as well as animated images that exemplify the dynamic functionality present in the tool); - users found that the images were effective, making the system clearer, because one could relate 'things' back to the actual tool; - users found that images made the process to find information easier, increasing efficiency; and - users appreciated the images because they separate the different parts of text, creating structure and organisation – also, making the display more appealing due to the colour.

Hypothesis 12		Background information delivery should also be through images (e.g. site, preliminary results, etc.).
Test		The users interacted with the tool's <i>Background Information</i> interface to test the above hypothesis (see Figure 4.5 in Chapter 4).
Results		47% of the users were <i>Very Satisfied</i> and 53% were <i>Satisfied</i> .
Feedback	Against	- a user found it too timely to gather all the information (Note: the researcher believes that the information is gathered during the normal course of a consultancy project, so this would be the merging point for background information);
	Improvement	<ul style="list-style-type: none"> - a user suggested an improvement to the image control (e.g. <i>QuickTime</i> control functionality); - a user suggested having only the next button instead of speed rate; - a user suggested a print functionality where all images get printed so that one could scribble on it and bring to a design team or client meeting; and - users suggested a gradual move through the images rather than looping.

	<p>In favour</p> <ul style="list-style-type: none"> - users appreciated the image display in synchrony with sound and alphanumeric formats to increase effectiveness – in addition, applying attributes such as colour and animation improved the display further; - a user appreciated the default display of the background information inside the projects manager’s interface to save screen space, while the user was also able to display it on a separate window to increase flexibility; - users found that thumbnails increased effectiveness (Note: thumbnail images are located on the right side of the interface to allow one to click on it to increase to full size); - users found that animated GIFs were effective in displaying shading patterns (Radiance outputs); - users appreciated the interface because it provided a visual indication about the site and other model simulation areas; - a user found it effective because it was like a slide show to revive one’s memory; - a user appreciated its use in distance project management (site images, <i>etc.</i>); - users appreciated its use for project briefing (initial information); - users found it effective to show to a colleague or client; and - user comment: <ul style="list-style-type: none"> <i>“Including extra information, such as: site images, Radiance animations, previous simulation results, etc. – is very effective because it does not get lost and it’s included in the analysis.”</i> <p style="text-align: right;">User from Group D</p>
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Hypothesis I3		IPV integration of third party software image results should be supported (e.g. CDF analysis).
Test		The users interacted with the tool's <i>Content Definition</i> interface and the internal window where CFD data was being displayed to test the above hypothesis (see Figures 4.7-4.8, 4.10-4.11 & 4.13 in Chapter 4).
Results		86% of the users were <i>Very Satisfied</i> and 14% were <i>Satisfied</i> .
Feedback	Against	- a user did not find useful the % information of images played.
	Improvement	<ul style="list-style-type: none"> - a user suggested that instead of the % information, one should have the time or location; - a user suggested the controls to be like in <i>QuickTime</i> software; - a user suggested the controls to be in a pop-up window to provide more space for images; - a user suggested that one should be able to display several image cells in the IPV-page without interacting so much with it (Note: the user is referring to the need to stop all cells at a certain point in the loop); and - a user suggested the use of a pop-up interface with the model geometry where the user could choose the location and time.
	In favour	<ul style="list-style-type: none"> - users appreciated the animation attribute for time varying and spatial data (effective in client presentations); - users appreciated the integration of third party results in the IPV-page; - users appreciated being able to stop on a set of results and invoke the IPV save or print functionality; - users found the control of results display effective: image resize and speed; - user comment: <ul style="list-style-type: none"> <i>"The excellence of this tool is that it brings together results from other software packages (e.g. CFD images) that are linked or related to other performance metrics."</i> User from Group B - users appreciated being able to present several cells in the IPV-page at different times or locations; and - users found it easy to load, control (speed) and rearrange (resize) images.

Alphanumeric

Hypothesis A1		Text should be in non-capital letters, Serif font and not underlined (except hyper-link) for ease of reading.
Test		The users compared a <i>Help</i> system with the above features and a Help system with the same information but different features to test the above hypothesis (see mainly Figures 4.1-4.6, 4.18-4.20 & 4.23 in Chapter 4).
Results		73% of the users were <i>Satisfied</i> and 27% were <i>Neutral</i> .
Feedback	Against	<ul style="list-style-type: none"> - all users preferred Arial font instead of Serif because it seemed bigger (for the same font size) and less hard on the eye and, therefore, easier to read; and - a user mentioned that the text could be underlined, in capital letters or bold if it conveyed an important piece of information.
	Improvement	<ul style="list-style-type: none"> - a user suggested that long text should be avoided because decreased readability; <p>Other alphanumeric related issues:</p> <ul style="list-style-type: none"> - users suggested the word-search functionality to increase efficiency; - a user suggested the use of multimedia techniques (such as dynamic display of text) to attract user attention and reduce display space; and - a user suggested (when applicable) that text should be linked to specific parts of images to increase effectiveness.
	In favour	<ul style="list-style-type: none"> - the majority of the users were annoyed if text was underlined without being a hyperlink because this was misleading; <p>Other alphanumeric related issues:</p> <ul style="list-style-type: none"> - user appreciated the inter-links between different parts of the text to increased efficiency; - users appreciated the hyperlinks to drill-down into detail information to increase insight; and - users appreciated the tool-tips for information retrieval to increased insight.

Hypothesis A2		The treatment of time should be via a calendar.
Test		The users compared a year calendar with highlighted simulated periods/days and the same information in alphanumeric data format to test the above hypothesis (see Figure 4.4 in Chapter 4).
Results		24% of the users were <i>Very Satisfied</i> , 41% were <i>Satisfied</i> , 29% were <i>Neutral</i> and 6% were <i>Dissatisfied</i> .
Feedback	Against	<ul style="list-style-type: none"> - a user found alphanumeric data more concise; - users said that the calendar showed unnecessary months; and - a user mentioned that the calendar was distracting, messy and not concise.
	Improvement	- users said that the calendar format could improve if the fonts were larger (less cramped).
	In favour	<ul style="list-style-type: none"> - a user saw merit in both formats, where the initial display would be in alphanumeric format and specialised displays in calendar format; - users appreciated that the calendar could trigger other functionality, such as change of simulation focus or be linked to weather data; - users appreciated the calendar because it was more visual/graphical, one could convey information very quickly, and provide a good summary; and - users appreciated the colours to separate the different periods/days.

Hypothesis A3		Search time decreases and flexibility increases when a projects manager is embedded in the tool. In addition, message alerts avoids user errors.
Test		The users interacted with the tool's <i>Projects Manager</i> interface to test the above hypothesis (see Figure 4.1 in Chapter 4).
Results		35% of the users were <i>Very Satisfied</i> , 47% were <i>Satisfied</i> , 12% were <i>Neutral</i> and 6% were <i>Dissatisfied</i> .
Feedback	Against	<ul style="list-style-type: none"> - a user said that the operative system could do the same job; and - a user mentioned that the project/design option names were not very intuitive because they depended on the names given by the simulation user.
	Improvement	- a user said that instead of messages to avoid user errors, some of the selection menu options should be greyed-out depending on the situation.

	<p>In favour</p> <ul style="list-style-type: none"> - users appreciated informative and clear messages to avoid user errors; - users appreciated the interface because it was similar to <i>Windows Explorer</i> which they were familiar with; - users appreciated the process of opening/closing objects (i.e. projects or design options); - users found it an effective manner to structure the important information for a project; - users appreciated the control over the display; - users appreciated that it was not necessary to write paths, instead one could browse to the directory (when folders/files were not in standard locations); - user comment: <ul style="list-style-type: none"> <i>“It’s very effective because it brings together the design options of a project even if the design option files are not in the same folder in a local drive. It allows me to load design options (that belong to the same project) from different locations, say Glasgow and London offices without coping / transferring them.”</i> <p style="text-align: right;">User from Group B</p> - users appreciated the fact that it handled an unlimited number of projects and design options; - users appreciated that the tool loaded the design option names linked to the project name from the IPV content file instead of the design option file names which might not give enough clues to differentiate them; and - user comment: <ul style="list-style-type: none"> <i>“It’s good to have all this information in a location, better than using the Linux’s file manger because you might have many files in a folder and you can easily get confused with which one is which!”</i> <p style="text-align: right;">User from Group D</p>
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Hypothesis A4		Alphanumeric data should be grouped, structured, spaced and aligned to decrease search times.
Test		The users interacted with the tool's <i>Content Definition</i> interface to test the above hypothesis (see mainly Figure 4.6 in Chapter 4)
Results		65% of the users were <i>Very Satisfied</i> and 35% were <i>Satisfied</i> .
Feedback	Against	--
	Improvement	--
	In favour	<ul style="list-style-type: none"> - in general the users were impressed with the structure and organisation of the data in the interface – they found the organisation of the different data sections by data-trees, tables and drop-down menus to be effective; - users found the flow of usage (left to right) effective, where the available metrics were on the left, the selection customisation in the middle and the table to be displayed on the right; - users found the interface easy and quick to use; - users appreciated not having pop-up windows to block the main interface view; and - users enjoyed the flexibility (full control over the display). <p>(Note: The same techniques were applied in other interfaces of the tool, such as the <i>Help</i> system and <i>Projects Manager</i>)</p>

Sound

Hypothesis S1		Experiential appraisal for acoustics assessment.
Test		The users interacted with the tool's <i>Content Definition</i> interface and the internal window where the acoustics functionality was held to test the above hypothesis (see Figure 4.14 in Chapter 4)
Results		70% of the users were <i>Very Satisfied</i> , 24% were <i>Satisfied</i> and 6% were <i>Neutral</i> .
Feedback	Against	<ul style="list-style-type: none"> - an engineering firm would not use it because it was too time consuming (maybe an acoustics consultant would); - not sure about the benefit to the client because it was too subjective; - it requires good sound equipment to reproduce the right quality; - user comment: <ul style="list-style-type: none"> <i>"We would present a chart with the reverberation time vs. frequency or even less, a couple of figures to the client to prove that does not exceed the max regs."</i> User from Group B - to create such an effect in the sound file would not be easy (Note: the researcher believes that this is out of scope of the hypothesis); - architect firms normally call the acoustics engineer and only want a score value saying that a project passed or failed; and - some people just wanted to know if it was within the limit of the regulations. <p>(Note: The researcher believes that a problem might occur if this technique was applied alone because the users might have listening difficulties)</p>
	Improvement	<ul style="list-style-type: none"> - the sound has a different user base, maybe musicians - acoustics engineers would rather have the reverberation time vs. frequency graph.

	<p>In favour</p> <ul style="list-style-type: none"> - the sound decay experience was effective alongside key values (e.g. reverberation/frequency); - clues about the sound source and receiver's locations were essential (small interface with the possible locations for source and receivers); - it was effective because the sound could be any type - a music track, speech or other; - user comment: <ul style="list-style-type: none"> <i>"The quality of the sound that reaches the listener depends on the ray traces of the sound wave (there are software that does that) and then manipulate the sound file to provide that effect would be very effective."</i> <p style="text-align: right;">User from Group A</p> <ul style="list-style-type: none"> - effective because one could experience the sound quality the listeners would experience in the room; - one could compare design options; - sound would help inexperienced people in acoustics; - this would bring things to the next level; and - user comment: <ul style="list-style-type: none"> <i>"The sound would be good to explain to a client, –why they can't have it curved!"</i> <p style="text-align: right;">User from Group C</p>
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Hypothesis S2		Sound alert to flag a performance metric above a critical value.
Test		The users interacted with the tool's <i>Content Definition</i> interface and the internal windows with the charts where the sound alert was set up for to test the above hypothesis (see Figures 4.6-4.7 in Chapter 4)
Results		25% of the users were <i>Very Satisfied</i> , 31% were <i>Satisfied</i> , 25% were <i>Neutral</i> and 19% were <i>Dissatisfied</i> .
Feedback	Against	<ul style="list-style-type: none"> - the sound did not add anything useful; - to flag a critical value and to complement the sound, the background colour change was too much, maybe only colour on a corner of the graph or the line with red, green and yellow as per the <i>Project Manager</i>; - instead of sound, a message with the number of cases that failed would be more effective - then a tab could change colour to indicate that at least one case failed which would be useful if many cases exist.
	Improvement	<ul style="list-style-type: none"> - to complement the sound, the line type/colour could be changed to dotted/red if above critical; - user comment: <p style="text-align: center;"><i>"I would prefer to set critical values at the project level (like project targets that apply to all design options) ...editing critical values in content definition can bring errors from the users' input."</i></p> <p style="text-align: right;">User from Group A</p> - linking the I²PV tool with a database with typical critical values (building regs as the default values) would be effective; - sound should be like a Boolean value (YES or NO). If YES, only one sound alert and if NO, no sound alert; and - an effective improvement to complement the sound would be the display of 'critical value = X units' on top of the line.

	<p>In favour</p> <ul style="list-style-type: none"> - the sound was not very important, but it highlighted the number of failed metrics; - user comment: <p><i>“Very useful and it makes sense, because the sound first gives the number of metrics above critical, the colour show where they are and the line show how much above critical are they...in terms of priority I think the 3 work well together.”</i></p> <p>User from Group A</p> - the priority of the three alerts was colour, line and sound; and - the sound was effective because some users might be colour blind (Note: the researcher believes that it is crucial to apply a combination of formats/attributes for the same purpose because it increased effectiveness and efficiency).
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Hypothesis S3		Voice annotation to deliver general information.
Test		The users interacted with the tool's <i>Background Information</i> interface to test the above hypothesis (see Figure 4.5 in Chapter 4).
Results		43% of the users were <i>Very Satisfied</i> , 38% were <i>Satisfied</i> , 13% were <i>Neutral</i> and 6% were <i>Dissatisfied</i> .
Feedback	Against	<ul style="list-style-type: none"> - some firms would not like the sound to be played because of noise pollution for colleagues (Note: although headphones would solve this problem); - the speech might be useful in an architecture firm but not in an engineering firm (more effective if one explains the images directly to the client); and - the process to record the sound and include all the images might be time consuming (Note: the researcher believes that the user was wrong here - almost all mobiles now have recording functionality plus wireless technology to transfer files to a laptop).
	Improvement	<ul style="list-style-type: none"> - what was in sound format should be also be available in text format (Note: the researcher believes that this would defeat the purpose of greater speed, in relation to recording 'on the go' instead of writing and listening 'on the go' instead of reading – however the researcher understands the difficulties of searching for details in a sound file; and that is quicker to read than to listen but with the downside that the visual channel would be blocked); - it would be useful to also have the text because it would help with the writing of client reports; - in a business the text is important to have for legal reasons; and - speech was far preferable but the text should also be available for future reference. <p>(Note: If a sound file exists for a particular still (or animated GIF) image, the user could drill-down into it to get a better insight on what is being displayed)</p>

	<p>In favour</p> <ul style="list-style-type: none"> - sound in synchrony with images and text (not the sound transcript) was effective; - it was quicker to record a memo than to write a memo; - the sound was effective because one could look at images while listening to the spoken voice; - the combination of media techniques: sound, images (still and animated) and text was an effective way to convey a message; - one could obtain a large amount of information in a second with the multimedia techniques (better than just text which we normally use); - user comments: <ul style="list-style-type: none"> <i>“It’s also nice to relax and listen to spoken voice and see some images rather than read reports and text.”</i> User from Group B <i>“I see the most benefits in the flexibility, because of the briefing of many projects involve some initial information, models, images, plus the politics of a job –you don’t know what has been promised before or said before, so someone recording a meeting or a conversation is good! This would educate the young engineers that do the simulations and the senior engineers as well.”</i> User from Group B - it was generally a good idea – visual and audio; - sound was much more useful than text, one could really have an idea about the project quickly; - for an architect firm, a good use of the sound could be to record the sound of the site - countryside sound or the urban sound - because this could affect the simulations built; - for an architect firm, the sound could be used to get a brief on a project along with a PowerPoint presentation; and - user comment: <ul style="list-style-type: none"> <i>“Useful if there are different teams working on the same job with some distance from each other – site (or extra information) records and spoken records would be invaluable! Good for distance project management.”</i> User from Group C
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