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Simultaneous presentation of measured and calculated environmental results

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ABSTRACT: Continuous measurement of internal and external environmental parameters is critical to our understanding of how buildings perform. Yet, the quantity and variety of time-series data can be quite overwhelming as well as onerous to decipher and present. In addition to this, is the fact that several of the collected data are useless in their raw format unless processed through algorithms to obtain identifiable and meaningful results.

These circumstances challenge the conventional way we present accumulated data and their processed outputs in order to get a better understanding of how and why the environmental performance occurred. It would be ideal if all of the collected and processed data could be presented in a simultaneous, yet, useful format. It is exactly the intention of this paper to suggest and present such a process as well as its format.

An example case study is provided where several parameters (air velocity, mean radiant temperature, humidity and air temperature) are measured periodically to calculate a time-series of internal comfort performance. However, external conditions of solar radiation and solar position as well as air temperature drive the interior building surface temperatures and help to explain the end result of internal comfort.

A program has been written to present the various sets of data graphically, in an integrated manner, animated as a function of time. The animation shows solar position, a cursor scanning weather data, the changing infra-red image and a representation of the resulting internal comfort performance throughout the monitored period.

Conference themes: Architectural
Keywords: building measurement, building performance, computer animation

INTRODUCTION

Previous papers by the first author have suggested the need for building performance measurement in situ. Other sources have endorsed the need for 'evidence-based' measurements as well. Newton (2008) acknowledges that our federal governments have failed to consider and compose a method for rating actual building measurement. Hawken et. al. (1990) state, "systems without feedback are, by definition, stupid". So if our building process uses no feedback we cannot learn from experience. Information must be gathered and fed back into future design work where it can initiate development by providing assessment of technologies, design options and complete building concepts (Luther & Schwede, 2006). R. Hyde, et.al. (2007), state that such knowledge generation is required by good professional practice, required by RAIA, as well as by AIA (American Institute of Architects), but is seldom performed systematically.

In response to the above needs, a building performance measurement program was assembled with support from a Victorian Science Technology and Innovation grant. The Mobile Architecture and Built Environment Laboratory (MABEL) has introduced a program to the industry to guide building stakeholders to achieve performance above and beyond present rating systems. It should be noted here that actual reporting of MABEL results and cases studies are to be found elsewhere.

In its four years of operation, MABEL has undertaken the measurement of over 30 buildings including offices, schools, hospitals, airports and houses. Projects have ranged from Darwin to Hobart and from Brisbane to Melbourne. What is most encouraging is that the European Commission has identified a similar need for action represented by developing an on-site building performance assessment standard. There, a committee has been established for the development of a standard on 'Criteria for the Indoor Environment including thermal, indoor air quality (ventilation) light and noise' (CEN Standards, 2004). Here, MABEL continues to develop its measurement process and data collection methods, to find an 'acceptance niche' within building rating systems, and to disseminate its knowledge in a 'standardized' format acceptable to the industry.

Yet, we are in the early days of a rating tool involving in situ measurement for Indoor Environmental Quality (IEQ). What is lacking is a critical mass of research in this area with experience of actual building measurement methods and reporting. Furthermore, it is the development of a reporting method and its measurement criteria that is so important.

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The authors believe that a conventional time-series graph approach misses and conceals information when reviewing results.

This paper tries to confront the complexity of measurement and to seek a simplified method of its reporting through an animation of results. It is not suggested that the following method become the actual form of rating but rather, by analysing existing collected data in pursuit of identifying rating parameters, a possible pathway is explored.

1. BACKGROUND

In 2006 the MABEL team investigated three houses in Darwin, NT, during the severe wet-season in February. For this project we intended to collect data to validate an energy and thermal simulation package (Accurate®) for buildings in the tropics. A similar project involving MABEL, the CSIRO, Sustainability Victoria and the Building Commission has been conducted on a mud brick house in Victoria. For that project, external weather and solar data as well as air exchange rates, room temperatures (dry-bulb and global) interior air temperature stratification and surface temperatures were measured (Delsante, 2007). The calculated (simulated room air temperatures) very closely modelled the actual result. Most importantly, the trends in temperature rise and fall were mirrored accurately.

For the Darwin project, three different house types were measured: total concrete, block-work and elevated. These houses all underwent measurement periods when each house was fully locked up and when it was open for natural ventilation. Again, it was the intention to collect data input variables as well as ventilation and interior resulting temperature results to validate the simulation package (Accurate) under chosen operational modes. The particular challenge was to determine whether the Accurate ‘thermal engine’ could cope with high natural ventilation rates and provide temperature trend data similar to measurements.

2. MEASURED DATA & RESULTS

To appreciate the developed animation programming of simultaneous data presentation, it is useful to become acquainted with the graphical output presently used in the reports. A brief summary follows regarding the various instrumentation and data collection categories.

2.1. Weather & Solar Data

It is fundamental to every Indoor Environmental Quality (IEQ) measurement to consider the external weather and solar conditions under which its interior response has occurred. Hence, the MABEL facility measures the external factors, direct and global solar radiation, direct and global illuminance, temperature, humidity, pressure, wind direction and velocity. These are averaged over a short period, typically one or fifteen minute intervals. Weather variables are applied to various data analyses and calculations such as:

- External temperature for the Adaptive Model of Thermal Comfort
- Wind speed and direction for the analysis of air exchange rates under natural ventilation and/or infiltration.
- Daylight factor or daylight ratio – external daylight availability to an interior daylight measurement.
- External background noise compared to that measured internally.
- Solar radiation, temperature, wind and humidity data-sets for thermal and energy validation simulations.

![Image](image_url)

Weather @ the Elevated House

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There are, no doubt, many other reasons to use the external data not mentioned nor acknowledged in this report. What is important is that such reasons may be recognised more easily through the simultaneous presentation of environmental data and calculation. Figure 1 illustrates the weather trend plotted with indoor air temperature. The ‘adaptive model’ comfort bands (by Brager and deDear, 2000) are also shown to indicate when internal comfort may be achieved during particular external conditions.

2.2. Temperature & Comfort

 Temperature and comfort may be shown in several forms relating to different comfort models, the most popular being the Fanger (static) model of comfort or ISO 7730 (1994). A result of this model is shown in Figure 2 below. This model is designed to show both the Predicted Percentage Dissatisfied (PPD - 80% satisfaction, darker outer grey band, and 90% satisfaction lighter inner band) as well as the Predicted Mean Vote (PMV). It is noticed that comfort is not often within the limits under this model.

Under the ‘Adaptive Model’ of comfort it is realised that comfort may be within reach for a substantially longer period of time (Figure 3). What is not indicated in the presentation of this graph is when (by time stamp) the comfort level is achieved.
2.3. Ventilation Rates
Ventilation analysis utilizes a tracer gas within a confined area of the building. Using the decay method, Air Changes per Hour (ACH) can be established. The particular portion of the building may or may not be open to the exterior; yet, it is still important to the analysis to know the external wind conditions and the pressure differential between the exterior and interior environments. As shown in the graph (Figure 4) the interior ventilation air change rate is somewhat related to the change in wind speed. However, if studied carefully it is noticed that wind direction also has an effect on ACH for this room. This chart is an example of how not to present this data effectively; how to do so needs further analysis.

![Figure 4 - Interior Air Change Rates Accompanied by Wind Speed and Direction](image)

2.4 Thermal Imaging
The intention of thermal imaging is to compare surface temperatures with the solar radiation gains or surrounding air temperatures. Surface temperatures are an indication of radiation affecting mean radiant temperatures in assessing thermal comfort. Therefore, thermal imaging is a great visual tool for indicating areas of temperature (hence radiative) imbalance. Figure 5 is an example of a window region that would be a cause of great thermal stress to an occupant sitting close by. In 24 hours sampling at fifteen-minute intervals, 96 of these images are collected.

![Figure 5 - Thermal Imaging the Interior of a Living Room](image)
3. AN ANIMATED ANALYSIS

3.1. Reasons and Intentions of Animation

Modelling the behaviour of a building operating in an environment is difficult, because the system is open, with many uncontrolled variable factors. Weather data and sun position represent the external environment which drives the internal behaviour. In turn, this internal behaviour is represented by measurements of temperature, humidity, air flow etc. and by thermal images of rooms in the building.

Such data is usually collected periodically, for example, every 15 minutes, and if numerical, can be plotted graphically as a function of time. At a glance, characteristics of the data, such as maxima and minima, or steady behaviour, can be determined from such graphs. Derived functions, such as the ASHRAE Comfort Index, can also be plotted.

However, a series of images, such as thermal images of a room, being two-dimensional, cannot be plotted as a function of time and needs to be displayed in a time sequence, as an animation. To relate the images to the plotted weather data, a cursor is displayed on the graph marking the time of the displayed image. Similarly, the sun’s azimuth and elevation can be animated on a plot of the sun’s path.

Such animation immediately unifies the various data: the thermal image can be related to the weather data prevailing at the same time and to the sun’s position. The comfort index can be read and reconciled. The data become accessible at a glance.

3.2. The Programming Background

The target environment is Microsoft Windows .NET Framework, which is a set of libraries which provide computing system services. This provides consistent support for software development independent of the language selected. Indeed, a complex software application can be developed in several different languages as needed. For example, we use two languages in this application, Eiffel and Microsoft Excel. The result is a program which runs using the Windows system just like any other program.

We have chosen to develop software using an Object-oriented method (Meyer, 1996). The outcome of Object-oriented methods is modularisation of the software into a system of “objects” which maintain and manipulate their own data, while also communicating with other objects as required. This decentralisation allows the design of a software system to be separated from the design and implementation of the code in each object. In other words, the design is independent of the programming language chosen (the coding). Being modular, the various parts of the system can be developed separately and then brought together. Indeed, a flexible system could be based on “plug-in” modules so as to cater for the handling of unanticipated forms of data, although we have not done this at this point.

The programming language chosen is Eiffel (ECMA, 2006), currently the most advanced object-oriented language measured in terms of the object-oriented concepts supported, while at the same time, using a syntax as simple and as readable as Pascal. Because it supports Object-oriented concepts so well, it also doubles as an analysis and design tool. The programming environment used provides a graphical view of the system as well as a text view of the code.

The main problem to be solved in this application is the coordination of the different items of data. Ensuring the data is valid can be difficult and is error prone, and it may need to be put into a suitable format, but it need only be done once. Apart from that, the weather data time interval needs to be specified; the solar data needs latitude, longitude and time zone; and images need time information. Only when all of this information is specified consistently can the items be viewed as a whole. The application provides a comprehensive configuration dialog to provide this information.

3.3. The Application & Results

The application opens a main window which holds four child windows. Each displays one set of data: a series of infrared images; a time-series of weather data, indicating a time by means of a cursor; an azimuth-altitude display of the sun’s local position; and an animated indicator of ASHRAE comfort.

Before the child windows can be displayed, configuration information needs to be entered by means of a dialog box as shown in Figure 6. These are

- latitude, longitude and time zone of the site for the solar display;
- the starting date and time for the infra-red image data, as well as the time interval between images;
- the name of the folder holding the infra-red images;
- the name of the comfort data file; and
- the name of the weather data file.

Dates and times in the various files need to be checked for consistency with each other and the dates.

After entering the required data, the configuration dialog is closed and the main window opened. The first infra-red image is displayed, the weather data for the whole time interval plotted, the sun’s path plotted and an image of the sun drawn to show the current solar azimuth and altitude. The initial comfort data is also displayed.

Clicking on the display advances it to the next infrared image, moves the cursor on the weather data and updates the sun’s location and the comfort display. The application can be set to update automatically providing hands off animation.

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A snapshot of the display is shown in Figure 7. In the top left hand corner is the thermal image of the room. Beneath that, is the external weather data. In the top right corner is the indication of personal comfort according to the ASHRAE standard. In the bottom right corner is the display of the sun’s position in the sky and its path throughout the day. The vertical cursor on the weather data links it to the time the thermal image was taken and the sun’s current location. The displays can be advanced in time manually or automatically.

As a result, the application is a tool for viewing several different kinds of data in a coherent and understandable manner. Results are readily available in a non-technical form. The application is not special purpose for this project; it can be applied to any system in which this data is collected. Furthermore, the system can be redeveloped so that the application can accept “plug-ins” allowing unanticipated forms of data to be accommodated, without a major project to re-develop the application. For example, a plug-in could be developed to handle the wind data as presented in Figure 4.

Finally, the benefits of presenting collected data, represented by individual charts and images and calculated numerical quantities in a single synchronised display are:

- all the data is presented as a snap-shot in a single display
- an aid to improving the perception (outcome) of actual thermal performance
- the causes of a particular thermal outcome may become more apparent
- it provides for an uncluttered and optimised form of multiple sets of data
- it eliminates erroneous conclusions often made by incorrectly matching up data from different charts and images.

CONCLUSION

Presenting measured and calculated results on building performance is a task that ‘should not be taken for granted’. It is a challenge to communicate results of performance even at the most basic level of temperature and relative humidity in a time-series plot. This paper discusses some of the more challenging issues of presentation, where on-going continuous measurements are related to ‘other activities’ occurring simultaneously, external or internal to the space under consideration. Although ‘static’ graphs or charts with additional calculated information can provide useful information, the authors of this paper are experimenting with other presentation methods and techniques. One of these is the result of the animation program as presented in this paper. The authors have found the simultaneous animation technique, which can be reviewed repeatedly, to be useful in revealing ‘hidden’ behaviours or ‘interesting information’ not otherwise easily captured by the static graph. We are yet in the early days of this research and there remains much more to be explored in regards to presentation techniques.

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