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Assessment of the Thermal Performance of Complete Buildings Using Adaptive Thermal Comfort

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Abstract

The paper presents a method of assessing the thermal performance of complete buildings using the adaptive thermal comfort concept. This facilitates the assessment of the thermal performance of whole building envelopes accounting for the percentage of time over which the building internal air temperature remains within a specified adaptive thermal comfort range.

This method promotes sustainable and energy efficient design by using an adaptive approach to assess the thermal comfort for occupants instead of energy usage, the common practice in existing rating tools. This universal approach can be used to compare the thermal performances of various buildings and is applicable anywhere in the world.

When the technique was applied to the assessment of the thermal performance of various walling types in several housing test modules over a 12 month period, the results indicated that the Insulated Cavity Brick module (InsCB) had the best building thermal performance, followed by the Insulated Reverse Brick Veneer (InsRBV), Insulated Brick Veneer (InsBV) and Cavity Brick modules (CB). These results were consistent with the previous findings from University of Newcastle (UON) research on walling systems and the AccuRate building assessment tool used in Australia.

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Keywords:Thermal performance; adaptive thermal comfort; sustainable buildings.

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1. Introduction

The accuracy of any thermal simulation has direct influence on the thermal performance of any building and the design of heating and cooling loads required to sustain thermal comfort. Many variables affect the thermal performance of a building and both independent and interconnected variables influence the thermal performance, with some having a greater impact than others (Rabah, 2005).

Due to the dynamic nature of weather conditions, these variables are constantly changing, which makes it difficult to accurately predict the thermal energy performance (Alterman, Page, Moghtaderi & Zhang, 2015), (Moffiet, Alterman, Hands, Colyvas, Page & Moghtaderi, 2015). To obtain an accurate assessment of the thermal performance of a building, an account must therefore be taken of the building as a complete system under the variable external conditions (Alterman, Moffiet, Hands, Page, Luo & Moghtaderi, 2012).

Energy assessment programs are different, depending on the country; various rating methods are used in the developed countries with few or no building energy assessment tools in developing countries. Therefore there is a need for a universal energy assessment tool for buildings, as well as techniques to encourage energy saving by using adaptive practices to obtain a thermal comfort level (e.g. open windows, changing clothes or low energy solution such as fans).

In this research, the aim is to find a new approach capable of predicting the thermal performance of a building envelope for any given set of climatic data based on adaptive thermal comfort. This approach can be used to compare the thermal performance of different buildings, taking into consideration the various building materials, orientation, shading, occupant behavior, weather at the site and the environment surrounding the building.

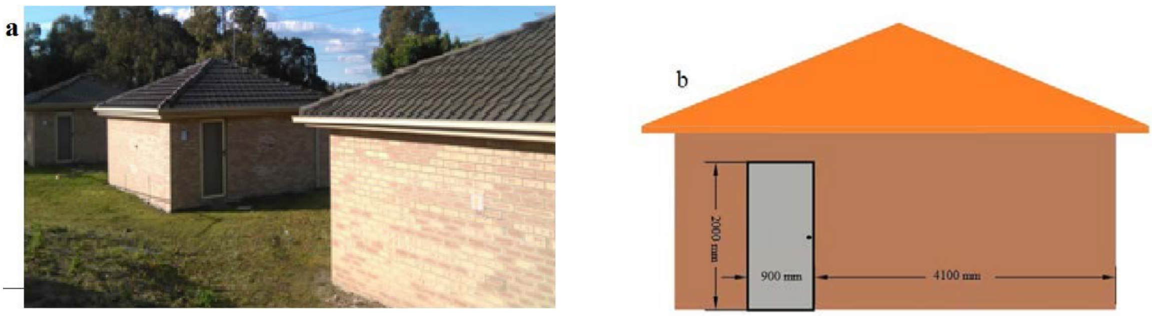
2. Methodology

The first step is determining the internal air temperature of a building under varying external conditions. The weather data used in this research was recorded over one year from four housing test modules on the campus of the University of Newcastle. The adaptive thermal comfort range was found by computing the fraction of time over which the internal air temperature of a building remained within the 90% adaptive thermal comfort limit.

2.1 Full Scale Test Modules

The research program on the thermal performance of housing in Australia in the Priority Research Centre for Energy at the University of Newcastle, Australia, has been underway for the past 10 years. The research has involved the construction of four full-scale housing modules, then monitoring the modules under different weather conditions.

The modules were selected to represent typical forms of construction in Australia, and were built at the University of Newcastle, Callaghan Campus (Longitude 151.7 E and latitude 32.9 S). The modules were placed 7m apart to reduce wind obstruction and avoid shading. With the exception of the walling system, all modules (Cavity Brick Module (CB), Insulated Cavity Brick Module (InsCB), Insulated Brick Veneer Module (InsBV), and Insulated Reverse Brick Veneer Module (InsRBV)) had a similar layout, with a square floor plan of 6m x 6m (see Fig. 1).



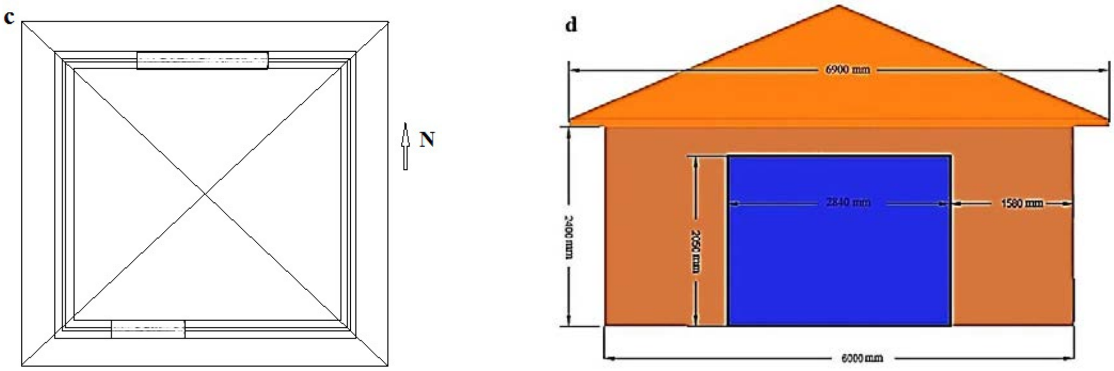


Fig. 1. (a) photo of full scale test modules; (b) southern face; (c) top plan; (d) northern face (window side)

All the modules were named after their walling system. More details of the module elements and material configurations in Table 1.

More than 100 sensors were installed in each module to record the external weather conditions and internal environment, with the data recorded at 5 minutes intervals over the testing period using. The external environment conditions solely determined the internal air temperature for all of the modules, as the interior was left to “free-float” without mechanical heating or cooling (Page, Moghtaderi, Alterman & Hands, 2011).

Table 1. Module elements and material configurations (Page, Moghtaderi, Alterman & Hands, 2011).

Module Element		Material Configurations	Comments
External walls	Cavity Brick	Two 110mm brickwork skins + 50mm air cavity	CB
	Insulated Cavity Brick	Two 110mm brickwork skins + 50mm air cavity with R1.0 polystyrene insulation	InsCB
	Insulated Brick Veneer	110 mm brickwork skin + air cavity + timber frame wrapped with glare reflective foil and R1.5 glass wool batts	InsBV
	Insulated Reverse Brick Veneer	Fibro-cement sheets fixed to timber stud frame with R1.5 glass wool batts + air cavity + 110mm brickwork skin	InsRBV
Roof	Ceramic	Clay tiles over a layer of foil sarking.	InsCB, CB
	Concrete	Concrete tiles over a layer of foil sarking	InsBV
	Metal	Coated corrugated sheets over a layer of foil sarking.	InsRBV
Door		Solid timber door 2040 x 820mm insulated with 75mm thick layer of polystyrene foam	InsCB, CB, InsBV, InsRBV
Window		Single pane glass window set in a light coloured aluminum frame 2050 x 2840mm	InsCB, CB, InsBV, InsRBV
Ceiling		10mm plasterboard + R3.5 glass-wool batts between rafters	InsCB, CB, InsBV, InsRBV
Slab		Concrete slab	InsCB, CB, InsBV, InsRBV

2.2 Adaptive thermal comfort

One of the principal ideas behind adaptive thermal comfort is that thermally unconfutable people respond in ways which have a natural tendency to restore their thermal comfort and to adapt to the changing conditions in their environment. This natural tendency is expressed in the adaptive approach to thermal comfort and is based on the findings of surveys conducted in the field which focused on collecting data about the instantaneous thermal response of subjects to the thermal environment in real conditions (Nicol & Humphreys, 2002).

The adaptive method was developed with the idea that occupants dynamically interact with their environment. One of the predictions of the adaptive hypothesis is that people in warm climate zones prefer warmer indoor temperatures than people living in cold climate zones. Occupants control their thermal environment by changing clothes, operating windows, fans or personal heaters, drinking water, and using sun shades, without resorting to the use of much mechanical heating and cooling energy (De Dear & Brager, 1998).

The comfort temperature for free-running buildings (no mechanical cooling or heating) in Australia can be calculated using equation (1) (Brager & De Dear, 2001):

$$Tc = 17.8 + 0.31\, x\, To \quad (1)$$

Where:

T_c: Comfort temperature (operative temperature (°C)).

T_o: The monthly mean of the outdoor air temperature (prevailing mean outdoor temperature). This is an average of the mean daily outdoor temperatures over no fewer than 7 and no more than 30 sequential days prior to the day in question.

There are two major acceptability limits in this approach;

90% acceptability limits = Tc ± 2.5°C (2)

Wherein, at least 90% of the occupants were satisfied. Note: this is used in this paper because more inhabitants find this range in their comfort zone.

80% acceptability limits = Tc ± 3.5°C (3)

Wherein, at least 80% of the occupants were satisfied.

For example, when the mean outdoor temperature is 23°C, the adaptive thermal comfort temperatures rises above the mean outdoor temperature and reaches up to 30°C, as shown in Fig. 2. The dark blue and light blue regions are the 90% for 80% acceptability ranges respectively, according to the adaptive method in the ASHRAE 55-2010 Standard (Tyler, Stefano, Alberto, Dustin & Kyle, 2013).

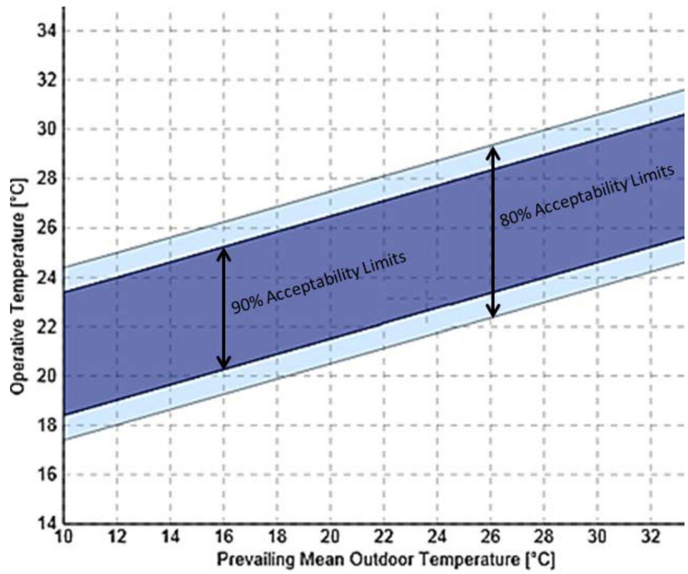


Fig. 2. The 80% and 90% acceptability limits for prevailing mean outdoor temperature throughout entire year (Tyler, Stefano, Alberto, Dustin & Kyle, 2013)

The recorded temperatures for each module were used to find the new adaptive thermal limit for all the modules: CB, InsCB, InsBV and InsRBV. The adaptive thermal limit can be then calculated by counting the number of hours when the temperature inside the module lies within the 90% comfort zone, compared to the total number of hours (8760 hours (365 days)).

3. Results and Discussions

The findings of the adaptive thermal comfort for (the 90% acceptability limits) for the whole year for the CB, InsCB, InsBV and InsRBV modules showed that the module with the best thermal performance was InsCB, followed by the InsRBV, the InsBV, and finally the CB module, as shown in Table 2.

Table 2. Adaptive thermal ratio for all modules over one year.

Acceptability limits / Module	CB	InsBV	InsRBV	InsCB
90% acceptability limits	56.8%	57.3%	61.2%	62.4%

The monthly thermal performance for the 90% acceptability limits of each module vary from month to month. For example, the CB building has the lowest thermal comfort in the winter months compared with the rest of the modules, while it performed best in only one month (April), as shown in Fig. 3.

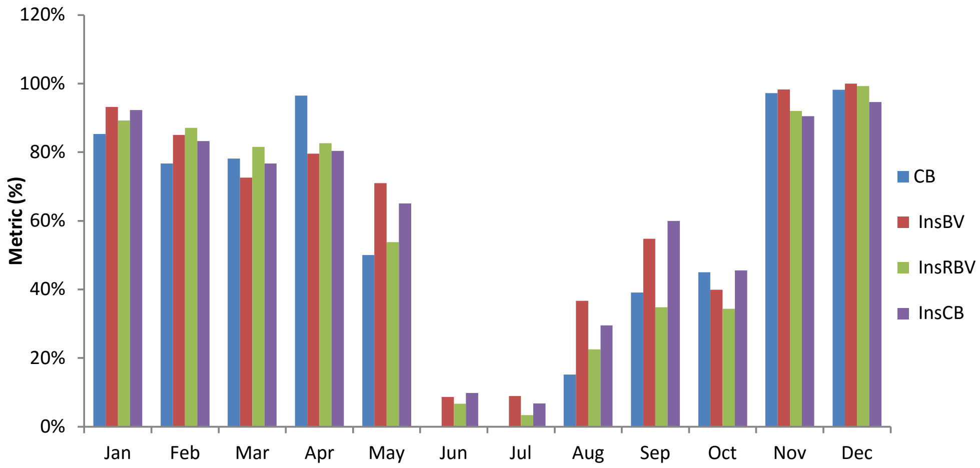


Fig. 3. Ratio of monthly internal air temperature which remains within the 90% adaptive thermal comfort range for each module.

Most modules perform badly in the winter months, and this indicates where improvements would be needed. This will help the designer to improve the module design by using, for example, double glazed glass for the window. This will significantly improve the thermal performance of the modules in the winter months as well as the modules' overall thermal performance.

3.1 Comparison of the adaptive thermal limit with previous UON research

Previous research on the thermal performance of the walling systems was carried out between 2008 and 2009 on the four modules under all seasonal conditions under free floating conditions, with no ventilation. Data from 6 weeks were obtained to represent each season for the free floating period. The results indicated that InsCB and InsRBV modules had the best building thermal performance, followed by the InsBV and CB modules (Page, Moghtaderi, Alterman & Hands, 2011). These results are consistent with the earlier findings from the adaptive thermal limit study.

3.2 Comparison of the new adaptive thermal limit with AccuRate

AccuRate Sustainability (V2.3.3.13 SP1) is a rating tool that assigns a star rating to a residential building in Australia, based on its calculated annual heating and cooling energy requirements. The assessment of the building is stated as a star rating of between 0 and 10: the more stars, the better the performance. Star ratings (bands) are set for each specific climate zone to allow fair comparison of buildings across climates. Using one year of typical weather data appropriate for the location, the heating and cooling energy requirements are calculated hourly over a period of one year (AccuRate Sustainability, V2.3.3.13 SP1).

Using AccuRate to compare the performance of the modules indicated that the InsCB and InsRBV modules had the best building thermal performance, with the least annual heating and cooling energy requirements, followed by the InsBV and CB modules, as shown in Table 3.

Table 3. AccuRate band results for all modules.

Module	CB	InsBV	InsRBV	InsCB
AccuRate band results	6.5	7.3	8.3	8.7

Comparing the new adaptive thermal limit with the AccuRate results indicates that the new adaptive thermal limit results for 90% acceptability limits matches the AccuRate results.

4. Conclusions

Existing energy thermal assessment tools assess the thermal performance of buildings using various rating techniques along with physical and material property assumptions to simulate the energy consumption. However, the dynamic nature of the external and internal conditions leads to significant differences between the theoretical and real results. The adaptive approach in the paper is based on the overall perceptions and resulting behavior of the occupants in achieving an adequate level of thermal comfort. The occupants decide an acceptable thermal comfort range by adapting to the internal environment of the building. This indirectly minimizes the energy usage and running costs of the building, thus enhancing its economic, environmental and sustainable performance.

A new universal sustainable building assessment tool to characterise the thermal performance of various buildings has been described. The study confirmed that the method is able to compare the thermal performance of different building types under variable weather conditions.

For the comparison of the performance of four housing test modules constructed with different walling systems, the results showed that the InsCB module has the best overall thermal performance, followed by the InsRBV, InsBV and CB modules. These outcomes were consistent with the results obtained using the energy assessment tool (AccuRate) and earlier research on the same modules and walling systems.

These promising results may facilitate the use of this technique as a new buildings assessment method to accurately predict the thermal performance of any building envelop to sustain an appropriate thermal comfort level.

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References

Rabah, K. (2005). Development of energy-efficient passive solar building design in Nicosia Cyprus. Renewable Energy, 30(6):937e56.

Alterman, D., Page, A., Moghtaderi, B., Zhang, C. (2015). Contribution of thermal resistance and thermal mass to the energy demand of walling systems, Mauerwerk. Volume 19, Issue 1, (/doi/10.1002/dama.v19.1/issuetoc) pages 64–73.

Moffiet, T., Alterman, D., Hands, S., K., Colyvas, Page, A., Moghtaderi, B. (2015). A statistical study on the combined effects of wall thermal mass and thermal resistance on internal air temperatures. Journal of Building Physics. 38 419-443 DOI: 10.1177/1744259113516248.

Alterman, D., Moffiet, T., Hands, S., Page, A., Luo, C., Moghtaderi, B. (2012). A concept for a potential metric to characterise the dynamic thermal performance of walls. Energy and Buildings, 54; 52-60.

Page, A., Moghtaderi, B., Alterman, D., Hands, S. (2011). A study of the thermal performance of Australian housing. Priority Research Centre for Energy. The University of Newcastle.

Nicol, J., Humphreys, M. (2002). Adaptive thermal comfort and sustainable thermal standards for buildings. Energy and Buildings, 34; 563-572.

De Dear, R.J., Brager, G.S. (1998). Towards an adaptive model of thermal comfort and preference. ASHRAE Transactions, 104 (1); 145-167.

Brager, G.S., de Dear, R.J. (2001). Climate, comfort and natural ventilation: A new adaptive comfort standard for ASHRAE Standard 55. Proceedings, Moving Thermal Comfort Standards into the 21st Century, Windsor, UK.

Tyler, H., Stefano, S., Alberto, P., Dustin, M., Kyle, S. (2013). CBE Thermal Comfort Tool. Center for the Built Environment, University of California Berkeley, available on: http://cbe.berkeley.edu/comforttool/.

Hearne Software/Energy Inspection. AccuRate Sustainability (V2.3.3.13 SP1). Help tool.