THE IMPORTANCE OF SIMULATION BEYOND ENERGY RATING

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ABSTRACT

This paper reports on a study of the thermal performance of two-storey apartments in Adelaide, South Australia. The overall design achieved an energy rating score around 7.5 Stars in the Australia's National Home Energy Rating Scheme (NatHERS); however, without air-conditioning some of the spaces were considered too warm during hot weather. Aspects of the building design and operation that contribute to poor performance are investigated. The paper points out that performing simulation to obtain an energy rating of the whole building may lead to incorrect assumptions about the building design, and argues that it is crucial to assess the performance of individual spaces at critical times in addition to performing energy rating.

INTRODUCTION

Predicting the energy performance of a new building design and comparing it to a reference value as determined in a building code has now become a standard procedure in many countries. In EU countries, the Energy Performance of Building Directive (EPBD) has encouraged countries to develop their strategies for building energy certification (Miguez et al. 2006, Hernandez et al. 2008, Ballarini and Corado 2009). This practice, often referred to as building energy rating, can be in the form of prescribing minimum standards, for example for temperature settings, air-tightness as well as light and heat transmissions. Another method is by performing energy calculations using building performance simulation to provide the prediction of the annual energy use of the entire building (Pérez-Lombard et al. 2009) and comparing the prediction with either a reference value or the performance of a reference building (ASHRAE 1989, Yik et al. 1998, National Resources Canada 1999, Soebarto and Williamson 2001, BRE 2012).

While a building design may meet the total energy requirement when assessed with an energy rating tool, as the intention is to obtain the total energy use, this rating process may overlook the thermal performance of individual spaces at times that are critical for thermal comfort. A building design that achieves a high energy rating can actually have some spaces that are not thermally comfortable at certain times, but their high heating or cooling demand may be compensated for by the low energy requirements of the other spaces or during periods when heating and cooling demand is low. Similarly, the rating for a building in a climate that requires long periods of heating may mask the fact that the cooling period, although short, may be intense, uncomfortable and even dangerous for some occupants.

This is an important consideration in light of predictions that many areas of the world will experience higher temperatures and more heat waves in coming decades (IPCC 2012, CSIRO 2007). Heat waves are a major source of weather-related fatalities in Australia (BOM 2011) with the elderly, chronically ill and low-income earners identified as particularly vulnerable (PwC 2011). For these groups, relying on air conditioning for thermal comfort is not ideal. Many people vulnerable to heat either do not have air-conditioning or may be unwilling to use it due to rising energy costs (Maller and Strengers 2011) and, furthermore, power outages are common during heat waves (Institute of Sustainable Resources 2010). Many authorities stress the importance, for those vulnerable to heat, of good climate-adapted or passive design over air-conditioning (McGregor et al. 2007, WHO 2004). In this regard, building simulation can be an important tool for improving knowledge of the performance of buildings during hot weather and not only for rating the overall building thermal or energy performance.

This paper reports on a study that is part of a research program, *Framework of Adaptation of Australian Households to Heatwaves* supported by the Australian Government's National Climate Change Adaptation Research Facility (Saman et al. 2012), where two of the main aims are to investigate occupants' thermal responses and adaptation to heat waves and the implications for building design. The study involves indoor environmental monitoring and a thermal comfort survey of 60 households; however, this paper focuses on ten dwellings for low to middle-income earners, considered to be part of the more vulnerable groups during extreme weather. While the overall building design achieves an energy rating score 7.5 Stars (out of 10 Stars maximum) in the Australia's National Home Energy Rating

Scheme (NatHERS) (Department of Climate Change and Energy Efficiency 2011), it is important to assess the indoor climate particularly during hot weather and when air-conditioning is not necessarily in use due to various reasons.

METHODOLOGY

The study employs a number of methods. First, interviews of the residents were conducted to gather information about their demographic background and strategies to ventilate and cool the dwelling and in particular in dealing with heat. Second, the internal temperatures and humidity in the living rooms and main bedrooms were measured and recorded continuously every 15 minutes over 3 summer months in 2012. Third, during the monitoring period the occupants were asked to respond to a “right here, right now” thermal comfort survey about their thermal sensation on ASHRAE 7-point scale, thermal preference on McIntyre 3-point scale, clothing type, activity, and ventilation strategy at the time. Results from the thermal comfort survey and indoor monitoring have been collated and analysed, and the results have been reported in Saman et al. (2012).

The monitored data, converted to an hourly interval, were then used to calibrate thermal simulation models of the dwellings. All dwellings had been previously simulated using the *AccuRate* software (Hearne Scientific Software 2013, Delsante 2005) in order to obtain their NatHERS energy rating. The simulation engine of *AccuRate*, originally called *Cheetah/ Chenath,* is based on the response factor method. The program has been tested and validated (Lomas et al. 1997, Delsante 2004) and Daniel et al. (2012) reported results of intermodal and empirical comparisons of simulation models AccuRate, Energy Plus (Crawley et al. 2008) and Ener-win (Degelman and Soebarto 1995).

Rating with this software is based on the total energy load for heating and cooling, compared to a reference value for a certain climate zone. For example, in climate zone 16, which is the zone for the case study building location, a rating of 1 is given when the total heating and cooling load is 446 MJ/m^2 while a rating of 10 is achieved when the total load is 3 MJ/m^2. For rating purposes a standard weather file (from the International Weather for Energy Calculations (IWEC)) was used; however, to calibrate the models by matching the predicted indoor temperatures to measured data, a real weather file, based on data from the local weather station, was compiled and used. These data consist of hourly temperature, humidity, global, direct and diffuse solar radiation, as well as wind speed and direction.

For this study the dwellings were simulated in the non-rating (free-running) mode to investigate indoor thermal comfort during the periods when cooling was not used in the actual dwellings. To ensure the accuracy of the model, the Coefficient of Variance of the Root Mean Square Error (CV(RMSE)) between the simulated results and measured data is calculated. A CV(RMSE) up to 20% is considered acceptable for hourly calibration (Bou-Saada & Haberl 1995, Kreider and Haberl 1994). Using the calibrated models, a number of alternative design strategies were then implemented to find out whether or not the indoor thermal comfort of the dwellings, particularly in the bedrooms, could be improved.

This paper concentrates on the conditions in the bedrooms for three reasons:

1. Many occupants mentioned during the interviews that the bedrooms became uncomfortably hot, particularly in the upper floors.
2. The bedrooms in these apartments do not have an air conditioner.
3. Conditions in bedrooms and a lack of sleep have been identified as risk factors for heat-affected people (Vandentorren et al. 2006).

CASE STUDY

Location

The apartments are located in a housing development, established as a model “green village”, situated 8 km northeast of Adelaide CBD, South Australia (34.8° SL, 138.6° EL). Adelaide has a mediterranean climate, with cool, wet winters and hot, dry summers. There is more heating required annually than cooling; however, though relatively shorter, the summer period can be quite hot. The hottest months are January and February, but the heat often continues into early April. In recent years there have been some record-breaking heat waves. In 2008 Adelaide had 15 consecutive days over 35 °C and in 2009 there were 6 days over 40 ºC (BOM 2010). During the study period, the maximum external temperature was 39.7 °C and it was more than 30 °C for 7.6% of total hours; however, there were no periods that could be called a heat wave according to the current Bureau of Meteorology definition for Adelaide: i.e. 5 consecutive days of 35 °C or more or 3 days of 40 °C or more. Tables 1 summarises the outdoor temperatures and humidity during the study period.

Table 1 Outdoor temperature (deg C) during the study

	February	March	April
Max	39.7	34.9	34.5
75%	26.3	23.1	21.3
Mean	22.1	20.1	18.5
25%	17.2	16.4	14.5
Min	12.1	11.4	8.7

The apartments

The apartments are a mixture of owner-occupied and rented properties with a high proportion of public authority housing. The units are either single or double-storey and all except one have two bedrooms. The exception, the largest unit, has three bedrooms. All one-storey units, whether they are on the ground or first floor, have a similar layout with a combined living, dining and kitchen space facing north, two bedrooms with south facing windows, and a combined bathroom and laundry room in the centre of the unit (Figure 1). In the two-storey units, the ground floor usually consists of the combined living, dining and kitchen space, bathroom and laundry to the south and bedrooms on the first floor.

This particular housing development has strict guidelines for site planning and the design of the buildings covering areas such as orientation, set back, window types, shading and more importantly, the requirement for 7.5 Stars (out of 10 Stars maximum) in Australia's National Home Energy Rating Scheme (NatHERS). This equates to a total heating and cooling energy load of 57 MJ/m^2 whereas the mandatory minimum requirement for housing in South Australia is 6 Stars or 96 MJ/m^2. In the case of the apartments, the apartment complex as a whole was required to achieve an average of 7.5 Star per dwelling with some achieving more than 8 Stars and the lowest achieving 6.6 Stars.

Building construction and systems

External walls are a combination of double (cavity) concrete blocks (total R Value of 0.47 m^2. °K/Watt un-insulated and 1.55 m^2. °K/Watt insulated) or insulated reverse masonry veneer (total R Value of 1.89 m^2. °K/Watt). Floors are concrete slabs apart from the upper level floors in double-storey apartments, which are timber. The ceilings and roof are insulated with R2.5 and R2 (2.5 and 2.0 m^2. °K/Watt) insulation respectively whilst the windows are timber-framed with low-e glazing (U = 3.92 W/m^2. °K: SHGC = 0.42).

For passive cooling, the main strategy is through a ventilation-stack positioned centrally in the hallway connecting the living room and bedrooms to release built-up warm air from these spaces. This stack ventilation has been designed to be used in conjunction with opening the windows in the living room and bedrooms. The ventilation is controlled via motorised louvers linked to a split reverse-cycle system air-conditioning system, which is placed on the ceiling of the small hallway leading to the bedrooms. It was found during the site visits, however, that the air registers of the air conditioners face only the living room and not the bedrooms. There was no other cooling mechanism in the bedroom except the ceiling fan. The combined living, dining room and kitchen also have ceiling fans.

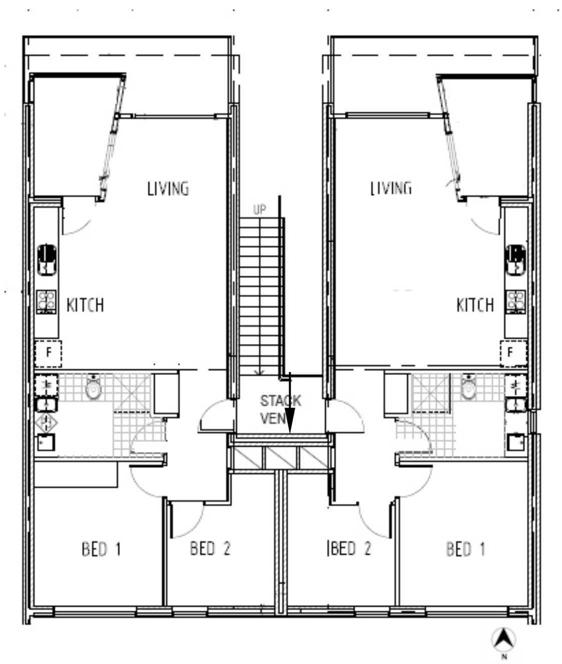

Figure 1 Example of a typical floor plan of a dwelling unit

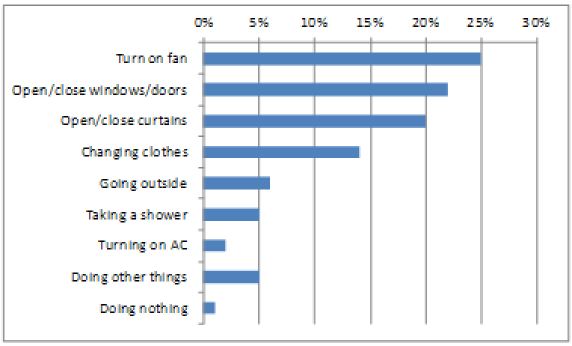

Figure 2 Occupant strategies when it is too warm

RESULTS

Occupants comfort and cooling strategies

All occupants were asked about their strategies for dealing with hot weather and their use of the air conditioners. Most of the respondents expressed concerns about the cost of using the air-conditioner hence other cooling strategies were used before the air conditioner was operated including turning on fans, opening windows when it was cooler outside, going outside and changing clothes (Figure 2).

During the study period the majority of the occupants (57%) were wearing light clothing and moderate clothing accounted for 30% of the responses, while very light clothing accounted for 8% of the time. Less than 5% of the responses came from respondents wearing heavy clothing. Thus, it can be concluded that the occupants wore clothing appropriate for the anticipated thermal conditions.

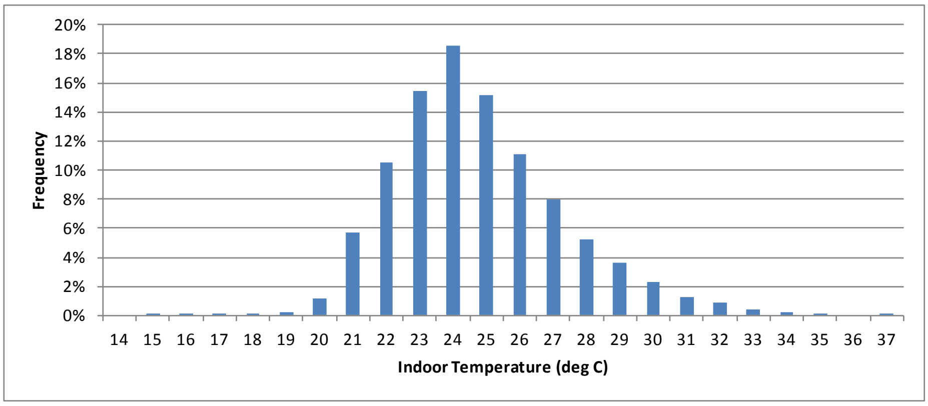

Figure 3 Frequency distribution of hourly indoor temperature in all bedrooms (1°C binning)

Figure 3 shows the frequency of distribution of the indoor temperature in the bedrooms. About 22% of the time the temperatures were above 26°C while the maximum reached 35° in one dwelling.

The average thermal sensation vote was calculated for every 1.0°C indoor temperature interval, shown in Figure 4. In the bedrooms, the 'neutral' to 'slightly warm' vote (0 to 1) was found to be between 23 to 26.7°C, 'slightly warm' to 'warm' (1 to 2) was between 26.7 and 30.3°C, and 'warm' to 'hot' (2 to 3) was between 30.3 and 34 °C. Figure 5 presents the relationship between thermal sensations and ventilation/cooling strategies for the entire dwellings. It is apparent that the use of air-conditioners (in the living rooms) only became more frequent when the occupant's thermal sensation was 'hot'.

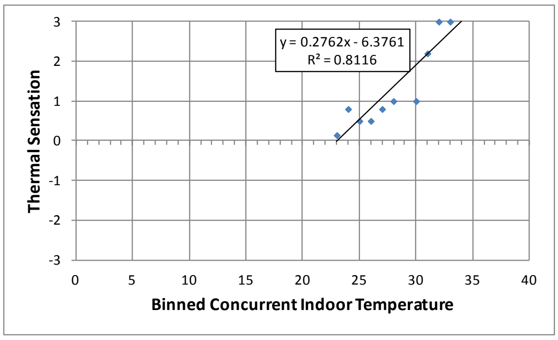

Figure 4 Bin average thermal sensation votes binned indoor temperature in the bedrooms

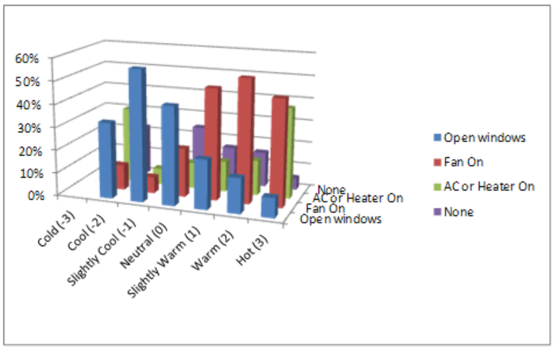

Figure 5 Occupant thermal sensations and ventilation/cooling strategies

These results show that although the building design achieves an average of 7.5 Stars, indicating a relatively low energy load compared to that of standard housing in South Australia, there was a considerable amount of time when the occupants felt beyond 'slightly warm'.

Focusing on the comfort performance of the bedrooms, the following section investigates ways to improve the building design in order to minimise the periods when the occupants would feel 'slightly warm' to 'hot', using simulation.

Analysis of the existing design

Due to paper limitation, only the analysis of three of the ten dwellings is presented here. Three dwellings have been selected to demonstrate a variety of conditions: an upstairs unit with a west-facing wall (Unit 1), an upstairs unit (Unit 2) and a ground floor unit (Unit 3), both in the middle of the block. All simulation inputs from the rating have been checked to ensure they well represent the actual building construction. Note that although the stack ventilation shaft is modelled, the opening to the hallway is assumed to be closed all the time because in reality the occupants stated that they rarely used it.

Figures 6 to 8 show the comparisons of the simulated and measured indoor temperatures of the bedrooms of the three dwellings. For clarity in presenting the results graphically, only 2-weeks of comparisons are shown here. The statistics of the comparisons are presented in Table 2, confirming that the models well represent the actual design within an acceptable range of accuracy. These calibrated models are then used to investigate design alterations to improve the comfort performance of the building particularly the bedrooms during a hot summer period.

Table 2 Statistics of comparisons between simulation results and measured data

	Average difference	Maximum difference	CV(RMSE)
Unit 1	1.2°C	3.5°C	5.1%
Unit 2	1.1°C	3.3°C	5.0%
Unit 3	1.6°C	5.8°C	8.6%

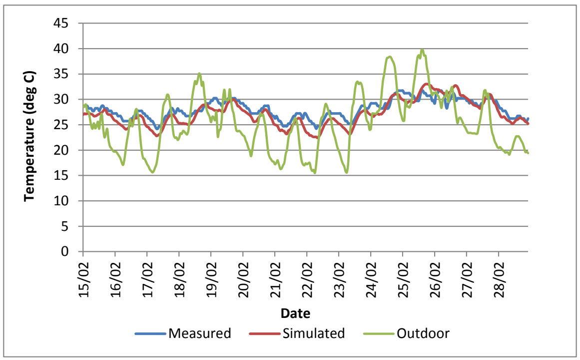

Figure 6 Measured and simulated bedroom temperatures of Unit 1

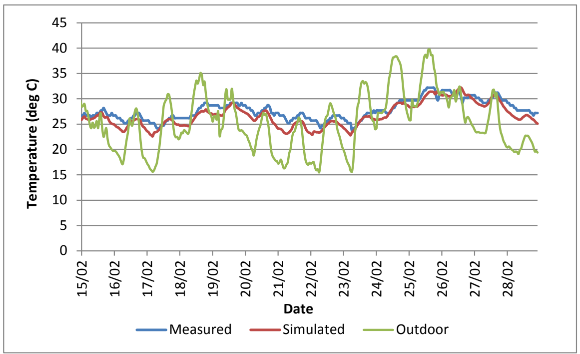

Figure 7 Measured and simulated bedroom temperatures of Unit 2

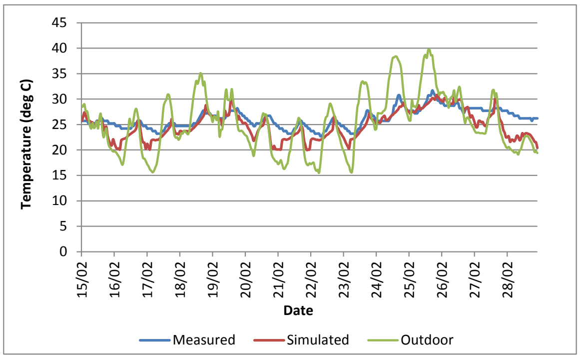

Figure 8 Measured and simulated bedroom temperatures of Unit 3

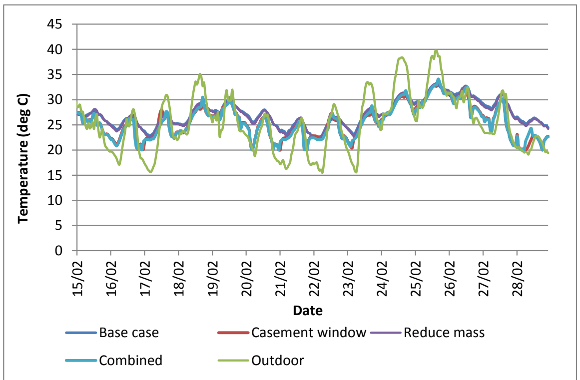

Figure 9 Changes in bedroom temperatures of Unit 1 due to design alterations

The simulation results show that in those 2 weeks, the bedroom in Unit 1 experiences 53% of the time temperatures above 26.7° (the temperature identified at which occupants are likely to feel 'slightly warm' to 'hot'). If only considering the time when the bedroom is occupied (between 4 pm to 9 am, which is the assumed occupied hours of the bedroom in the *AccuRate* program), this bedroom experiences slightly warm to hot conditions for 49% of the time. Unit 2's bedroom experiences slightly less hours of temperatures above 26.7 ° with 41% of the time in total, or 39% during the assumed occupied hours. Being on the ground floor, Unit 3's bedroom experiences the least amount of time of temperatures above 26.7°, with 24% in total or 23% during assumed occupied hours. These results show that, despite the fact that the building achieves an average rating of 7.5 Stars, the bedrooms of these apartments experience temperatures above 26.7° for a considerable amount of time.

Based on the information from the occupants, confirmed with observations during the site visits and information from the drawing, one of the major problems in the bedrooms is lack of cross ventilation. The bedrooms have awning windows that can only be opened up to 100 mm. The second problem is internal mass and insulation – for such a small space, there is a considerably large amount of thermal mass, which means, once the space heats up, it takes a long time for the heat to escape to the outdoor. The bedrooms in Units 2 and 3 are also carpeted, which means the build-up heat is retained inside the room even in hot summer days. For Unit 1, the bedroom is also affected by the exposure of the western wall to the afternoon sun.

Proposed changes

This section discusses the impact of altering the design using the calibrated model by: (1) changing the window type and openability, (2) reducing internal mass of Unit 1, ie. by changing the internal leaf of the external wall to insulated timber stud wall, (3) removing the carpet in Units 2 and 3, and combining all these strategies. Note that these investigations focus on lowering the bedroom temperatures at night because that is when the bedroom is likely to be occupied.

Changing all windows of the bedrooms to casement windows with 60% openablity has the largest impact on reducing the indoor temperature as the window opening would allow more heat loss and night-time ventilation. Note that in the simulation, the windows are (logically) assumed to be closed when the outdoor temperature is above the indoor, hence increasing the openability of the windows would not reduce the peak bedroom temperature that occurred when the outdoor reached 39.7 °C.

In the upstairs Units (1 and 2), changing the window type and openability results in lowering the night-time temperature in the bedroom by between 2 to 5.8

°C (Figure 9). In the ground floor of Unit 3; however, changing the window type and openability has lesser impact.

In Unit 1, reducing internal mass only lowers the indoor temperature by a very small amount. The lighter construction actually makes the space warmer during the day as there would not be much mass to absorb the heat. In Units 2 and 3, removing the carpet from the bedroom could reduce the room temperature by 1 to 2 °C.

The combined strategies of changing the window type and openability as well as reducing internal mass (in Unit 1) or removing carpet (in Units 2 and 3) reduces the number of hours when the bedroom temperature is above 26.7 °C in those two weeks by 35%, 39% and 31% respectively. If only the assumed occupied hours are considered (between 4 PM and 9 AM), the reduction would be 38%, 40% and 23% respectively.

Other strategies were also investigated, including changing the roof colour to light colour, and adding external shading devices. It is found that adding shading does not cause much improvement because the existing window shading, in the form of overhangs or eaves, is already successful. Changing the roof colour to help improve the room temperatures of the upper floor would not make any difference. This is because the ceiling of the upper floor is already well-insulated thus changes in the roof cladding would not have much impact on the space underneath the ceiling insulation.

Rating of the new designs

With the above alterations, the energy rating of these three units are re-calculated. This is to investigate whether changing the design to improve performance in the free-running or non-airconditioned mode would also result in an improved performance if cooling and heating are used. It is found that for all three units, an increase of 0.2 Star rating would be achieved with the combined changes. In Unit 1, the cooling load is predicted to decrease by 27% whereas the heating load would be reduced by an average of 6%. In Units 2 and 3, the change would slightly increase the predicted heating load (if the carpet is removed) while the cooling load would be reduced by 23% and 12% respectively.

DISCUSSIONS

Though the change in the Star rating of these dwellings may not be significant, the changes in the design would have a noticeable impact on the cooling load. This points to an important issue – since the building is located in a temperate climate where heating is more dominant than cooling, only looking at the achieved energy rating may not reveal the performance of the individual spaces particularly in the summer.

Analyses of the monitoring and thermal comfort survey of the case study buildings and occupants show that the occupants would start to feel ‘slightly warm’ when the temperature is above 26.7°C. While this thermal sensation does not necessarily result in the occupants turning on the air-conditioners, the authors argue that it is important to investigate the design further and find ways to improve the building performance in order to reduce uncomfortable thermal environment for the occupants. This is a particularly crucial issue in the design of low-cost housing as the occupants are not necessarily financially able to use the air-conditioner.

The study found that, without air-conditioners in the two weeks of hottest period during the study, the bedrooms in the three dwellings experienced temperatures above 26.7°C between 23% and 40% of the time during the assumed occupied hours. The main issue of the design is found to be the window type and openability. The existing design has an awning type of windows, which can only be opened by no more than 100 mm. This has prevented nigh-time ventilation required to remove the build-up heat during the day.

The study found that changing the window to a casement type with 60% openability would significantly reduce the number of warm to hot hours by at least 23%. With another alteration (ie. reducing the internal mass in Unit 1, or removing the carpet in Units 2 and 3), the change in Unit 1 would reduce the number of hours of above 26.7 °C from 123 to 76 hours (Table 3) while in Units 2 and 3, the change would reduce the number of warm temperatures from 99 to 55 hours and 57 to 44 hours respectively. This means, if the windows can be opened to allow more night-time ventilation, the likelihood of using the air-conditioner would be much less thus the energy cost could be minimised.

Table 3 Summary of changes from the base case to the combined strategies

	Unit 1		Unit 2		Unit 3	
	Base case	Alt design	Base Case	Alt design	Base Case	Alt design
Total hours above 26.7°C	178	116	138	84	81	56
% of Total hours*	53%	35%	41%	25%	24%	17%
% Change	35%		39%		31%	
Occupied hours above 26.7°C	123	76	99	59	57	44
% of Total occupied hours**	52%	32%	42%	25%	24%	18%
% Change	38%		40%		23%	

*Total hours for 2 weeks = 336 hours; **Total occupied (assumed) hours for 2 weeks = 238 hours (4pm to 9 am)

CONCLUSION

This paper has demonstrated the importance of assessing the comfort performance in individual spaces of a residential housing in addition to looking at the whole building performance through energy rating of the overall building design. As rating tends to be based on the total heating and cooling load or energy, it can potentially mask the performance of certain spaces at crucial times. In the case study presented in this paper, though the building design as a whole achieves a relatively high energy rating (7.5 Stars out of a maximum of 10 Stars), the bedrooms suffer from high temperatures during a hot summer period including at night time when air-conditioning is not available. A warm to hot bedroom is a particular concern as research has shown that poor conditions in bedrooms and a lack of sleep can be risk factors for heat-affected people.

Using simulation, it is predicted that the thermal performance of the bedroom can still be improved if the bedroom windows are changed to a type that can be opened sufficiently to allow good night-time ventilation. Although other alterations could also have some impact, such as reducing internal mass by changing the walls to lighter construction, or by removing the carpet, changing the window type and openability would have the most significant impact. Further, this simple change will not require additional energy use, such in the case of running an air-conditioner.

This study has addressed:

(1) the importance of simple passive design strategies over the use of air-conditioner,

(2) the importance of assessing the thermal performance of individual spaces in addition to assessing the whole building performance such as in the case of building rating, and

(3) the role building performance simulation has in investigating ways to improve the performance of both the building and individual spaces.

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REFERENCES

ASHRAE (1989), ASHRAE/IESNA Standard 90.1-1989, Energy Efficient Design of New Buildings Except Low-Rise Residential Buildings, American Society of Heating Refrigerating and Air-conditioning Engineers, Atlanta.

Ballarini, I. and Corrado, V. (2009). Application of energy rating methods to the existing building stock: Analysis of some residential buildings in Turin, Energy and Buildings, Vol. 41(7): 790-800.

BOM (2011). Heatwaves, Commonwealth of Australia, Bureau of Meteorology, http://www.bom.gov.au/wa/sevwx/perth/heatwaves.shtml. viewed 27th October 2012

Bou-Saada, T E., & Haberl, J S. (1995). ‘An improved procedure for developing calibrated hourly simulation models’, Proceedings of Building Simulation 1995, IBPSA, Wisconsin, pp 475-484.

BRE (2012). National Calculation Method. Building Research Establishment, UK, http://www.ncm.bre.co.uk/. Accessed 14 January 2012.

Crawley, D B., Hand, J W., Kummert, M., & Griffith, B T. (2008). ‘Contrasting the capabilities of building energy performance simulation programs’, Building and Environment, vol 43, pp 661-673.

CSIRO (2007). Climate Change in Australia. Technical Report, Commonwealth Scientific and Industrial Research Organisation and Bureau of Meteorology.

Daniel, L., Soebarto, V. and Williamson, T. (2012). Evaluating the suitability of the AccuRate engine for simulation of massive construction elements, Proceedings of The 46th Annual Conference of the Architectural Science Association (ANZAScA), Griffith University, 14-16 November.

Degelman, L O. and Soebarto, V I. (1995), ‘Software Description for ENER-WIN: A Visual Interface Model for Hourly Energy Simulation in Buildings’, Proceedings of Building Simulation 1995, IPBSA, Madison, pp 692-696.

Delsante, A. (2004). A validation of the ‘AccuRate’ simulation engine using BESTEST, CSIRO, Sydney.

Delsante, A. (2005). Is the new generation of building energy rating software up to the task? - a review of Accurate, Proceedings of ABCB Conference ‘Building Australia’s Future 2005’, Surfers Paradise, 11-15 September 2005.

Delsante, A. Hernandeza, P., Burkeb, K, and Lewisa, J.O. (2008). Development of energy performance benchmarks and building energy ratings for non-domestic buildings: An example for Irish primary schools, Energy and Buildings, Vol. 40(3): 249–254.

Department of Climate Change and Energy Efficiency (2011). Nationwide House Energy Rating Scheme (NatHERS), Administrative and governance arrangements, January.

Hearne Scientific Software (2013). AccuRate Sustainability. http://www.hearne.com.au/products/accurate/ Accessed 15 January 2013.

Hernandez, P., Burke, K., Lewis, J.O. (2008). Development of energy performance benchmarks and building energy ratings for non-domestic buildings: An example for Irish primary schools, Energy and Buildings 40(3): 249-254

Institute of Sustainable Resources (2010). Impacts and adaptation responses of infrastructure and communities to heatwaves: the southern Australian experience of 2009, Final case study for National Climate Change Adaptation Research Facility.

IPCC (2012). Managing the risks of extreme events and disasters to advance climate chane. Cambridge, U.K.

Kreider, J F., & Haberl, J S. (1994). 'Predicting Hourly Building Energy Use: The Great Energy Predictor Shootout - Overview and Discussion of Results', ASHRAE Transactions, vol 100, no 2, pp 1104-1118.

Lomas, K J., Epple, E., Martin, C J., & Bloomfield, D P. (1997). Empirical validation of building energy simulation programs, Energy and Buildings, Vol 26, pp 253-275.

Maller, C. J. & Strengers, Y. (2011). Housing, heat stress and health in a changing climate: promoting the adaptive capacity of vulnerable households, a suggested way forward, *Health Promotion International*, vol. 26, no. 4, December 1, 2011, pp. 492-498

McGregor, G., M. Pelling, Wolf, T. & Gosling, S. (2007). Using science to create a better place - The social impacts of heat waves. Science Report for Environment Agency. Bristol.

Míguez, J.L., Porteiroa, J., López-Gonzálezb, L.M., Vicuñab, J.E., Murilloa, S., Morána, C. and Granadaa, E. (2006). Review of the energy rating of dwellings in the European Union as a mechanism for sustainable energy, Renewable and Sustainable Energy Reviews, Vol. 10 (1): 24–45.

National Resources Canada (1999). Performance Compliance for Buildings—Specifications for Calculation Procedures for Demonstrating Compliance to the Model National Energy Code for Buildings Using Whole Building Performance, Canadian Commission on Building and Fire Codes, May.

Pérez-Lombarda, L., Ortizb, J., Gonzáleza, R., and Maestrec, I.R. (2009). A review of benchmarking, rating and labelling concepts within the framework of building energy certification schemes, Energy and Buildings, Vol. 41(3): 272–278.

PwC (2011). Protecting human health and safety during severe and extreme heat events: A national framework, report prepared by PricewaterhouseCoopers Australia for the Commonwealth Government.

Saman, W., Bennetts, H., Miller, W., De Dear, R. and Soebarto, V. (2012). A framework for adaptation of Australian households to heat waves. Report to the National Climate Change Adaptation Framework.

Soebarto, V.I. and Williamson, T.J. (2001). Multi-criteria assessment of building performance: theory and implementation, Building and Environment, Vol. 36(6): 681-690.

Vandentorren, S., et al. (2006). 'Heat-related mortality - August 2003 heat wave in France: risk factors for death of elderly peple living at home', European Journal of Public Health, 16 (6), 583-91.WHO (2004). Health and global environmental change: Heat waves: risks and responses, World Health Organisation.

WHO (2004). Health and global environmental change: Heat waves: risks and responses, World Health Organisation. Series 2

Yik, F.W.H., Burnett, J., Jones, P. and Lee, W.L. (1998). Energy performance criteria in the Hong Kong Building Environmental Assessment Method, Energy and Buildings, 27 (1998): 207–219.