

Proceedings of 8th Windsor Conference: *Counting the Cost of Comfort in a changing world* Cumberland Lodge, Windsor, UK, 10-13 April 2014. London: Network for Comfort and Energy Use in Buildings, <http://nceub.org.uk>

Evaluating the influence of thermal mass and window size in a direct gain system on the annual and lifetime energy consumption of domestic Australian light weight construction

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Abstract

Climate responsive design ensures thermal comfort in buildings without using excessive energy for heating and cooling. This study explores how the relationship between the quantity of north (equator) facing window area, the quantity of thermal capacity and the distribution of thermal capacity in a space can improve comfort and energy efficiency in residential buildings in Australia, and optimise lifetime CO₂-e emissions. The study concludes that thermal capacity can improve the thermal efficiency of the simulated structure, primarily through its influence on annual cooling loads. A direct gain system is only appropriate for the climate in Penrith. Thermal capacity should be used in Melbourne and Brisbane to mitigate summer overheating. When lifetime CO₂-e emissions are calculated no single configuration in any particular climate emerges as the optimal solution. The results suggest that it would be useful to explore further modifications to the fabric and form of the building in each climate.

Keywords: Thermal capacity, window size, embodied energy

1.0 Introduction

There are numerous factors that affect thermal comfort in a building. Climate responsive design ensures thermal comfort in buildings without using excessive energy for heating and cooling. Design decisions are made in response to the local climate which also influences our perception of thermal comfort (de Dear and Brager, 1998). An optimum design uses the orientation and organisation of the house on a site, the judicious placement and sizing of openings, insulation, ventilation and thermal capacity to create and maintain thermal comfort. This study explores how the relationship between the quantity of north (equator) facing window area, the quantity of thermal capacity and the distribution of thermal capacity in a space can improve comfort and energy efficiency in residential buildings in Australia. The analysis focuses on three climates in Australia's three largest population centres.

Thermal capacity stores and then releases thermal energy thus helping to stabilise the temperature range inside a building. Adding thermal capacity also means increasing the embodied energy of the construction system. A lightweight construction system, particularly if it uses timber products, contains significantly less embodied energy

than a heavyweight construction system using concrete and bricks (Hammond and Jones, 2008, Chen, 2010).

1.1 Australian lightweight construction

Domestic construction is dominated by lightweight and brick veneer construction systems. In terms of thermal performance brick veneer behaves in a very similar way to lightweight construction (Gregory et al., 2008, Sugo, 2004). The internal temperature of lightweight buildings tends to follow the external temperature profile. The use of domestic air-conditioning is increasing rapidly up from 59% in 2005 to 73% in 2011 (Australian_Bureau_of_Statistics, 2011), in turn this will lead to a significant increase in domestic CO₂ emissions since 96% of Australia’s energy comes from carbon based resources (BREE et al., 2013).

1.2 Australian Climates

There are a broad range of climates in Australia ranging from cool temperate in the south to tropical in the north. Australia’s three largest cities, Melbourne, Sydney and Brisbane, and the majority of the population are located on the east and south east coast. The three cities experience three different climates described in summary below. The climate data used for these descriptions was obtained from the Australian Bureau of Metrology (www.bom.gov.au). The comfort zone plotted on the temperature charts is defined by the adaptive comfort model with 80% acceptability (ASHRAE, 2010).

1.2.1 Melbourne

Melbourne’s climate (Figures 1 & 2) is cold and cloudy in winter; and warm, sometimes very warm or hot in summer. In the cooler half of the year the mean daily maximum temperature falls below the comfort zone with 10% of minimum temperatures (decile 1) below 5°C. Winter is cloudy with mean daily sunshine hours below 4. In the warmer half of the year the mean maximum temperature is within the comfort zone but the mean minimum temperature remains below the comfort zone. In summer extreme temperatures are experienced with 10% (decile 9) of maximum temperatures above 35°C in January and February (decile 9 - 35.6 and 34.7 °C). The mean diurnal range ranges from 7.2 degrees-C in June (winter) to 11.6 degrees-C in January (summer). Summer skies are predominantly cloudy.

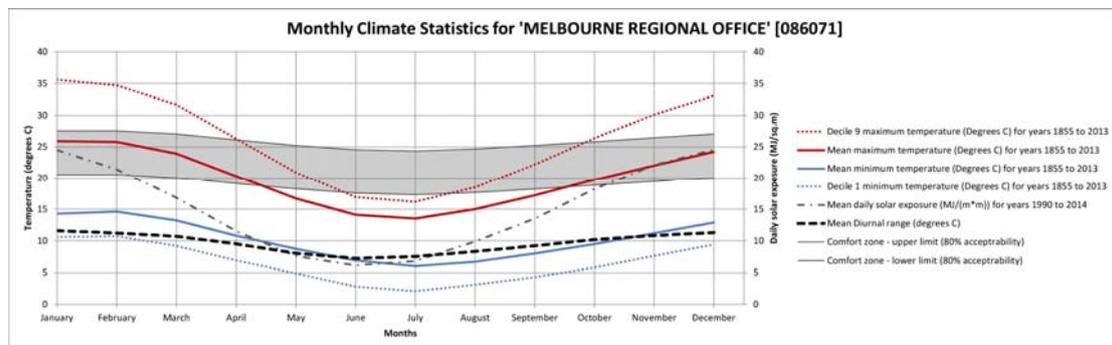


Figure 1. Annual temperature data for Melbourne

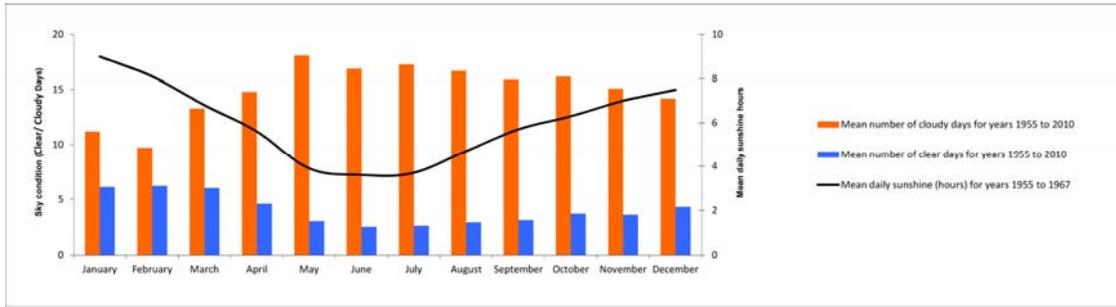


Figure 2. Annual sunshine data for Melbourne

1.2.2 Penrith (Sydney)

The climate in Sydney (figures 3 & 4) becomes significantly more extreme as the distance to the east coast increases. Penrith is about 30km from the coast. Penrith experiences hot summers, warm winter days with cool or cold winter nights. The mean maximum temperature is within the comfort zone for 9 months of the year, rising just above it in December and January and falling just below in July. More than 10% of maximum temperatures exceed 35 °C in December, January and February. In the cooler months of the year the minimum temperature falls below 5 °C more than 10% of the time between May and September. The winter sky is relatively clear and mean daily hours of sunshine remain high throughout the year. The mean daily diurnal variation is above 10 degrees-C throughout the year.

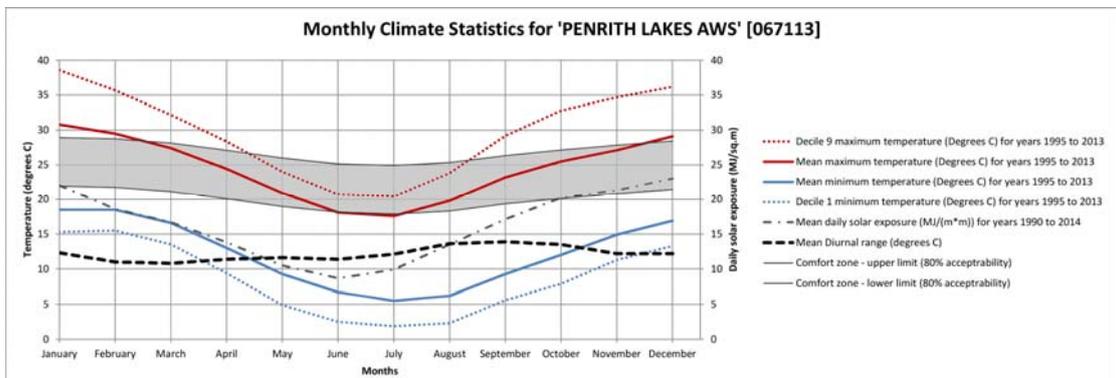


Figure 3. Annual temperature data for Penrith (Sydney)

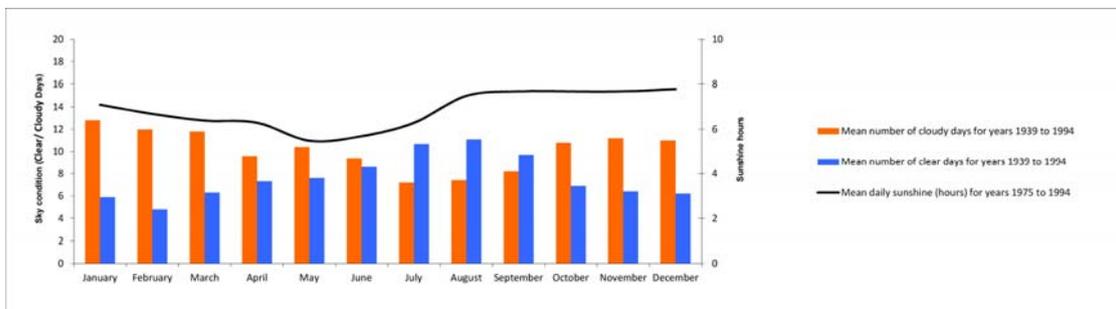


Figure 4. Annual sunshine data for Penrith (Sydney)

1.2.3 Brisbane

Brisbane's climate (figures 5 & 6) is warm and humid in summer and cool in winter. The mean maximum temperature remains within the comfort zone throughout the year ranging from the upper limit in summer to the lower limit in winter. The mean minimum temperature is below the comfort zone throughout the year falling to below 10 °C in July. More than 10 % of the minimum daily temperatures are below 10°C between May and September. The summer is dominated by cloudy and rainy days. Winter days are generally clear. Mean daily sunshine hours remain high throughout the year and rise in the winter and spring months. The maximum temperatures in summer are modest compared to the other two climates. The Mean daily maximum temperature does not exceed 30 °C and the highest recorded decile 9 temperature is 32.7 °C in January. The mean diurnal range varies from 8.7 degrees-C in January to 11.5 degrees-C in August.

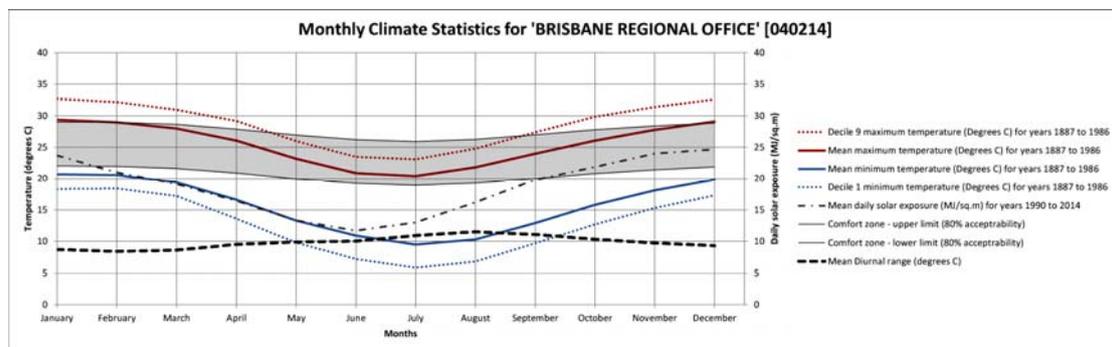


Figure 5. Annual temperature data for Brisbane

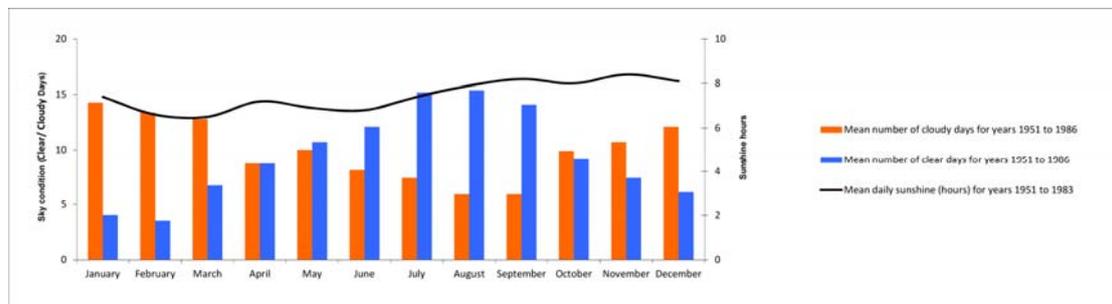


Figure 6. Annual sunshine data for Brisbane

2.0 Form and fabric

2.1 Design guidance

Design guidance promotes the use of thermal capacity in order to reduce energy consumption and increase comfort (Reardon, 2001, Hollo, 1986) (www.thinkbrick.com.au). This advice is qualitative rather than quantitative with little advice for designers interested in understanding how much thermal capacity is needed or where that capacity might best be located in the space (Slee and Hyde, 2011).

2.2 Direct gain systems

The design guidance proposes the use of a direct gain (or passive solar) system in all of the three climates being considered in this paper. In winter a direct gain system uses the thermal energy storage properties of thermal capacity to absorb solar energy during the day and then release that energy during the evening and night to help keep the space warm. During summer the windows are shaded to avoid sunlight entering the space directly and the thermal capacity is expected to absorb thermal energy from the air helping to lower the ambient air temperature. This thermal energy is dissipated using cool evening breezes.

2.3 Windows

The size, orientation and shading of the window is critical to this direct gain strategy since it controls both the quantity of solar energy allowed to enter the space and the ventilation of the space. A number of authors provide “rules of thumb” relating window area to the quantity of thermal capacity in a space assuming that the thermal capacity is on the floor. Evidence to support the suggestions is not provided and the suggested rules themselves vary widely between authors (Baggs and Mortensen, 2006, Greenland and Szokolay, 1985, Oppenheim, 2007) (table 1).

Table 1. Recommended north (equator facing) glazing area as a percentage of floor area

	(Greenland and Szokolay, 1985)	(Baggs and Mortensen, 2006)	(Oppenheim, 2007)
Brisbane	20-25% floor area	9.5%	-
Sydney		15.5%	-
Melbourne		13.5%	15–20% floor area

2.4 Ventilation

In passive and mixed mode systems ventilation is used to cool the fabric of the building and to provide sensible or comfort cooling for the occupants. In order to cool the fabric of the building a night ventilation strategy is employed. Shaviv et al(2001)has shown that the influence of the rate of ventilation on temperature follows a law of diminishing returns. Shaviv also finds that a minimum external diurnal temperature swing of 6°C is required for the strategy to be effective with good night ventilation (20 air changes per hour), Givoni (1998)suggests that the diurnal range should be 10°C. Kivva et al(2009) has shown that there is an optimum air speed around 2.5m/s for removing thermal energy from the fabric. Above and below this speed the removal of thermal energy becomes less efficient. La Roche and Milne (2004) carried out a series of experiments with two test cells in Los Angeles, California where they varied the thermal capacity, window size and ventilation method during summer months. They showed that an “intelligent” ventilation system that only ventilates the space when the outside air temperature is cooler than the internal air temperature is significantly more effective than continuous ventilation. They also showed that reduced solar penetration (smaller windows) and increased thermal capacity improves the thermal performance in the summer.

What these periodic ventilation methods fail to deal with is the need for some ventilation when a space is occupied in order to maintain adequate air quality and, during warmer weather, provide sensible cooling (ASHRAE_2010_Addendum_D, 2012, Toftum, 2004). In Australia, with the cultural emphasis on outdoor living, opening doors, windows and natural ventilation are an important part of any house design. This ventilation brings warmer air into a space that will, through convection and conduction warm up the fabric. In warm weather natural ventilation can also bring delight to the thermal experience because of its natural variation – the breeze (Xia et al., 2000, Zhao, 2007, de Dear, 2010).

2.5 Thermal capacity vs. Lightweight

Materials that possess the qualities of thermal capacity tend to be dense and require considerable amounts of energy to extract, move and process. The chemical reaction that turns limestone into concrete releases enormous quantities of CO₂. All of this energy is said to be “embodied” in the material that arrives on site. In contrast lightweight materials, particularly timber, are responsible for the emission of relatively low quantities of CO₂-e, or “embodied energy” (embodied CO₂-equivalent – E- CO₂-e). Some argue that the storage of carbon in the timber makes it a carbon negative building product. Others argue that since the building will be demolished the sequestration is only short term and so not relevant to climate change, or that the world's timber resources are shrinking so that while timber is, in theory, renewable it is currently not being renewed (Hammond and Jones, 2008).

The principles of the use of thermal capacity to improve the energy efficiency of a space are well established. When the embodied energy, or embodied CO₂-equivalent of the fabric of the building is also considered a balance has to be found between the initial investment of CO₂-equivalent into the fabric of the building and the energy saved over the lifetime of the building. How or where this balance is struck depends on the anticipated lifetime of the building, and the local climate.

In a study of an English semi-detached house Hacker et al found that, over 100 years in a scenario assuming a “medium-high” climate change scenario, a high capacity house would have lower lifetime E- CO₂-e emissions than a lightweight house (Hacker et al., 2008). The study suggests that after about 50 years the stabilising influence of thermal capacity on temperature saves enough energy to offset the initial high cost in terms of embodied CO₂.

Another UK study by Kendrick et al has suggested that while thermal capacity can be very useful lightweight construction can be optimised to achieve similar levels of thermal comfort (Kendrick et al., 2012). Kendrick et al suggest that the design approach needs to be more nuanced than simply thermal capacity or lightweight, pointing out that thermal capacity can help keep a room cool during the day but then make it harder to cool down in the evening. They suggest that bedrooms would be better built from lightweight construction because they are used at night so it is important to be able to get them to a comfortable temperature quickly in the evening. Living areas occupied during the day would benefit from the stabilising influence of thermal capacity on ambient air temperature.

In another optimisation study in Sydney, Australia, Bambrook et al (2011) found that while some thermal capacity is useful additional thermal capacity made little difference. The suggestion that the influence of the thermal capacity on temperature wanes with quantity is supported by other research by Shaviv et al and Slee et al

(Shaviv et al., 2001, Slee et al., 2013). Both studies show that adding thermal capacity to a space reduces the diurnal temperature range in that space and that adding additional thermal capacity has less of an influence, until a point when adding further capacity makes no difference to the temperature variation of the space at all. Bambrook et al conclude that the addition of bulk insulation and increased glazing performance were the dominant efficiency measures

3.0 Research Questions

This paper seeks to understand how, in a direct gain system commonly advocated for energy efficient housing in Australia:

- How the impact of the quantity of thermal capacity in a space effects the predicted annual energy consumption?
- How the location of the thermal capacity in the space effects the predicted annual energy consumption?
- How the size of the north (equator) facing window effects the predicted annual energy consumption?
- How the introduction of thermal capacity influences the lifetime CO₂-equivalent emissions of a space?

In the three most populous cities in Australia: Melbourne, Greater Sydney and Brisbane. In Sydney the climate changes as the distance from the coast increases. We have chosen to use a climate file from Penrith, in Sydney's west because the majority of the city's population lives in the west and that is where the majority of new houses are being built. For Melbourne and Brisbane we have chosen to use the climate files for the city centres.

4.0 Method

4.1 The test cell building

We designed a single room house to replicate a reasonable living area in a house with internal dimensions of 8m (E-W), 4m (N-S) and 3m high. There is a south facing window 2m long and 0.6m high and a full height north (equator) facing window that has a variable width. The roof overhangs so that the north facing window is fully shaded at noon on the spring and autumn equinoxes. The base case model is a lightweight structure. Thermal capacity is added to the inside of the building envelope in the form of concrete slabs (floor and ceiling) and bricks (walls) (Fig. 7) to create eight different configurations (table 2):

4.2 Simulation software

We used BERS Pro to simulate the energy use of the space and AccuRate to calculate the embodied energy in each construction variation. BERS Pro and AccuRate are both accredited under the Australian National Home Energy Rating Scheme (NatHERS) that is used for statutory approvals for new houses in Australia. The simulation model was not validated for this particular experiment. The software has been validated using the Bestest methodology as part of the accreditation process (BERS_Pro_Plus, 2010, Delsante, 2004). We used the default settings for the programs as stipulated by the Australian Building Codes Board. The settings simulate the operation of the building in a mixed mode system automatically opening and closing windows, and calculates heating and cooling loads to maintain an internal

temperature between the set points defined below. The heating and cooling loads are based on the use of a split cycle air conditioning unit. A standard occupancy pattern and auxiliary heat loads for a family are defined (NatHERS, 2012). In this study, a one room house is considered, categorised in the software as kitchen/ living space. Thermal comfort is maintained from 0700 to 2400. The heating setpoint is 20.0 °C and the cooling thermostat setpoint is set at January’s neutral temperature, which generally has the highest mean monthly temperature in Australia (table 3).

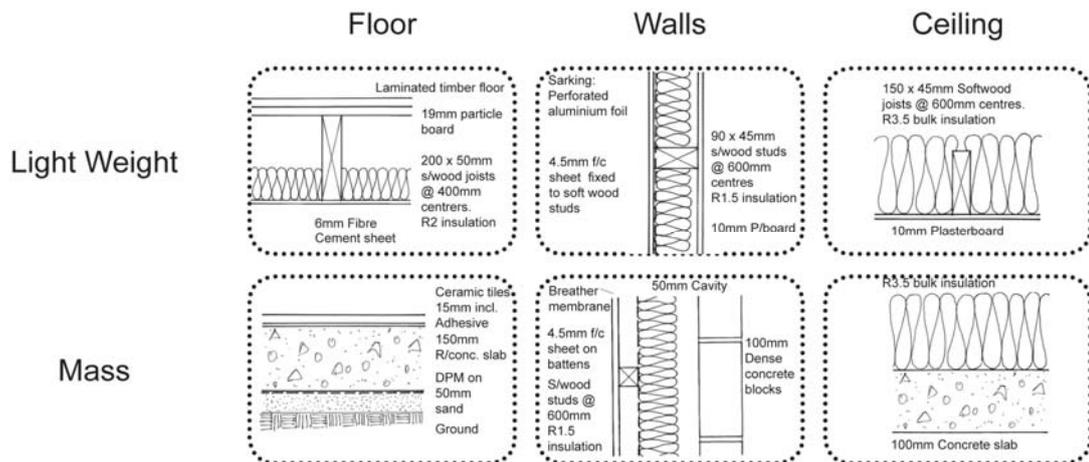


Figure 7. Floor, wall and ceiling construction variations

Table 2. Construction typologies (LW – lightweight, M – Thermal Capacity added)

Typology:	A	B	C	D	E	F	G	H
Floor:	LW	M	LW	LW	M	M	LW	M
Wall:	LW	LW	LW	M	LW	M	M	M
Ceiling:	LW	LW	M	LW	M	LW	M	M

Table 3. Heating and cooling set points for simulation

	Melbourne	Penrith	Brisbane
Heating set point	20°C	20°C	20°C
Cooling set point	24.0°C	24.5°C	25.5°C

The software uses the same weather files that are used for EnergyPlus simulation software. The weather files are embedded and locked within the software, and users are not allowed to add a new weather file or alter existing files.

We used the predicted annual heating and cooling loads expressed as MJ/m² of floor area to assess the energy and comfort performance of each scenario.

5.0 Results

The results for the 64 simulations carried out for each climate are illustrated by the graphs in figures 8 - 13 below with an accompanying description. Thermal capacity is described in KJ/k.m^3 where m^3 is the volume of the space, i.e. thermal capacity per cubic meter of space. Construction typologies are referred to by their letter (A – H) and, where the window size is important, by the letter and the window size, e.g. A/25% (typology/window size).

5.1 Melbourne

5.1.1 The impact of the quantity of thermal capacity

In Melbourne annual energy consumption falls when some thermal capacity is added to the lightweight structure (Graph 8.i - B or C compared to A). As additional capacity is added the annual cooling load is reduced further but the annual heating load is increased (graph 8.iii) resulting in no net reduction in annual energy use and, in certain scenarios, an increase in annual energy use.

5.1.2 The impact of the location of thermal capacity

The location of the thermal capacity has a particularly pronounced effect on the annual heating load in the medium-heavyweight configurations F and G (graph 8.i). When the thermal capacity is moved from the floor to the ceiling annual energy use falls by up to 39% (5% window area). This reduction is the result of reduced annual heating (graph 8.iii) and is surprising because classic direct gain systems rely on thermal capacity in the floor to assist in heating a space.

The distribution of the thermal capacity has a smaller influence on the annual cooling load in the medium weight structures B, C and D: When thermal capacity is moved from the floor or ceiling to the walls and the quantity increased there is no improvement in performance (graph 8.iii).

5.1.3 The impact of the size of the window

For all construction typologies increasing window area results in an increase in annual energy consumption (graph 8.ii). The relative increases in the annual heating and cooling loads are similar except for typologies E, F and G that have high thermal capacity and high annual heating loads with small or large windows.

5.1.4 Lifecycle CO₂ emissions

In Melbourne the configuration with the lowest annual energy consumption, Typology G/5% also has the lowest predicted lifetime CO₂-e emissions after 25, 50 and 100 years (Figure 9). The embodied CO₂-e of this medium-heavyweight structure accounts for 34% of the 25,725kg net CO₂-e emissions after 25 years. With the same window area typologies B, C and D have considerably less embodied CO₂-e and, after 25 years have predicted net CO₂-e emissions less than 1000kg higher. After 50 years these four configurations are still the most efficient separated by 4,500kg CO₂-e net emissions and the 3 less efficient configurations separated by only 1,637kg CO₂-e.

Construction typologies:

A	B	C	D	E	F	G	H
Embodied CO ₂ -e : 4,828 kg	Embodied CO ₂ -e : 6,245 kg	Embodied CO ₂ -e : 6,525 kg	Embodied CO ₂ -e : 8,358 kg	Embodied CO ₂ -e : 8,995 kg	Embodied CO ₂ -e : 8,995 kg	Embodied CO ₂ -e : 9,275 kg	Embodied CO ₂ -e : 10,692 kg
Sequestered CO ₂ -e : 3,874 kg	Sequestered CO ₂ -e : 2,745 kg	Sequestered CO ₂ -e : 3,874 kg	Sequestered CO ₂ -e : 3,124 kg	Sequestered CO ₂ -e : 2,745 kg	Sequestered CO ₂ -e : 2,745 kg	Sequestered CO ₂ -e : 3,874 kg	Sequestered CO ₂ -e : 2,745 kg

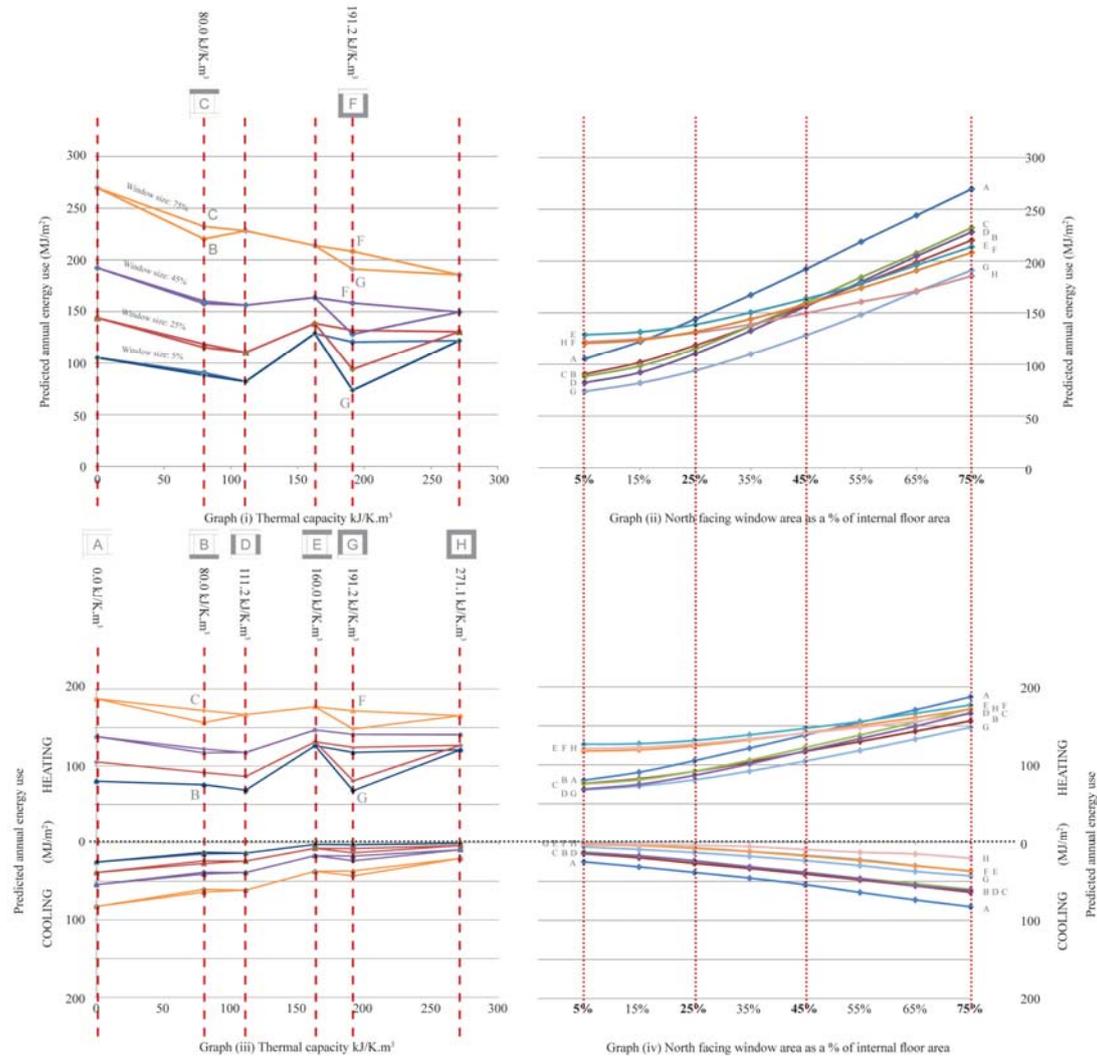


Figure 8.

Graphs 8.i, 8.ii, 8.iii and 8.iv – Melbourne - Predicted annual energy loads plotted against thermal capacity and window area

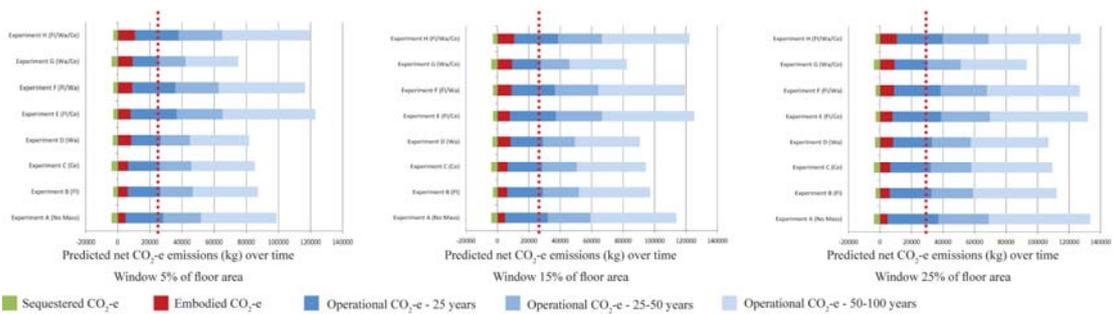


Figure 9. Melbourne - predicted net CO₂-e emissions over 25, 50 and 100 years

5.2 Penrith

5.2.1 The impact of the quantity of thermal capacity

In Penrith annual energy consumption falls as the quantity of thermal capacity in the space is increased (graph 10.i). This fall is primarily due to a reduction in annual cooling energy loads (graph 10.iii). The annual heating load falls when capacity is added to the lightweight typology (Compare typ. A with typ. B & C). When additional capacity is added (typ D-H) and the distribution altered the thermal response of the space becomes more complex (graph 10.iii). For the configurations with the smallest window (5%) increasing thermal capacity in the space above 111 kJ.K.m³ increases energy consumption (graph 10.i).

With smaller windows the influence on annual cooling loads of adding thermal capacity to the space diminishes with quantity. Increasing the thermal capacity above 160 kJ/k.m³ (of space) has a minimal influence on the cooling load, following a similar pattern to that observed by Shaviv et al and Slee et al (Shaviv et al., 2001, Slee et al., 2013).

The response of the annual cooling load to increasing quantities of thermal capacity is “stepped” rather than approximating to a curve (graph 10.iii). Increasing the quantity of thermal capacity by 39% (Typology B/C to D) results in almost no change in thermal performance. A further 44% increase and redistribution (D – E) results in improvements in performance with more significant improvements occurring in configurations with larger windows. The “stepped” response is also clear on the graph plotting cooling load against window size (graph 10.iv) where different construction typologies are separated into four groups (table 4):

Table 4. Separation of construction typologies into 4 groups

Lightweight:	Typology A
Medium weight:	Typologies B, C and D
Medium –heavyweight:	Typologies G,E and F
Heavyweight:	Typology H

5.2.2 The impact of the location of thermal capacity

This “stepped response” of the cooling load illustrated in graph 10.iii suggests that the location of the thermal capacity on the floor (B), or on the ceiling (C), or on the walls (D) makes little difference to the cooling energy load. When there is thermal capacity in the walls and then capacity is moved from the ceiling to the floor (typologies F and G) the cooling load is hardly effected however there is a significant change in the heating loads particularly with small and medium sized windows (<45%). A similar effect was observed in Melbourne.

5.2.3 The impact of the size of the window

In Penrith there is an optimal balance between the size of the window and the quantity of thermal capacity in the space (graph 10.ii). For the lightweight and medium weight structures (A, B, C and D) increasing window size reduces efficiency overall. For all typologies increasing window size increases the annual cooling load (graph 10.iv). For structures with some thermal capacity (B-H) there is an optimal window size where the annual heating load is minimised, this must be balanced with the increasing annual cooling load meaning that it is only the medium heavy and heavyweight

Construction typologies:

Typology	Embodied CO ₂ -e (kg)	Sequestered CO ₂ -e (kg)
A	4,828	3,874
B	6,245	2,745
C	6,525	3,874
D	8,358	3,124
E	8,995	2,745
F	8,995	2,745
G	9,275	3,874
H	10,692	2,745

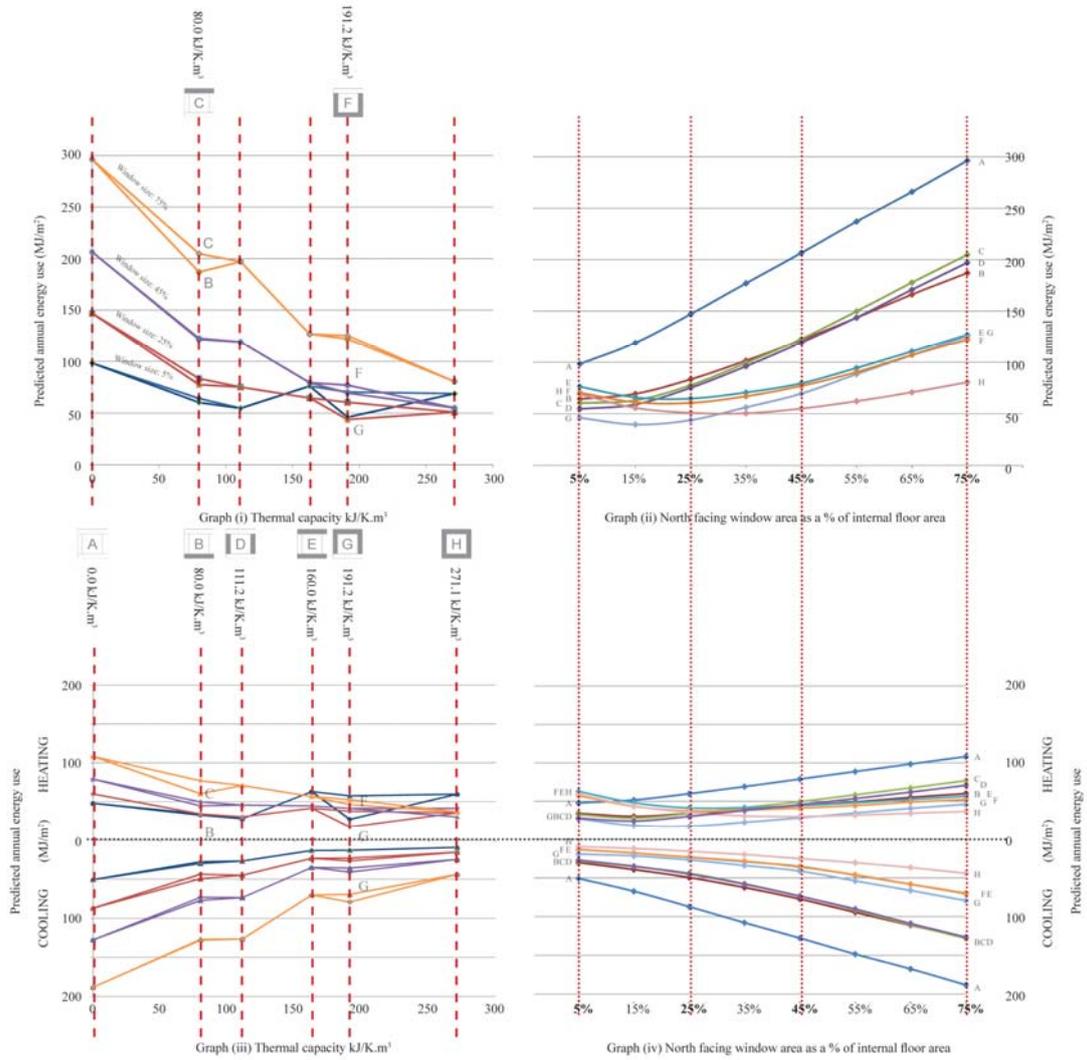


Figure 10.

Graphs 10.i, 10.ii, 10.iii and 10.iv – Penrith (Sydney) - Predicted annual energy loads plotted against thermal capacity and window area

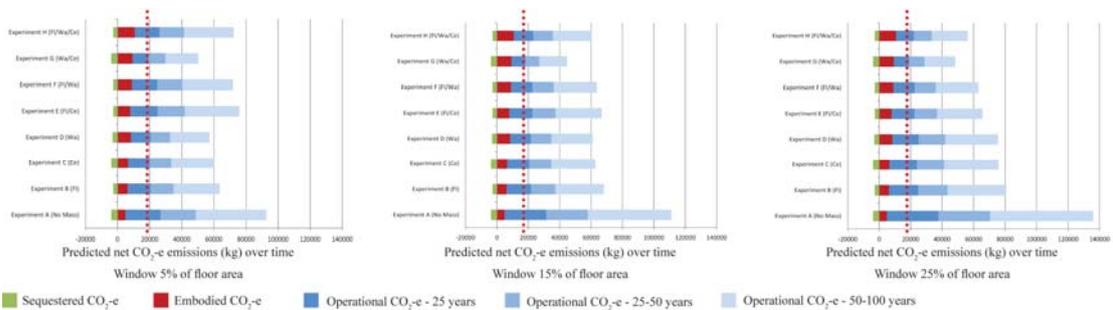


Figure 11. Penrith - predicted net CO₂-e emissions over 25, 50 and 100 years

typologies E, F, G and H that find an optimum balance between thermal capacity and window size. The balance point depends on the quantity and configuration of the thermal capacity.

As with Melbourne the classic explanation of a direct gain system appears to be defied: The most efficient construction typology is G with capacity in the walls and the ceiling and a window sized at 15% of the floor area. The high capacity typology (H) is the next most efficient when the window is sized at 35% of floor area. Construction typologies E (capacity on the floor and ceiling) and F (capacity on the floor and walls) are comparable with each other and most efficient when the window is 25% of the floor area.

5.2.4 Lifecycle CO₂ emissions

After 25 years the configuration with the lowest predicted net CO₂-e emissions is G/15%, also the configuration with the lowest annual operational emissions (Figure 11). This is a medium-heavyweight construction with walls and ceiling in thermal capacity (9275 kg CO₂-e) accounting for 51% of the net emissions after 25 years. The structure that achieves a net CO₂-e emission level close to typology G is typology C with annual operational emissions 59% higher than typology G but 25 year net emissions only 14% higher because of the structure's lower embodied energy.

5.3 Brisbane

5.3.1 The impact of the quantity of thermal capacity

In Brisbane annual energy consumption falls with the addition of thermal capacity to the space (graph 12.i). There is a small reduction in annual heating loads when thermal capacity is added to a lightweight structure (Typ. A compared to B/C) but overall the annual heating load is minimal and the efficiency of the space is dominated by reductions in the cooling load. The “stepped” response to additional thermal capacity observed in Penrith is also seen in Brisbane and the typologies form into the same four groups. There also appears to be little benefit to adding additional thermal capacity to the space beyond 160 kJ/k.m³(typ. E).

5.3.2 The impact of the location of thermal capacity

The “stepped” response of the cooling loads to the addition and distribution of the thermal capacity observed in the climates of Melbourne and Penrith is observed in Brisbane.

5.3.3 The impact of the size of the window

Increasing the size of the window reduces the energy efficiency of all the typologies exponentially (graph 12.ii).

5.3.4 Lifecycle CO₂ emissions

In Brisbane, where predicted annual energy consumption (in this simulation) is relatively low, the embodied energy of the structure forms a larger part of the net CO₂-e emissions and means that for the relatively efficient structure (H/5%), at 185kg CO₂-e/year, embodied energy is responsible for 70% of net emissions after 25 years making it less efficient than lighter weight typologies B, C and E (figure 13). Configuration H/5% is still marginally less efficient than configurations E/5% and F/5% after 50 years. However in all cases these net differentials are less than 2,000 kg CO₂-e overall.

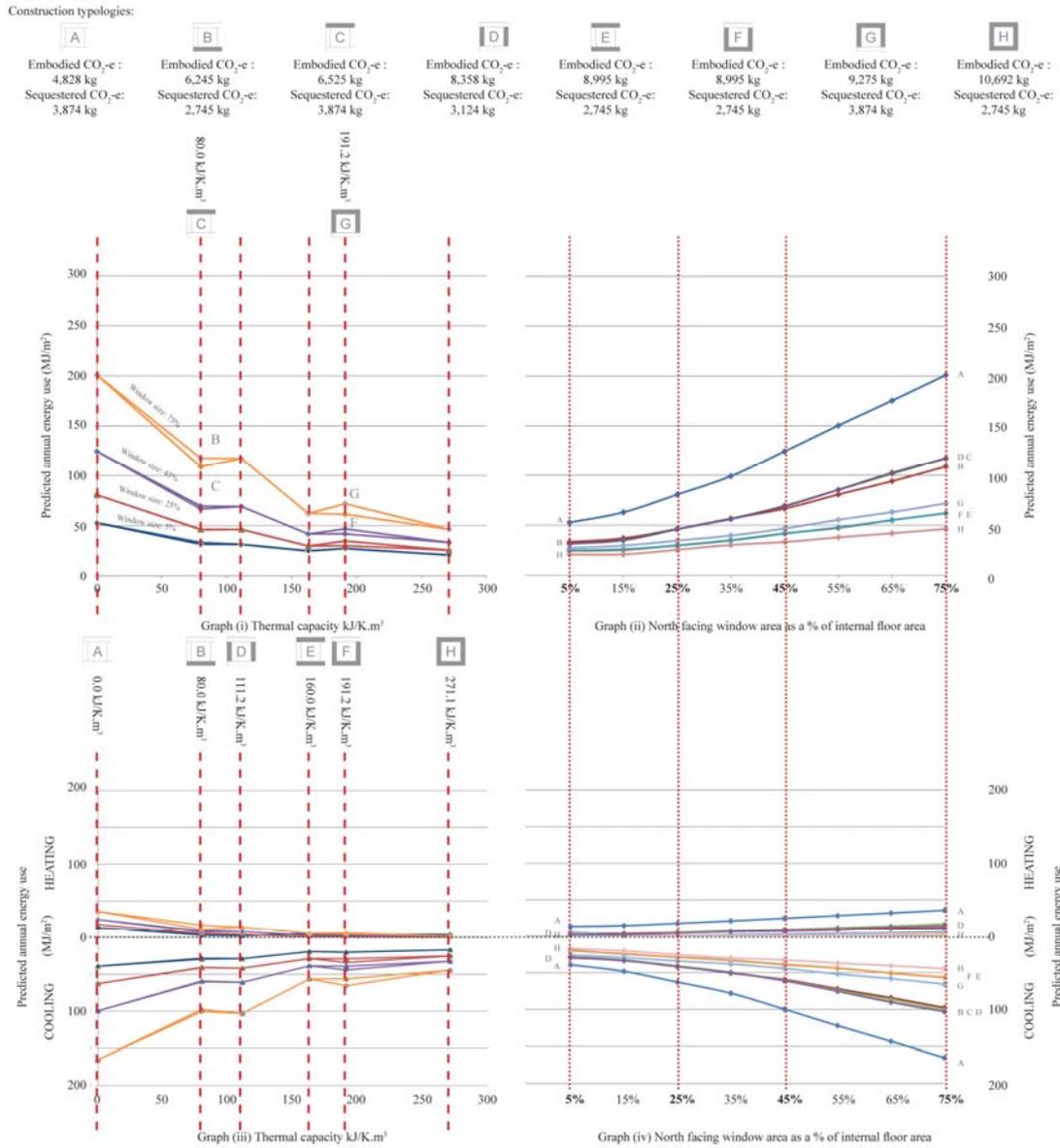
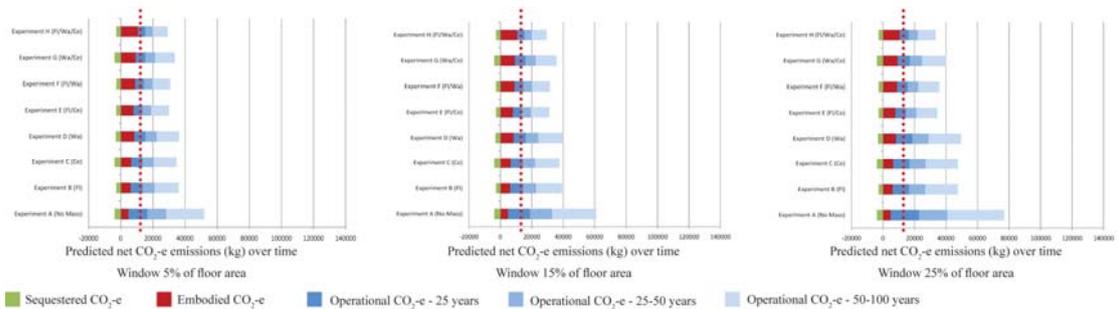


Figure 12.

Graphs 12.i, 12.ii, 12.iii and 12.iv – Brisbane - Predicted annual energy loads plotted against thermal capacity and window area



5.4 Summary

The results from the three climates have the following in common:

- The influence of thermal capacity on the energy performance of the space becomes more pronounced as the size of the window is increased. The largest improvements in energy efficiency associated with thermal capacity occur when the window area is large (75% of floor area).
- In all climates increasing the quantity of thermal capacity reduces the annual cooling load.
- Energy consumption increases with increasing window area. In Penrith there are four construction scenarios where there is an optimum window area that will minimise the annual energy consumption for a particular construction (construction variations E, F, G and H). The balance point differs between construction variations.
- The location of the thermal capacity influences the thermal performance of the space. How this manifests itself differs from climate to climate.

6.0 Discussion

It is clear that the thermal response of the simulated building to variations in the quantity and distribution of thermal capacity, and changing the size of the north (equator) facing window, is different in each of the three climates. Therefore the configuration that minimises net CO₂-e emissions over the lifetime of the building will need to be different in each climate.

In all three climates increasing the size of the window and the corresponding direct solar gain caused an increase in annual cooling loads, the increased window size also caused an increase in heating loads in Brisbane and Melbourne. Only in Penrith was an optimum window size observed.

In the contrasting climates of Melbourne and Brisbane, were it not for the limitations of the experiment, one might conclude that small windows are more efficient. However, since we did not vary the level of solar shading it might also be suggested that (i) better solar control is needed and/or that (ii) a direct gain strategy is not appropriate for these climates:

In Melbourne it appears to be the distribution rather than the quantity of thermal capacity or the size of the window that improves annual energy performance. The cold and cloudy winter climate is not favourable for significant and regular direct thermal gains from the sun in winter. Graph 8.iii shows us that the space does benefit from the presence of thermal capacity in summer. The warm and occasionally hot summer with outside diurnal temperature range greater than 10 °C is favourable for utilising thermal capacity for night cooling.

In Brisbane the simulation suggests that there is little need for winter warmth and so the principle purpose of a direct gain system, storing warmth from the sun to reduce heating requirement on cool evenings, is redundant in this climate. The addition of thermal capacity reduces the annual cooling load in Brisbane (graph 12.iii) but, with the configuration we simulated, increasing the size of the window increases the cooling loads. It is therefore likely that, like in Melbourne, the benefit of thermal capacity is in storing “coolth” rather than warmth, utilising the modest diurnal

temperature range. In Penrith the influence of thermal capacity on annual cooling loads is also important.

In Penrith the principles of a direct gain system do appear to apply. There is clearly an optimal balance between the quantity of thermal capacity and the size of the window. It is surprising that the most efficient configuration does not have a ground slab. This may be because in our simulations the ground slab is cast directly on the ground (ground coupled) as is the practice in Australia. This may mean that cool and cold winter nights in both Melbourne and Penrith cause thermal losses from the ground slab offsetting passive solar gains made during the day.

When the embodied CO₂-e emissions of the structure are also considered the benefits of high levels of thermal capacity are less obvious. In the simulations structures with less thermal capacity were very nearly as efficient and occasionally more efficient than higher capacity typologies over 25, 50 and even 100 year time frames.. The operational CO₂-e emissions have been calculated using current emissions figures (BREE et al., 2013) for Australia where 96% of energy comes from carbon based sources. If renewable energy sources are utilised more effectively in Australia, then the balance between operational energy and embodied energy will change, possibly significantly. This will make lower embodied energy structures more efficient over longer time frames.

7.0 Conclusion

The study simulated a single space building in the three Australian climates of Melbourne, Penrith (Sydney) and Brisbane. The quantity and location of the thermal capacity and the size of the north (equator) facing window were varied. The calculated annual heating and cooling energy loads were used to assess the impact of the variations. The predicted annual energy consumption was converted into kg of CO₂-e and combined with the calculated embodied CO₂-e of each configuration to estimate the lifetime CO₂-e emissions of the various scenarios over 25, 50 and 100 years.

It is clear that thermal capacity can improve the thermal efficiency of the simulated structure in all three climates, primarily through its influence on annual cooling loads. It seems likely that a direct gain system is only appropriate for the climate in Penrith and that thermal capacity should be used in Melbourne and Brisbane to mitigate summer overheating.

The location of thermal capacity influences the annual heating load. This may be due to heat lost through the ground coupled concrete slab in winter.

Increasing the size of the window increases the annual cooling load in all three climates and the annual energy consumption in Brisbane and Melbourne. Increasing solar shading (reducing direct gain) may mitigate this effect. In Penrith an optimum window size can be found for a particular quantity of thermal capacity.

When lifetime c CO₂-e emissions are calculated a number of possible optimal configurations emerge from simulations with no single configuration in any particular climate emerging as the optimal solution. Medium weight and medium-heavyweight typologies offer comparable solutions. The results suggest that it would be useful to explore further modifications to the fabric and form of the building in each climate

including reducing or eliminating direct solar gain and insulating the building from the ground.

8.0 Acknowledgements

This research was funded by Forest and Wood Products Australia with additional assistance from CSR as part of a project investigating the use of thermal capacity in timber framed construction across Australia. The project was carried out by the University of Sydney, Australia.

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