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Occupant comfort, the housing industry and electricity infrastructure: understanding the synergies

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ABSTRACT

Despite increasingly stringent energy performance regulations for new homes, south-east Queensland has a high and growing penetration of, and reliance on, air conditioners to provide thermal comfort to housing inhabitants. This reliance impacts on electricity infrastructure investment which is the key driving force behind rising electricity prices. Using a case study approach, this paper reports initial findings of a research project that seeks to better understand three key issues. First, how families manage their thermal comfort in summer and how well the internal temperatures of these homes reflect the simulated thermal performance used as part of the building approval regulation; second, the extent to which the homes have been constructed according to the building approval documentation; and third, the impact that these two issues have on urban design, especially in relation to electricity infrastructure in urban developments.

Keywords: building simulation, housing, thermal performance, urban infrastructure

Introduction

South-east Queensland's predicted population growth will require an additional 754,000 dwellings [1], providing challenges and opportunities for urban design. Despite a relatively benign subtropical climate (26-28° south) where 65% of annual hours are within 18-28°C, the region currently has more than 1.6 million air-conditioners servicing about 1.2 million dwellings. 74% of the region's homes are thought to have air conditioners and the rate of installations in 2010 was around 3000 systems per week[2]. 13% of the region's electricity network is utilised for less than 1% of the year – on extreme temperature days – representing a massive overcapitalisation in infrastructure that must be passed on to consumers and through infrastructure charges on developments [3]. The optimisation of house design and construction to provide occupants with thermal comfort whilst reducing reliance on heat removal devices, has benefits for occupants as well as electricity networks and urban development [4-6].

The aim of the research was to examine, from multiple sources, the thermal performance of six houses during a period of four consecutive hot summer days. The purpose of the research was to gain a better understanding of the synergies between house design, house performance and occupant behaviour. Such understanding underpins the design and cost of energy infrastructure in urban development.

Methodology

The houses: The objects of the research are six detached dwellings in a master planned residential estate - Springfield Lakes – in Queensland, Australia (latitude 27.6° south). All dwellings are one story and were constructed between 2004 and 2009 (since the introduction of energy efficiency regulations for housing). The estate is located in climate zone 2 (sub-tropical) as determined by the Australian Building Codes Board and climate data set 10 (Amberley) is used for building simulations according to the Australian National Home Energy Rating Scheme (NatHERS) [7].

The families: The houses are occupied by a total of 18 individuals. Family types vary from single parent families to couples with children and adults without children. The employment status of adults includes full-time, part-time and shift-working jobs. One or two adults of each household participated in a semi-structured interview including general demographic questions followed by specific questions about the house air conditioning (AC) system and how frequently occupants use the AC during summer. The survey also included questions about occupants' thermal comfort expectations and how they behave during hot days before turning on AC (Table 1).

Data collection: BersPRO 4.2, an accredited simulation program under NatHERS, is being used to simulate the thermal performance of the building envelopes according to the building approval (BA) plans for each house. To measure actual thermal performance, each of the houses had multiple temperature sensors installed in the main living room, bedroom and another section of each house (e.g. office or second bedroom). A sensor was also located on the main air conditioner (AC) outlet of each house (the main living room) and in the outdoor patio area. Sensors recorded temperature data every 15 minutes, at a resolution of half a degree Celsius. A relative humidity sensor was also placed in the main living room. The period of study for this paper was February 28 – March 2, 2012. These dates presented four consecutive days where the maximum temperature was over 30^{o}C, as recorded by the Bureau of

Meteorology (BOM) at weather station 040004 (Amberley), approximately 22 km north-west of the Springfield Lakes. Key temperature data is shown in Table 2.

Table 1 Demographic, construction and experiential variables of case study houses

Indicator		**House Variables**					
		House 1	**House 2**	**House 3**	**House 4**	**House 5**	**House 6**
Number of occupants	*Child*	0	2	3	0	2	1
	Adult	1	2	2	3	2	1
Occupancy		Work from home	Children at home	Children at home	Nil Daytime	Shift work	Shift work
Construction year		2004/8	2007	2009	2007	2007	2006
Building area (m^2)		198.48	234.84	191.12	155.4	217.4	140.6
Internal living area (m^2)		182.03	173.99	146.64	120.6	166.6	Est. 110
AC system/s		Whole house ducted	Split units	Split unit	Split unit	Split units	Split units
Number of ACs		1	5	1	1	2	2
Other cooling		Ceiling fans	Ceiling fans	Ceiling fans	Ceiling fans	Ceiling fans	Portable fans
AC use during summer		Day: office & living room; whole house when hot	Day: living room when <32; night – bedrooms	Living room when <28^0	Living room when <26^0	Living room and main bed when <30^o	Living room and main bed when<30^0
AC thermostat set point		24^{o}C	24^{o}C	24^{o}C	24^{o}C	25^{o}C	24^{o}C
Use of window openings for cross ventilation		Not in summer	Yes; close when AC on	Yes; close when AC on	Some-times	Some-times	Some-times

Table 2 Amberley BOM (and Springfield Lakes) weather observations for study period

	28 Feb 2012	**29 Feb 2012**	**1 Mar 2012**	**2 Mar 2012**
Minimum temperature (°C)	17.9 (22.16)	16.2 (21.66)	17.3(21.16)	16.9(20.66)
Maximum temperature (°C)	30.4 (35.16)	32 (34.66)	31.9(34.16)	33.2(36.16)
Mean temperature (^{o}C)	24.15(26.5)	24.1(26.86)	24.6(26.99)	25.06(27.19)
9am Temperature (°C)	26.1(25.6)	23.8 (27.17)	25.6(27.17)	25.8(27.17)
9am relative humidity (%)	73	83	72	62
3pm Temperature (°C)	29.5 (34.67)	31.4 (34.66)	31.4(33.66)	32.4(35.16)
3pm relative humidity (%)	48	46	39	39

Results

All households stated that they operated their air conditioner/s in response to changing external climatic conditions, rather than leaving the AC on all / most of the time during summer (Table 1). Their reported behaviour closely matches the assumptions made by NatHERS i.e. that occupants will manage their comfort by firstly using natural means (e.g. opening windows), secondly by using mechanical means (e.g. ceiling fans to increase air flow and hence sense of comfort [8]) and lastly by removing excess heat (e.g. through air conditioning). The cooling set points of the air conditioners, though, are not reflective of their stated decision points to operate the air conditioner, but rather seem to be a reflection of government and utility messages that seem to convey that 24-25°C is the optimal temperature for operating air conditioners [9, 10].

External temperature measurements at Springfield Lakes reveal higher minimum and maximum temperatures than weather station data (table 2), although similar diurnal temperature range. This is not unusual as housing estates are likely to suffer from the urban heat island effect due to higher radiant heat and restricted ventilation due to urban forms (building and road materials and urban layout). The mean temperature for these four days was 2.4 degrees hotter than Amberley. Histograms allowed analysis of how different rooms within each house responded to the external temperature over the period of 96 hours (figure 1). Assuming an adaptive comfort band of 18-28°C [6, 11], the histogram shows that the main bedroom and living room overheated – making these rooms hotter than the external temperature. It also shows that it is likely that the bedroom and office air conditioners were on for very short periods of time, but that the air conditioner in the living room was not utilised.

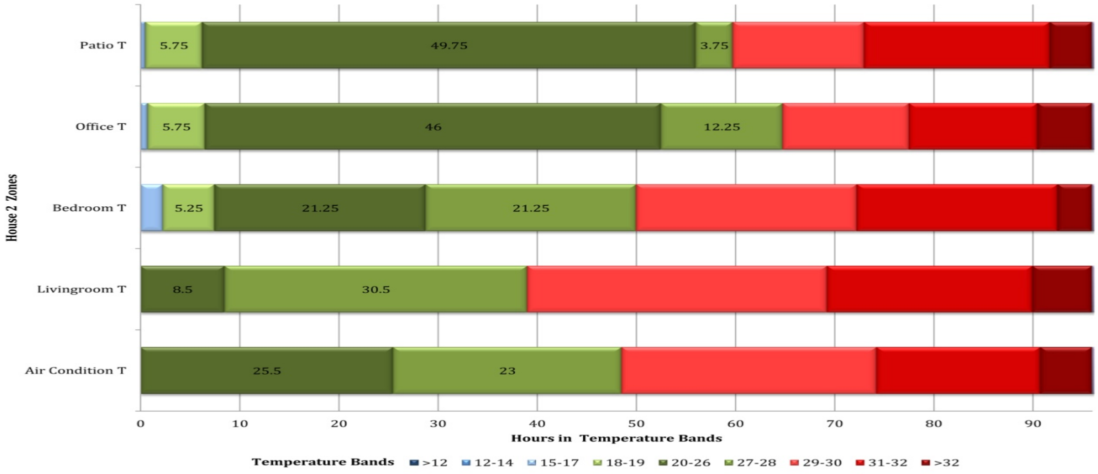

Figure 1: temperature histogram of House 2 Feb 28 – Mar 2

A comparison of the thermal performance of each of the main bedrooms with each other and the external temperature (Figure 2) shows that, with the exception of H1 which was air conditioned overnight, none of the bedrooms cooled overnight to the same extent as the external air. The slow rate of cooling in these rooms would seem to indicate that night cooling strategies are either not available (e.g. poor design) or are not being utilised by occupants (e.g. not opening windows overnight). H1 bedroom shows an internal temperature lag of approximately 2 hours and that this room exceeded the external temperature by several degrees. This would seem to indicate that the design features of the house (especially insulation and shading) are not being effective in limiting heat transfer into the building. The air conditioner was used to remove excess heat from about 5.30pm. (Note that all rooms show a temperature lag.) H6 bedroom indicates that it is likely the shift worker turned on the AC at about 1pm and that the thermostat was probably set to about 26°C.

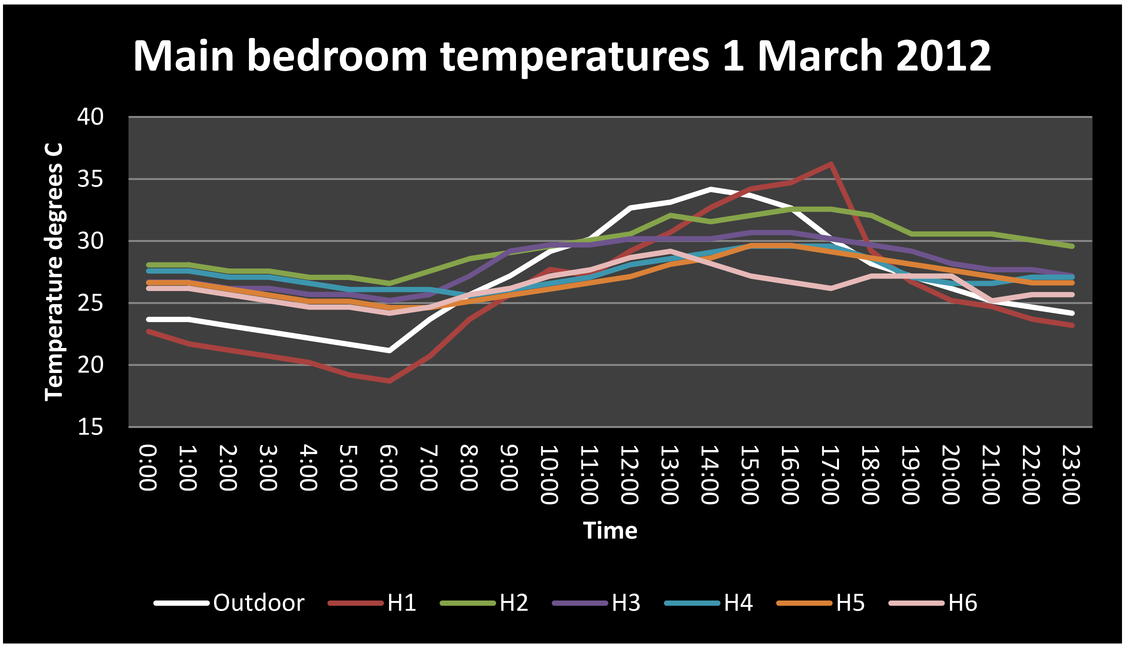

Figure 2: comparison of bedroom temperatures March 1

Discussion and Conclusion

The growth in the reliance on the electricity market to provide occupant comfort by pumping out excess heat, has significant economic, ecological and social implications [5]. Increased regulation of the thermal performance of the building envelope is meant to reduce the need for occupants to purchase space heating and cooling which accounts for an average of 38% of Australian household energy use and 20% of greenhouse gas emissions [12]. More analysis is needed on these houses (and the additional 20 houses being monitored), to try to identify why these houses appear to be overheating in summer. There is some evidence, based on initial examination of each house's design documentation and thermal images, that underperformance could be attributable to multiple parties in the housing supply chain, including designers, builders and the regulatory system, building inspectors and certification processes. This would be consistent with findings of underperformance in other energy efficiency technologies [13]. The thermal performance of bedrooms in particular needs addressing. NatHERS assumes that bedrooms are unoccupied for much of the day and therefore no cooling energy is applied prior to 4pm (for the process of house efficiency ratings). However in this study, only one house out of six was unoccupied during the day and four of the six houses had occupants who were very likely to regularly use bedrooms during the day and night (e.g. shift workers and young children). Furthermore, the overheating of the bedrooms (and the living rooms) presents challenges for electricity distributors as cooling of these spaces is likely to occur between 4-8pm, the peak demand time. Increasing the energy efficiency of the building envelope is considered the first vital step in moves towards zero energy homes [14] and one could argue that if houses were designed and built to dramatically reduce or eliminate over-heating, then the contribution to peak demand would be minimal. More research is required in this area, including the role that building simulation software, combined with regulatory compliance checking of buildings as constructed, could contribute to planning of our energy infrastructure to reduce overcapitalisation and lower costs.

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