BUILDING SATISFACTION - USING THERMAL MODELLING TO IDENTIFY AREAS OF BUILDING USE FOCUS FOR POST OCCUPANCY EVALUATION

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ABSTRACT

Buildings do not perform as modelled. There are many reasons for this, for example change of scope, functions, assumptions, weather, user behaviour and so forth. This paper investigates the latter. It turns the use of Post Occupancy Evaluation (POE) around and asks: what is the impact of people on building performance?

Based on IES modelling, the researchers identified those areas of performance that were sensitive to user behaviour and used the process of post occupancy evaluation to observe this as well as the standard elements related to user satisfaction. Using a small City of Melbourne community building, we report on the difference between expected and actual performance and report on the importance of user behaviour. We also present this novel approach to designing a POE.

Keywords: thermal simulation, user impact on performance and post occupancy evaluation

INTRODUCTION

Even the most efficiently designed building often does not perform as well as intended, or modelled (Myers, Reed, & Robinson, 2007; Lutzkendorf & Lorenz, 2005; Torcellini, et al., 2004; Meir, Garb, Jiao, & Cicelsky, 2009). There are many reasons for this, for example change of scope, functions, assumptions, weather, user behaviour and so forth. This paper investigates the considerable influences of Occupant behaviour on modelling outcomes, as recent research by Janda (2011) has shown that the occupants' impact is often misunderstood and underestimated in determining the efficiency of building performance.

We investigated the role of the users by looking at a small building in Melbourne called the Venny, which is located at the JJ Holland Park in Melbourne, Australia. This building was developed as a low cost solar passive design utilising shipping containers as skins for external walls. The plan view of different spaces of the building is shown in Figure 1a and b. The total floor area of this building is 185 m^2.

In order to carry out this investigation, we modelled the Venny in IES-VE and then carried out a Post Occupancy Evaluation (POE). Our aim was to develop an approach that may inform behavioural sensitivity studies for future modelling.

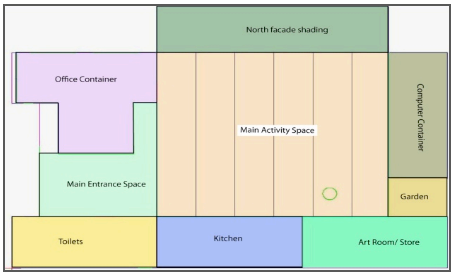

Figure 1a - The Venny building plan view and internal spaces

Figure 1b - The Venny photo (source: City of Melbourne)

This paper will first introduce IES modelling, then explore the main aspects of the literature with regards to occupant influence on building performance, and finally outline our approach to conducting a POE. This will be followed by a presentation of the findings and discussion of what this could mean for future modelling approached.

Occupant Behaviour and Building Performance

> *"If a change occurs such as to produce discomfort, people react in ways which tend to restore their comfort"*
> *(Humphreys & Nicol, 1998)*

Buildings are designed for occupants, and occupants affect its thermal and energy performance (Janda, 2011). A weakness of building simulation is the necessity to predict the occupant behaviour, in order to predict the actual building performance. Studies have found that even efficiently designed and constructed buildings can consume more energy and produce less energy than originally expected (Torcellini, et al., 2004). One of the main issues found is that the accuracy of the predicted performance is reliant on the way the variables are used in building simulation to predict occupant behaviour. The literature provides precedence to predicting occupant behaviour in influencing simulation outcomes:

- Scheduling: Studying occupancy type and hours (Yinong, Hokoi, Nakahara, Takada, & Miura, 2002)
- External factor controls: Studying the effect of temperature, humidity, wind and rain, based on assumption of occupant behaviour (Yoshida & Kono, 2002)
- Assumption of occupants controlling windows to achieve necessary ventilation rates as intended by design (Frank, 2005)

While the methods above have contributed immensely to the building modelling sector, the results are not always reliable, as they do not portray the reality of occupant behaviour (Rijal, Humphreys, Nicol, Samuel & Clarke, 2007).

In the late 1990s, Nicol and colleagues investigated the actual occupant behaviour in office buildings in Europe, UK and Pakistan; they specifically examined impact of users and their interactions with window, lights, blinds, heaters and fans (Nicol, Raja, Allaudin, & Jamy, 1999; McCartney, Nicol, & Stevens, 1998). Using this primary data two separate papers were established; the first compared the three different locations and occupant reaction to the outdoor temperature and the use of windows, lights, blinds, heaters and fans (Nicol, 2001). The second utilised the survey findings focused specifically on the UK data and predicted the effect of open windows based on indoor and outdoor temperatures, and the result of occupant behaviour on the thermal comfort and energy use of the building (Rijal et al. 2007).

Both papers successfully managed to create mathematical equations that predicted occupant behaviour regarding window opening (among other opening profiles). The first study focused on control behaviour of users in a building, while the second study focused on predicting occupant behaviour in specific situations and incorporate the predictions into modelling of energy performance and thermal comfort.

Our study acknowledges the validity of mathematical equations, but argues that the use of sensitivity analysis combined with a POE can demonstrate to the managers and users of the building, the importance of their role in achieving (or hindering) the desired outcome of green buildings.

This will extend the life of the model beyond its role as an initial design tool; resulting in its employment for increasing the validity of building simulation as well as educating its users on their impact.

IES modelling

The energy simulation model was developed in the IES VE Virtual Environment software version 6.2 in conjunction with Energy Plus, and considered the following points:

1. A temperature profile was created to represent the green roof thermal zone
2. Natural ventilation and night purging settings were defined based on profiles set in Macroflo
3. Local shading elements such as adjacent buildings and trees were incorporated

Weather data of the data collection period was used in the modeling to ensure the ability to compare, actual to modeled data. Also the occupancy hours of the Venny when first modeled only took into consideration the hours open to public. In actual fact, the staff of the Venny worked eight hour days, carrying out the administrative tasks before the children arrive, and tidying up the place after. The hours of occupancy within the model had to be increased by 3.3 times in order for the comparison to be accurate.

An addition to the initially determined conditions of the model, was the use of real weather data within the set data collection period to increase the accuracy of comparison between the modelled and actual conditions.

An Introduction to Post-Occupancy Evaluation

The Post-Occupancy Evaluation (POE) can be defined as *"the process of evaluating buildings in a systematic and rigorous manner after they have been built and occupied for some time"* (Preiser, Rabinowitz, & White, 1988, p3).

While a post-occupancy building evaluation a mandatory process for occupational therapists (Cooper, Ahrentzen, & Hasselkus, 1991), it has yet to be made mandatory within the built industry in Australia. Currently, the Victorian State Government has made it a necessity to conduct a POE for any building project that is over four million dollars, however, this only concerns capital works project (DHS, 2010).

It is argued by proponents of the POE that many other industries such as product and car manufacturing use some form of evaluation tool, however, buildings which cost a lot more remain un-evaluated, hindering the potential for increasing accountability, sustainability and optimal performance (Cooper et al., 1991)(Meir, Garb, Jiao, & Cicelsky, 2009).

Post Occupancy Evaluation Methodology

The POE is carried out through three categories; the technical, functional and behavioural effects of the building performance (Preiser et al., 1988).

A POE can involve a walk-through of the building, observation, data collection, surveys and interviews in order for carrying out the evaluation process (Loftness, Azizan, Choi, Kampschroer, Powell, Atkinson & Heerwagen, 2009; Preiser et al. 1988).

In the POE of the Venny we approached the three areas are follows:

- The technical category of the POE considered the Indoor Environment Quality (IEQ) and the building control systems, which was examined through the monitoring of the IEQ (temperature and humidity sensors), surveys and interviews of the staff.
- The functional category of the POE covered the design layout of the building, the use of space and the success of a building for its intended purpose, and was examined through interviews, observation and a walk-through of the building.
- The behavioural category of the POE examined the behaviour of its occupants within and towards the building. This data was obtained using surveys, interviews and observation.

The design of the survey and interviews

The survey was based on the format of the ASHRAE 55-2004 Appendix E thermal comfort questionnaire, which includes questions related to thermal comfort, activity levels, equipment usage, occupants' clothing, air movement, humidity, noise, overall happiness, healthiness, workgroup morale and productivity. There were additional questions derived from the research of Buratti et al. (2009), Lee et al. (2009) and Yao et al. (2009), as well as later altercations based on the research of Haghighat, Huo, Zhang and Shaw (1996), Davis (1984), Lai and Yik (2007), Choi, Loftness and Aziz (2009) as well as Rowe (2001).

The addition of questions was to investigate the influence of:

1. *Location*, as the same building can have different comfort levels, both in physical (Haghighat, Huo, Zhang, & Shaw, 1996) and psychological terms (Davis, 1984) in different spaces.
2. *Gender,* to determine if there was a difference in perception of comfort; as women are known to be more 'harsh' in judging the comfort of the environment (Lai & Yik, 2007) (Choi, Loftness, & Aziz, 2009).
3. *Mode of transport,* to determine the activity preceding the respondents entering the Venny, which might have a big effect on their perception of the building's IEQ (Rowe, 2001)

Additionally, semi-structured interviews were conducted with the staff of the Venny, to gain insight of staff understanding and connection with the building, compared to visitors (Friedmann, Zimring, & Zube, 1978).

A semi-structured interview allows the interviewer "more flexibility to digress and probe based on interactions" within an interview, which results in greater amount of information (Blee & Taylor, 2002). This method of interviewing provides the opportunity for respondents to clarify and elaborate their responses (Blee & Taylor, 2002) which can provide the interviewer better understanding of the issues concerned. However, there are negative associations with semi-structured interviews, such as the possibility for bias, which is tied to the interviewer-respondent relationship, and the non-standardisation of format for each interview can lead to a difficulty in analysing the data (Dean, Eichhorn, & Dean, 1969).

A structured set of interview questions was prepared to prevent incomparable data from being obtained. The purpose of using semi-structured interviews is to obtain information not directly on the list of questions, that the respondent might want to share.

RESULTS

Due to the stage of the research we will discuss the winter results with a focus on the influence of the user on the results.

Winter Modelled Results

The results for the modelled winter conditions showed the 8.6 kW gas heater has been adequately sized to handle the heating loads with a set-point of 21°C. This set-point of 21°C was determined based on the requirement to maintain indoor temperature above 19°C as this lower set-point was insufficient to handle heating load peaks. The achieved optimal thermal comfort conditions and reduce set-point temperature from 21°C to 19°C is recommended that gas heater is turned on 30 min before opening hours on days under 10°C.

The annual percentage of occupied hours above 19°C provides an acceptable operative temperature in winter for most of the spaces.There were several assumptions for the original modelling of the Venny:

1. The split system was used during occupied hours: from 3pm to 5pm on weekdays.
2. The office was an enclosed space with a random discrete function for the door opening profile.

The gas heater is located in the main activity space, where occupants are expected to be located most of the time, and the modelling shows that the annual percentage of hours above 19°C reaches 98.5%. This could be increased to 100% if heater is turned on before occupied hours as mentioned above, and the temperature set-point is increased for the coldest days.

Adjusting the Model & Sensitivity Analysis

The occupancy hours of the original model needed adjustment in order to provide increased accuracy of the modelling results. The actual occupancy hours of the Venny is shown in Table 1 below.

Furthermore, the model employed the actual temperature profile of the suburb of Burnley, due to its similar geography and density to Kensington. The original and adjusted models were then compared by conducting a sensitivity analysis.

Table 1- Actual Occupancy Hours of the Venny

Day of the Week	Open to Public	Public Holiday	Staff Hours
Monday	Closed	Closed	10am - 6pm
Tuesday	3pm - 9pm	1pm - 5pm	10am - 9pm
Wednesday	3pm - 5pm	1pm - 5pm	10am - 6pm
Thursday	3pm - 9pm	1pm - 5pm	10am - 9pm
Friday	3pm - 5pm	1pm - 5pm	10am - 6pm
Saturday	1pm - 5pm	1pm - 5pm	12pm – 6pm
Sunday	1pm - 5pm	1pm - 5pm	12pm – 6pm

Figure 3 above shows the comparison between the original and the adjusted model, and shows the high accuracy of the original model. However as this research intends to assess the extent of occupant influence on the building performance, the results of the sensitivity analysis was later compared with the real logged temperatures of the spaces.

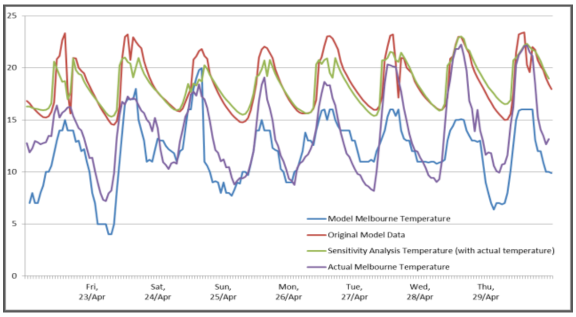

Figure 3 – Comparison of Original and Adjusted Model of Office

Winter Post-Occupancy Evaluation Results

Walk-through

The walk-through of the Venny involved comparing potential sources of dissatisfaction in the workplace based on the requirements of Leaman and Bordass. Potential areas of dissatisfaction within the Venny are identified through thermal comfort, lighting, noise, smell, space, storage, occupant control and productivity.

In general, there were not many sources of dissatisfaction, and the walkthrough shows the Venny performing well as a club-house building. The sources of dissatisfaction were found mainly in the office, upon which further investigations were carried out through the interview and temperature logging.

The areas of dissatisfaction were mainly within the office, with glare, thermal comfort and the lack of storage space creating dissatisfied occupants.

Sensor and observational data results

The thermal data collected from the Venny have been classed as the Office and the Main Activity Space, and the temperature of both spaces were analysed for the period of 22nd to 29th April 2011, as shown in Figure 4.

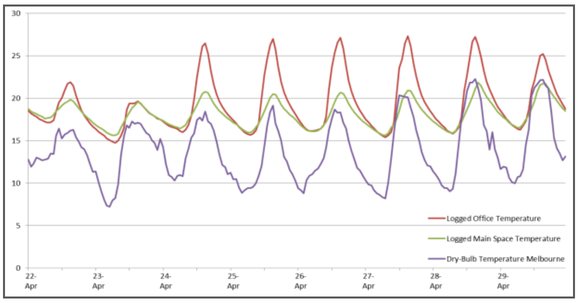

Figure 4- Main Activity Space and Office Logged Temperature Profile

The temperature difference in the office and the main activity space was an average of 4.5°C, the reason for the temperature difference being attributed to the shaded north veranda of the main activity space, while the office north-facing windows did not have this shade. The office also had additional heat gain from electrical equipment such as computers and printers.

The heater was not working during the period of data collection, therefore the fluctuation in temperature was caused predominantly by thermal mass, the number of occupants as well as the opening profile of the doors and windows. The external conditions influenced the indoor temperature thermally as well as its influence on occupant action, such as staying indoors and keeping doors and windows closed.

The discomfort within the office resulted in the staff experimenting with seating locations and angle-adujustment of their computers screens, which was carried out in the hope of creating a comfortable environment to work in. The staff were very happy overall with other aspects of the office, especially the increased space and area for meetings as well as the improvement of the rest of the Venny.

Interview results

Interviews conducted on the staff of the Venny helped to provide an understanding of their experiences in the new environment. The staff were asked what they liked about the building. The respondants felt they were positively impacted by the building. They reported uing fans and windows to help control the indoor thermal comfort. The aspects that were not working well was glare, which seems to be 'tolerated'by the staff, who experiment with computer locations and so forth to try to adapt to the problem. Positive feedback was given in relation to acoustics, security, flexibility and visual connectivity. The new office's larger size allowed for its multi-functional use as a meeting room and a sick room. While, the glass north wall of the main activity space provided direct visual linkage to the outdoors, which the respondents particularly noted that they enjoyed due to the security benefits as well as psychological benefits by visual linkage to the environment. The interviews also showed some aspects of the Venny that the responders felt could be improved, these are listed in Table 3 below.

Table 2: Potential Improvement for the Venny

Potential Improvement for the Venny	Occupant Behaviour Toward Features
Building Control System	The system gets 'stuck' sometimes, and the only way to fix this problem is to shut down the building
Glare (in office)	Trying out different angles of the shading, but the perforated metal causes a strobe effect. Adjusting angles of computer screens and seating location.
Heat gain (in office)	Occupants turn on the air-conditioning in order to deal with the discomfort
Storage space	The staff recycled old storage units due to the lack of funding for furniture
Heater not working (main activity space)	The staff wear their jackets around the Venny, until it gets warm enough

Interesting anectodes

Several intersting outcomes came from the interviews. The first was the 'unique and interesting journey' of the staff to deal with the Building Control System. At times, staff would have to shut down the building, like you would a computer, to 'reboot', and the manager commented that it would have been nice to have a 'manual' for the system detailing how to manage the system.

Another anecdote that was positive was the willingness by the staff to adapt to the building's heater not working. They were happy to keep their coats rather than adding individual heaters.

In summary the interviews found that the general opinion of the staff towards the new Venny was that it was functioning very well overall.

Survey results

Eleven visitors to the Venny completed a short survey between the 21st of April and the 11th of May 2011. The surveys questioned the respondent's perception of the IEQ and comfort levels within the Venny from a scale of one to ten, with five being 'ideal'. One survey was discarded due to irregularity of responses.

The overall results indicated that the majority of respondents were satisfied with the IEQ of the Venny;

- 90% found the air movement and artificial lighting was ideal, and;
- 80% found the noise and humidity levels were ideal
- 70% found natural lighting ideal
- 60% found the thermal comfort of the Venny ideal

Therefore, the main areas of dissatisfaction in the Venny are the thermal comfort and the natural light, with the rate of dissatisfaction considered high compared to the general occupant dissatisfaction rate of buildings, which is aimed to fall between 10% and 30% (Chan, 2000, p. 162). The survey results has a significant difference with that predicted by the modelling, which initailly showed user satisfaction in all parts of the Venny except in the toilet area.

Several factors appeared to influence the perception of comfort in the Venny, such as the mode of transport, location in the building, and the gender of the respondent.

Location within the Venny posed an important issue to address, as the different areas of the Venny have different IEQ, different construction materials, mechanical equipment as well as orientation of the building (Haghighat, Huo, Zhang, & Shaw, 1996; Davis, 1984). In this survey, respondents who were in the kitchen recorded a 100% satisfactory rate. Only half the occupants in the Main Activity Space found the temperature ideal, while 17% of respondents found the humidity, natural lighting, and noise levels not ideal. The occupants in the office recorded 100% dissatisfaction concerning natural light, and a 50% dissatisfaction for the other 5 categories, making the office clearly less comfortable than the kitchen and hall.

Mode of transport to the Venny had an influence on the perception of comfort among survey respondents, as the physical intensity of the activity preceding entering a building has an influence on the perceived occupant comfort level up to an hour after arrival (Rowe, 2001). The respondents of the Venny who were least satisfied with the IEQ in decreasing order were; the cyclists, walkers, public transport and drivers. Physical intensity of the preceding activity appeared to influence the perception of comfort within the Venny.

Gender also proven to have an influence on sensitivity to the environment (Choi, Loftness, & Aziz, 2009; Lai & Yik, 2007). The survey respondents were no exception to this rule, with 100% of female respondents finding the thermal comfort levels less than ideal, as opposed to 17% of male respondents. Male respondents however, seemed to be more sensitive to noise, with 33% finding the noise levels of the Venny more than ideal, compared to 0% of women.

The conclusion of the survey is that the Venny is performing well in general, but can be made more comfortable. The survey found that the thermal and natural lighting issues within the office were the biggest area of dissatisfaction.

ANALYSIS OF THE MODELLED AND ACTUAL CONDITIONS

Thermal

As the thermal conditions of the Venny received the least favourable response from the survey, it was analysed in further detail. It should be noted that the actual temperature from the period of the 22nd to the 29th of April was used in the model, to decrease the variables.

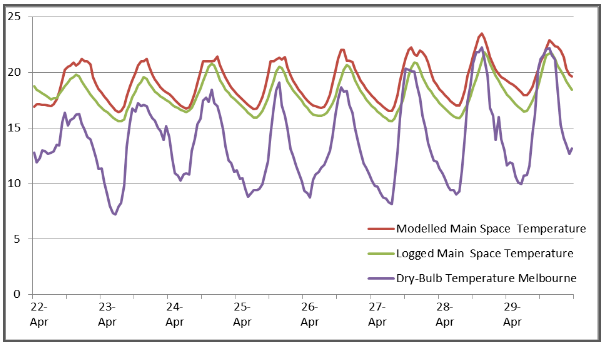

Figure 5: Modelled and Logged Temperature for Main Activity Space

Figure 5 shows the similar results of the modelled and logged temperatures in the main activity space. This similarity shows the success of the modelling in predicting temperature of the main activity area when using the actual external temperature file.

However, the comparison of the modelled and logged temperatures of the office is shown in Figure 6 and 7, showed significant difference.

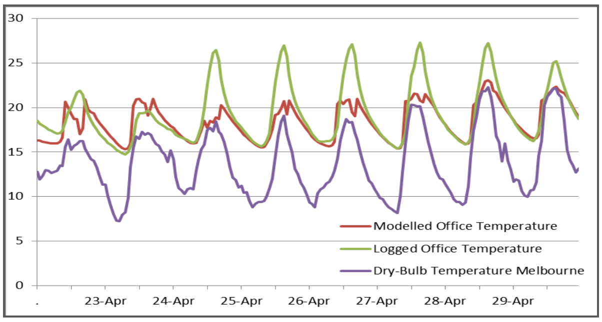

Figure 6: Modelled and Logged Temperature of the Office

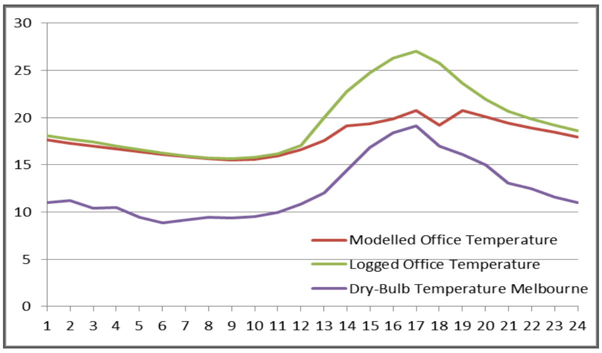

Figure 7: Hourly Modelled and Logged Temperature in the Office on the 25th of April 2011

Energy

The energy use of the Venny was obtained from the model without the Burnley temperature data; due to the absence of data available for the time period of the electricity bill acquired, which was from the 16th of December 2010 until the 16th of March 2011.

As the external temperature does not have a big influence on the building's energy use, mainly due to the passive design elements incorporated into the Venny, this was not seen as an important factor in influencing the accuracy of results. Regardless, the general picture of the data can be seen in Table 4.

Table 3- Modelled and Actual Energy Use of the Venny for December 2010 to March 2011

Model	Energy Use	CO_2 Emissions
Model Energy Use	1673.3 kWh	2217 $kgCO_2$
Actual Energy Used	891.7 kWh	1247 $kgCO_2$

Summary of the Analysis

There are two main reasons that could be responsible for the variation of temperature and energy use of the Venny:

1. *Climatic conditions*

Although the modelling used actual temperature, the solar intensity and cloud cover data was not obtainable. Cloud cover could make a big difference in heat gain, as the clouds act as a shade from the sun, and therefore allowing less sunshine into the windows.

2. *Occupant behaviour*

Due to the nature of the Venny, the actual hours of occupancy is hard to determine. Figure 7, shows that the modelling includes some assumptions about people coming in and out of the office space, while in reality it was obeserved that staff rarely use the office in the afternoon due to the requirement of monitoring the children in the building and the yard. Thus the computers and other electronic devices, and solar radiance, in the afternoon are heating up the well sealed space.

DISCUSSION

From the intial modelling, the observed performance through the POE for the Venny over this short period has showed some significant deviations from the expected. The main issue was that the heater was not working, which is not the fault of the modelling. There were several elements that needed to be amended in order to increase the accuracy of the model, which were:

1. Updating the weather file, by incorporating the actual weather data from Burnley
2. The hours of operation were different and the number of building users had increased

confirming the findings of Yinong et al. (2002)

3. The windows, shading system and equipment were not being used as expected, confirming the research of Yoshida and Kono (2002) and Frank (2005). This led to dissatisfaction and the response by the users was to adapt

Finally, a lesson from this work is that there are some aspects that cannot be acounted for in modelling, this is that the users were happy to adapt to both the thermal and glare conditions; choosing for example to wear their coats. This confirms the work of Leaman and Bordass (2007) which predicts that the Venny as a 'green' building encourages visitors and staff to tolerate more discomfort within the building than they normally would.

Limitations

There were several limitations to this research. The nature of the Venny and the limited period for the data collection decreased the opportunity for obtaining survey participants, especially as there are not many adults visiting the property.

This resulted in the small sample size of the survey respondents, which decrease accuracy of the results and conclusions made. However, the issues that were examined through the survey had been previously investigated with similar results, therefore providing validity to the conclusions drawn from this research.

Finally, there are some aspects that cannot be accounted for in modelling, such as the occupant behaviour as well as the bias of occupants for tolerating more discomfort within a "green" building than they normally would (Leaman & Bordass, 2007). However, as the 'coping' of the staff and occupants are mostly temporary, or easily resolved as determined by the POE, this limitation is negligible

CONCLUSION

This project has shown the success and failure that building modelling can have within the same building. Therefore, it needs to be stressed again the importance of the POE to be made mandatory.

The modelling of the Venny proved to be successful in the main space of the building, however the office showed a lower accuracy of modelling. This is due to the different uses, and equipment within the spaces, as well as the methods in which the spaces are used by the occupants. This conclusion would not have been possible without the use of a POE.

The discrepancy in the results were tied to variables that could not be quantified accurately in modelling. This research proves the need for building modelling to be validated in order for a better understanding of buildings in general, as well as the variables within them, such as occupant behaviour. The more research conducted on buildings and occupant behaviour, the higher the likelihood of the assumptions being made in the modelling process being accurate in the longer run.

This paper argues that it is a useful exercise for building modellers to work through the implication occupant behaviour and decisions on building performance. Particularly, working through the implications of:

- Occupancy hours and numbers, and the impact of decisions made by building users, for example brining in their own little heaters;
- Opening and closing windows and shading systems; and,
- Impact of different weather events – that is warm and cold years.

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