An Evaluation of Natural Ventilation and Comfort of a Multi-Storey University Office Building

Mark B. Luther[1] and Benedict Dozie Ilozor[2]

[1&2] Built Environment Research Group, School of Architecture and Building, Deakin University, Geelong, Victoria 3217, Australia; Email: luther@deakin.edu.au

ABSTRACT

Ventilation and comfort assessment of buildings is not a new practice in post occupancy evaluation (POE) of buildings. Most evaluations have been based on perceived assessments by the occupants collated through questionnaires asking for a Yes/No response or qualitative scale rating. While this study does not deal with a POE survey, it was initiated by the lack of comfort and overheating complaints of the occupants of the subject university building. It is for this reason that an investigation was conducted on the design expectations and actual ventilation performance associated with the thermal comfort of this building.

The floor plan of this university building is typical to office buildings, comprising of a central interior hallway, with rooms to either side fronting an external operable window (see floor plan in Figure 1). It is intended that this building is treated to comply with natural ventilation principles. Door grilles are provided to allow for an expected air flow exchange between rooms and hallways, as well as a total cross-flow ventilation through the building. No HVAC (mechanical) system is used for heating or cooling in this building. Heating is through a hydronic perimeter radiator system.

This study involved an investigation into ventilation and associated thermal comfort through continuous measurement in a specified room of the building. Its aims are to:

1. To establish thermal comfort conditions for a typical office in the building.
2. To establish the existing ventilation performance under various external conditions.
3. To analyse the possible reasons for the passive thermal control problems, and to provide alternative measures for improvement.

Keywords: natural ventilation, thermal comfort, building ventilation, office environments

[1] Dr Mark Luther is Director of Built Environment Research Group (BERG), School of Architecture and Building, Deakin University, Australia.

[2] Dr Benedict D. Ilozor is Head of Facilities Management for Built Environment Research Group (BERG), and Management Discipline Coordinator for Architecture and Construction Management, School of Architecture and Building, Deakin University, Australia.

INTRODUCTION

This research is based on a case study of Building C at the Burwood Campus of Deakin University, Australia (Figure 1). The design of the building was claimed to be suitable for accommodating its occupants under natural ventilation and other passive thermal conditions specifically during summer periods. Unfortunately, the thermal conditions within Building C have undergone criticism from its occupants which prompted this investigation. The aims associated with this research are:

- To establish thermal comfort conditions within a typical office space in the building.
- To investigate the existing ventilation performance of the building.
- To analyse the possible reasons for the passive thermal control problems and to provide alternative measures of improvement.

Several analytical methods were used for the investigating the above mentioned points. These included:

- Thermal Comfort Meter Testing
- Tracer Gas Testing
- Wind Speed and Temperature measurements at the window
- Smoke machine experiment
- Fluid Mapping

Natural ventilation is the flow of outdoor air through a building caused by pressure differentials at the façade. It will occur where openings are available at points exposed to different levels of air pressure between inside and out (Givoni, 1997). Ventilation is recognised, understood and studied in accordance with the AS 1668 Australian Standard. It is expected that the reader of this report is familiar with the standard and its associated terminology.

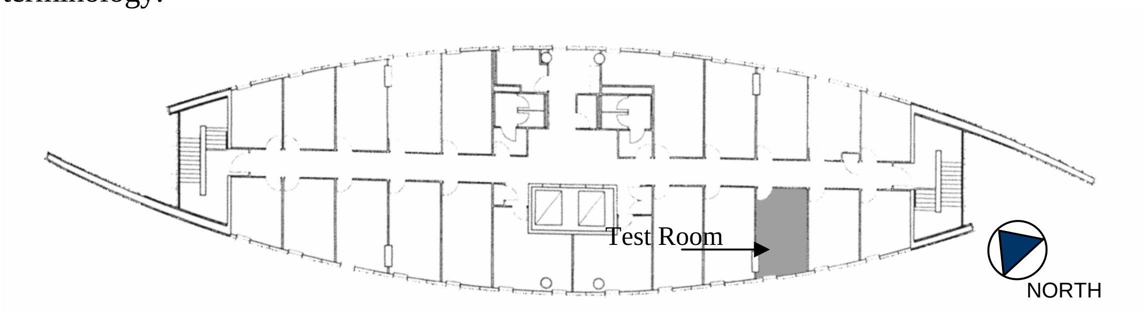

Figure 1 Upper Floor Plan of Building Architecture Australia, September/October 1997, p.72

ESTABLISHING ROOM CONDITIONS & COMFORT

There is no mechanical ventilation system within the building. Passive ventilation (only) is relied upon for thermal comfort. The expectation of the design assumes that cross-ventilation, from one side of the building through the corridor to the other, provides sufficient ventilation in order to maintain proper thermal comfort levels. The building design involves a central corridor with offices to either side, each with an external wall. Office doors are directly opposite those from the office across the corridor, with each door having a 600mm wide by 300m deep grill, 150mm off the floor.

An initial study involved the recording of interior air (dry-bulb), external window frame, air and glass temperatures over a two week (end of summer, March) period. Figure 2 charts the time-series plot of measured results of this period.

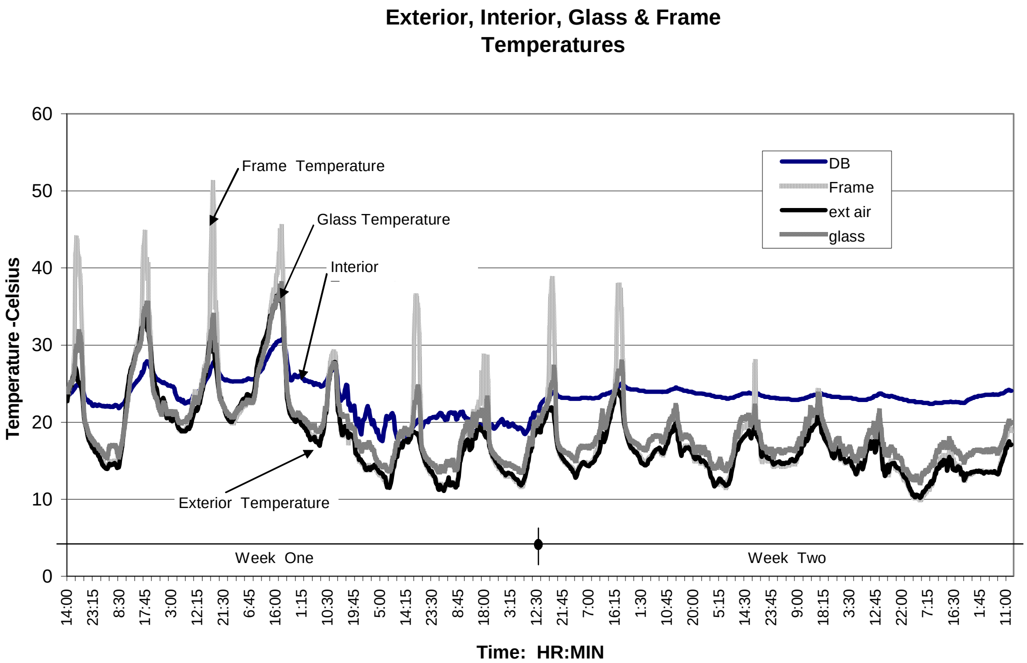

Figure 2 Measurements of Temperature for the Selected Office Space

Figure 2 indicates the measurement of exterior air temperature exceeding 32 °C which would be above desired interior comfort level temperature. Passive ventilation during these periods would be detrimental to maintaining comfort heating the building interior. Further problems with the window frame and glass temperature are also experienced. Such surface temperatures will increase the mean radiant temperature on the interior. These interior temperature conditions were examined via a simulation of the ISO 7730 Standard (Fanger). The percentage dissatisfied with these conditions could be on the order of 50%.

It was further observed and concluded for this space, that:

- there would be a limit of thermal comfort (according to ISO 7730) when internal air velocity was less than 1m/s at 28-30^{o}C.
- external temperatures, (from weather data files) exceed a peak of 30^{o}C on 29.5 days of a year. Therefore, the building fabric and passive ventilation conditions must compensate for this in order to maintain thermal comfort requirements within office spaces.

A remedy to these above conditions was sought through the assistance of a venting system. It was recognized that the air movement within the space was practically nil. Although venting during an external air temperature above 30°C would not be recommended, the initial objective is to increase the air flow within the space.

EXPLORING A POSSIBLE SOLUTION

In an attempt to solve the ventilation problem, it was decided to install a small fan (Lenco Slimline Exhaust Fan, 200mm) within the door where the grills were otherwise placed. The theory of this is that the fans will induce ventilation and exhaust air into the central corridor. The capacity of the fan (66.66 L/s) should create an air change rate of 5.7 per hour. Figure 3 illustrates the results of air velocity within the room with and without the installed system running.

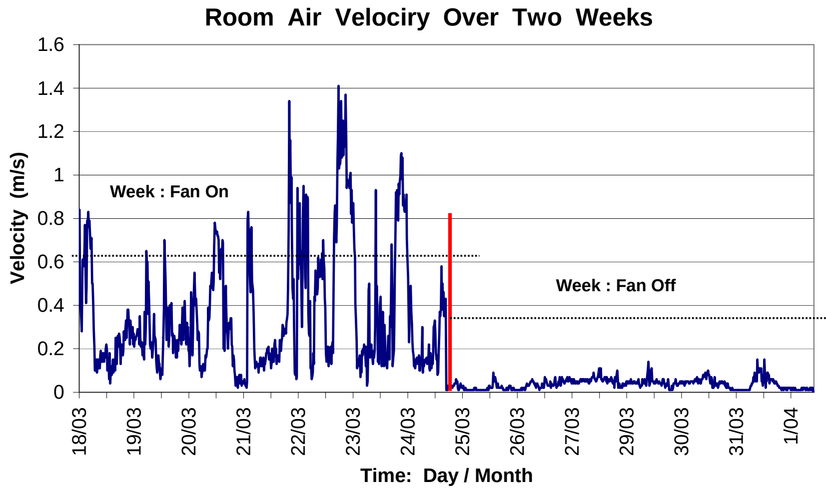

Figure 3 Room Air Velocity: with and without door fan on

It is clearly indicated that the room velocity is increased with the assistance of the door fan. A closer look of the actual ventilation rates and flow-streams within the space was desired in hopes to obtain a better understanding of the building as a ventilation system. As a result tracer gas studies were performed within the space for three specific cases: 1. a closed room, 2. window open and door fan off and 3. window open and door fan on. Table I presents the results.

Test Case	Test Description	Decay Rate (air changes/sec)	ACH in room (air changes per hour)
1	Closed Room (no fans)	0.0002	0.72
2	Window open (no fan on)	0.0026	9.36
3	Window open (fan on)	0.002	7.36

Table 1 Tests of Office Ventilation Rates under Various Conditions

It was noticed that for case 2, on the particular test day, a higher air-change rate has been recorded for having the fan off than compared to the fan being on. Possible reasons for this are as follows:

- placement of the Microtip (sensing instrument) on the table is not in the flow stream of the fan and window.
- A short-circuiting of the fan acting against the window ventilation stream.
- A wind direction dependent result which is circumstantial and can not be relied upon.

When the fan is **off** ventilation occurs by way of thermal force, with the air changes occurring through and at the window. When the fan is **on** ventilation occurs by way of wind force, with air entering the window and being forced out the door through the fan. The air is travelling from the window and across the room, predominantly at a level lower than the working plane (see Figures 3&4). The tracer gas is therefore remains more stagnant at a level above the working plane when the fan is on. When the fan is off, it is mixing with incoming air and exiting through the window. Mixing primarily occurs through the process of incoming and exiting air through the window when the fan is off.

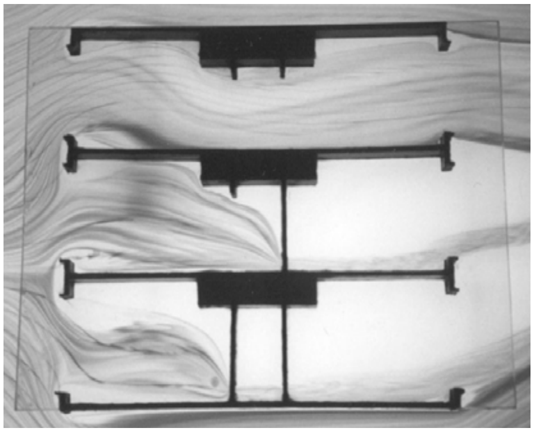

Figure 3 Sections – Fluid Mapping

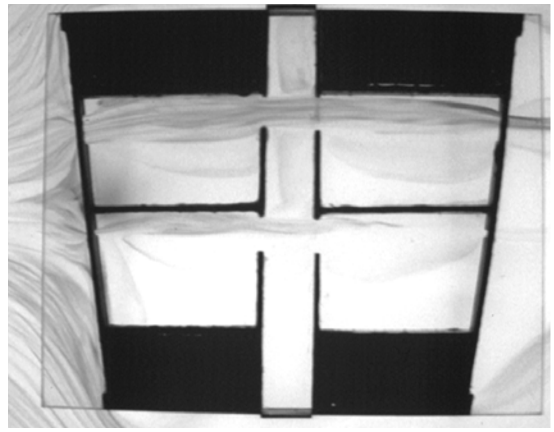

Figure 4 Plan View – Fluid Mapping

MEASUREMENT OF THERMAL COMFORT

Additional measurements were taken at 15 minute intervals over the two weeks (as previously indicated in Figure 1) which allowed for a comprehensive assessment of thermal comfort to be made. The thermal comfort apparatus measuring globe

Figure 5 Thermal Comfort Meter for ISO 7730

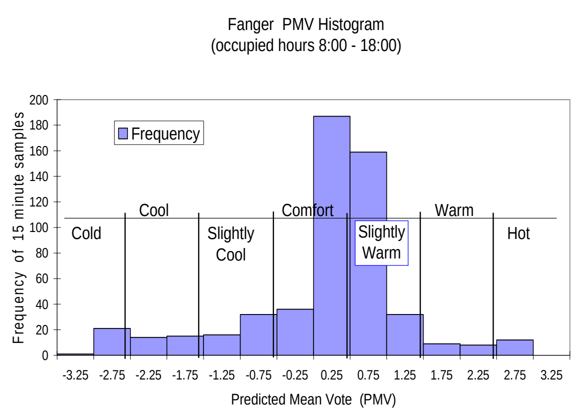

Figure 6 ISO 7730 Predicted Mean Vote

temperature, humidity, air velocity and air temperature at desk level as shown in Figure 5. Through the ASHRAE-55 thermal comfort program (Fountain and Huizenga,1996) a calculation of the Predicted Mean Vote (ISO 7730 – Fanger) was calculated for the occupied hours of the two week period and charted in Figure 6. For this two week period where external temperatures are not considerably high (with the exception of two days) that the space would be rated as slightly warm. The space would have been rated uncomfortable if the room air velocity had remained as without the fan use.

Since the building is a naturally ventilated building and such buildings are reliant on air movement (during summer periods) an 'adaptive model' of thermal comfort is applied (Figure 7). An adaptive comfort model utilises similar parameters to those of ISO-7730 but is strongly linked to external mean temperature (Luther and deDear, 2003). It is noticed for the most part, that occupied thermal conditions are well within a 90% acceptable range. There remain several occurrences of extreme hot conditions where perhaps a window should be shut and ceiling fans could operate.

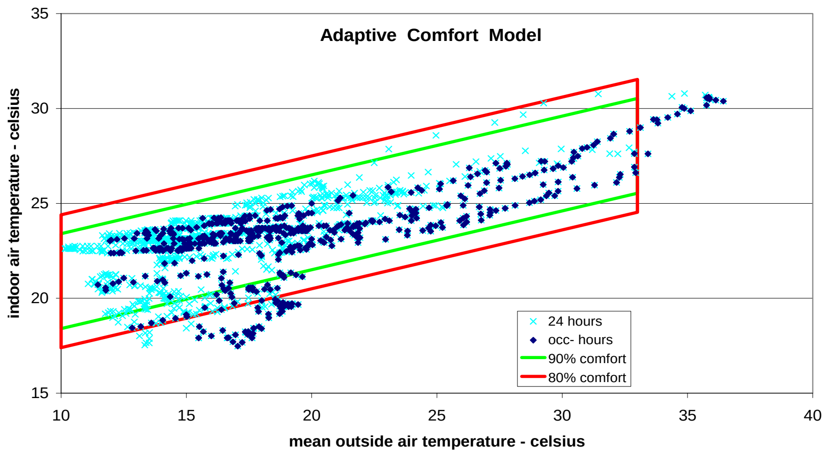

Figure 7 The Adaptive Model of Thermal Comfort (deDear and Brager)

CONCLUSIONS

The thermal comfort problems experienced within this building are due partly to its overall ventilation design strategy. The assumption of cross-ventilation, from one office across a corridor and through the next office is unreasonable. It is suggested that a mechanical exhaust in the corridor provide a negative pressure for reliable office ventilation to occur. Modes of operation under hot summer conditions are left unresolved within this design. An exposed mass interior with manually operated ceiling fans and a solar shaded window including a non-radiating frame might provide a start.

The presented methods of in-situ testing and fluid-mapping established that the design and orientation of the building do not fit with those of passive ventilation and natural cooling. It was also discovered that the local conditions, along with the existing building fabric, are unsuitable for passive thermal control all year round. Due to the buildings operational typology (natural/passive) an adaptive comfort model should be applied over that of the ISO-7730 (Fanger) static comfort model. The south-west perspective of the test office suggests that many of the other offices would incur more direct sun, and therefore have considerably worse thermal comfort conditions than the office tested.

REFERENCES

deDear RJ, Brager G (1998) Developing an Adaptive Model of Thermal Comfort and Preference. *ASHRAE Transactions* 104:145-167
Fanger PO (1970) Thermal Comfort, *Danish Technical Press*, Copenhagen
Fountain, M.E. and Huizenga, C., (1996),"A Thermal Comfort Prediction Tool", *ASHRAE Journal*, September
Givoni, B. (1998), Climate Considerations in Building and Urban Design, Van Nostrand Reinhold, New York.
International Standard ISO 7730, (1984) Moderate Thermal Environments Determination of the PMV and PPD indices and Specification of the conditions for Thermal Comfort, *International Organization for Standardization*, Switzerland.
Luther M.B. and R. deDear, (2003) Applying the Adaptive Model of Comfort, *Environmental Design Guide*, RAIA (Australia), August