Can Mass-timber Construction Materials Provide Effective Thermal Capacitance in New Homes?

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ABSTRACT

Since Australia's acknowledgement of climate change and its need to reduce greenhouse gas emitting activities, the national construction regulations (BCA and NCC) since 2003 have included residential thermal performance requirements. Initially in 2004 the minimum thermal performance requirements was 4 Stars and in 2010 it became 6 Stars. It is planned during the next decade that the thermal performance regulation will increase to a zero energy requirement. Current policy and regulation development is aiming to include the assessment of embodied energy and carbon sequestration in new homes by 2016. The improvement from no thermal performance regulation to the 6 Star minimum requirements can, in most cases, be met by increasing levels of floor, wall and ceiling insulation, improving glazing selection and reducing house infiltration losses. However, for many parts of Australia the improvements required to achieve 7 Stars or more, will need to include the careful consideration of the type and placement of construction materials which provide thermal capacitance.

Traditionally, the materials selected to provide additional thermal capacitance include masonry and concrete based products. However, they are massive and have a relatively high value for embodied energy. Their significant mass requires the structure of the building to be increased, thereby further increasing the quantity of building materials and their relative embodied energy. There has been no research to date exploring whether timber products can provide effective thermal capacitance in residential or commercial construction. This research is exploring the use of unique mass-timber products to provide a new form of thermal performance capacitance within the built fabric of new and existing homes. The development of mass timber products is a new paradigm in material and building science research in Australia, requiring the accounting for carbon emissions, carbon sequestration, material embodied energy and material thermal properties for this renewable resource. This paper focuses on the results from preliminary building simulation studies encompassing house energy rating simulations and a comparative analysis of embodied energy and carbon storage for a series of house plans in Australia.

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KEYWORDS
House Energy Rating, Embodied Energy, Carbon Sequestration, Thermal Capacitance

INTRODUCTION

Since Australia's acknowledgement of climate change and its need to reduce greenhouse gas emitting activities, the national construction regulations (BCA and NCC) have since 2003 included residential thermal performance requirements. Initially, these regulations required all new homes be designed to a 4 Star minimum thermal performance, which was increased to 5 Stars and then 6 Stars in 2010 (ABCB 2010). It is planned that the level of thermal performance will increase to a Zero Energy requirement by 2020 (Pitt & Sherry 2010). The improvement from no thermal performance regulation to the 6 Star minimum requirements can, in most cases, be met by increasing levels of floor, wall and ceiling insulation, improving glazing selection and reducing house infiltration losses (Dewsbury 2012). However, for many parts of Australia, the improvements required in the residential building fabric to achieve 7 Stars or more, in the coming decade, will need to include the careful consideration of the type and placement of construction materials which provide thermal capacitance (Attia 2011; O'Callaghan 2011).

Traditionally, the materials selected to provide thermal capacitance include clay brick, and cement and concrete based products (Gnauk 1985; Greenland 1985). These products do provide good thermal capacitance. However, they are massive and have a relatively high embodied energy (Alcom 1996). Their significant mass requires the structure of the building to be increased to carry additional load, thereby increasing the quantity of building materials and their relative embodied energy. The use of a concrete slab-on-ground floor, which results in only a moderate addition of thermal capacitance, has been used extensively since the adoption of the 5 Star minimum requirements (Iskra 2004). To further improve the thermal performance, additional thermal capacitance must be added within the home. If the current palette of materials is used in greater quantities, the relative quantity of embodied carbon within the home will increase. As the new carbon economy paradigm advances, the use of these products will increase the carbon costs of Australian homes.

Similarly, research into the appropriate use of thermal capacitance in Australian residential construction has been limited. Much of this research has come from the anecdotal experience of architects and builders using the principles of Solar Passive Design (RAIA 2009). A limited number of desktop studies have explored the development of guides for the design and construction industry. However, these have not been successful in promoting a thermal performance understanding or a significant adoption of thermal capacitance within Australian homes. Even though timber products have a significant specific heat value, there has been no research to date encompassing the use of timber products and their capacity to work effectively as thermal mass, absorbing and releasing energy, in residential or commercial construction.

Acknowledging the need to revalue resources in the context of a carbon economy, recent improvements to building simulation programs have included the capacity to account for the embodied energy and carbon storage within the built fabric of homes (Chen 2010). These tools are still in their development stage and there are many assumptions and simplifications within their algorithms. However, recent research which has used these tools has focused on the comparison between traditional timber and brick homes with limited thermal capacitance. These preliminary studies have shown a 10% to 17% difference in the possible carbon storage between a timber-clad and floored home, when compared to a brick clad, concrete floored home (Carre 2011). This was a very simple assessment but it highlights the significant differences in the embodied energy and carbon storage properties of building materials. If elements within the home were made from mass timber products, which provide additional thermal capacitance, the respective quantity of stored carbon would increase significantly. Timber products, which are used extensively in most Australian homes, have a high specific heat value indicating their suitability for use as thermal capacitance (Dewsbury 2012).

To test these hypotheses several house plans were selected. The plans ranged from 4 Stars to greater than 9 Stars in there thermal performance design standards. Ten of these houses are the focus of this paper and represent an average of the houses simulated. Some sample plans from the ten houses are shown in Figures 1 to 4. Using house plans, elevations, sections and door and window schedules, each house was carefully simulated using the CSIRO developed AccuRate Sustainability software. The ten houses were of different size and configuration with varying amounts of conditioned floor area, with the conditioned floor area shown in Table 1.

THERMAL PERFORMANCE SIMULATIONS

The AccuRate Sustainability software uses the CSIRO developed CHENATH building thermal simulation engine. Previous empirical validation research has shown that the software requires calibration but that its capacity to simulate standard residential building systems seems sound (Dewsbury 2011; Geard 2011). This same research did identify an unrecognised structural thermal capacitance effect requiring further improvement and calibration. This matter has not been considered in this research, as the effect would apply equally to all materials. Most Australian houses use an internal partition walling system, which comprises plasterboard sheeting affixed to a timber frame. When thermal mass is added to homes, this wall is often replaced with a concrete block wall with either a render or plasterboard sheet finish. For the purposes of this analysis five partition wall types were simulated in each of the case study houses, namely:

- 10 Plasterboard, 90 Timber stud frame, 10 Plasterboard
- 10 Plasterboard, 90 Concrete Block, 10 Plasterboard
- 10 Plasterboard, 90 Softwood, 10 Plasterboard
- 10 Plasterboard, 90 Hardwood, 10 Plasterboard
- 110 Softwood

The 90mm softwood, 90mm hardwood and 110mm softwood partition systems were used to simulate the effect of mass-timber construction.

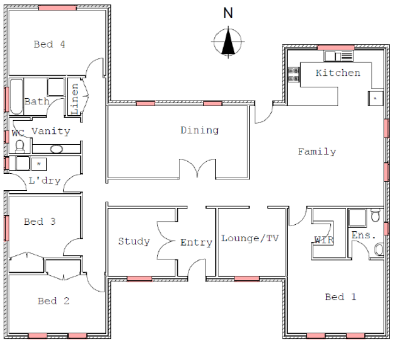

Figure 1. *Case study house 2*

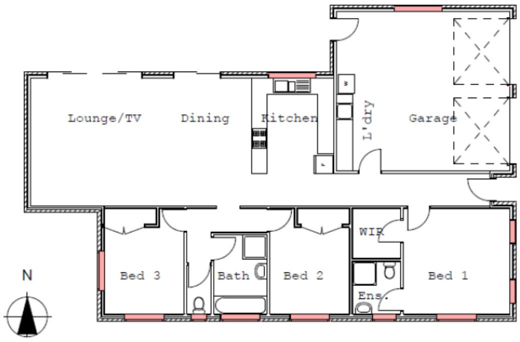

Figure 2. *Case Study house 3*

Figure 3*:Case study house 4*

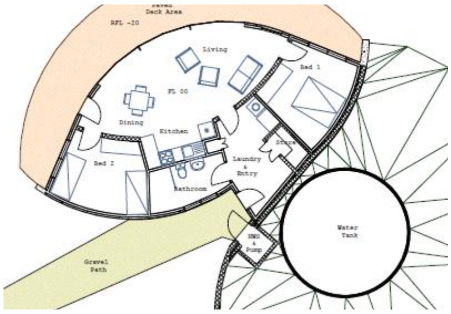

Figure 4*:Case study house 5*

Table 1: *Case Study Houses Conditioned Floor Area*

House	*Conditioned Floor Area (m^2)*
House 1	61.8
House 2	138.9
House 3	95.8
House 4	100.2
House 5	55.4
House 6	116.1
House 7	231.8
House 8	142.3
House 9	104.9
House 10	73.1

The results of the thermal simulations are shown in Table 2. As would be expected the addition of the concrete block partition walls improved the thermal performance in all the case study houses. The concrete block partition walls improved the thermal performance by between 2% and 22% with an overall average or 9%. However, the use of the mass-timber hardwood partition system improved the thermal performance by between 3% and 27% with an average of 10%. The relative improvement in thermal performance for each partition walling system is shown in Table 3. This indicates that the use of a hardwood mass timber partition walling system would provide a better thermal performance result than the traditionally adopted concrete block system. If the argument for the use of mass-timber construction is to be used in the context of carbon accounting, not only should its effect on thermal performance be considered but also its impact on embodied energy and carbon sequestration.

Table 2: *Results from Case Study House Thermal Simulations*

house	*Partition Wall System and Relative energy Rating (mj/m2.annum)*				
	10 PB/ 90 Stud/ 10 PB	*10 PB/ 90 Block/ 10 PB*	*10 PB/ 90 Softwood/ 10 PB*	*10 PB/ 90 Hardwood/ 10 PB*	*110 Softwood*
House 1	388.0	341.8	358.8	353.3	359.9
House 2	330.3	322.1	323.0	321.9	323.2
House 3	550.7	521.0	534.3	528.6	534.9
House 4	244.8	240.2	226.5	229.7	225.8
House 5	245.5	236.2	227.1	229.3	226.3
House 6	145.3	132.2	134.9	134.2	134.8
House 7	50.6	46.9	42.0	42.9	41.8
House 8	189.0	147.0	138.9	137.7	138.5
House 9	97.1	84.4	80.0	81.2	74.6
House 10	139.3	125.5	126.5	126.1	126.3

Table 3: *Percentage Improvement in Thermal Performance Relative to Walling*

Partition Wall System	*Minimum Improvement*	*Maximum Improvement*	*Average Improvement*
10 PB/ 90 Block/ 10 PB	2 %	22 %	9 %
10 PB/ 90 Softwood/ 10 PB	2 %	27 %	11 %
10 PB/ 90 Hardwood/ 10 PB	3 %	27 %	10 %
110 Softwood	2 %	27 %	11 %

EMBODIED ENERGY

In 2009, the CSIRO, with financial support from Forest and Wood Products Australia, developed an embodied energy and carbon sequestration calculator, which was integrated into the AccuRate software (Chen 2010). The module calculates a CO_2 equivalent value (ECO_2) for each built fabric element's embodied carbon. Due to the distinct variation in Australia's urban and regional material supply and construction chains, the 'To Factory Gate' accounting method was adopted. This parameter does not account for building material emissions that result from the construction, repair and maintenance and end of life stages. Other elements which can significantly impact the ECO_2 calculation, (including foundations, wall framing detail, doors, and staircases) are not included in the module for reasons of user efficiency (Chen 2010). The AusLCI methodology was used to establish and select the ECO_2 of each material (AusLCI 2009). This research used the ECO_2 module within the AccuRate Sustainability software. No changes were made to the default ECO_2 values within the software. The addition of thermal mass whether concrete block or mass-timber increased the amount of embodied energy within the house designs, as shown in Table 4. However, the mass softwood wall systems have less material embodied energy than the concrete block wall systems. The mass hardwood variant has a significantly higher material embodied energy value than the concrete block wall system and requires further investigation. Table 5 illustrates the relative percentage difference in the material embodied energy for each house when compared to the standard plasterboard and stud frame partition walling system. This table highlights the significant difference obtained by the mass hardwood variation, with embodied energy values between 1.6% and 6.5% greater than the concrete block system. Another interesting aspect from this analysis is the reduction of 0.6% (average) in the embodied energy values for the 110 mass softwood walls compared to the plasterboard and mass softwood walls.

Table 4: *Embodied Energy Values for Each Case Study House*

House	*Embodied co2(-e) emmissions (kg)*				
	10 PB/ 90 Stud/ 10 PB	*10 PB/ 90 Block/ 10 PB*	*10 PB/ 90 Softwood/ 10 PB*	*10 PB/ 90 Hardwood/ 10 PB*	*110 Softwood*
House 1	18995	20804	20161	21393	20023
House 2	32934	36361	35943	39060	35592
House 3	31300	35081	33755	36296	33469
House 4	40302	42611	41799	43355	41624
House 5	18230	19499	19053	19908	18957
House 6	37695	40679	39638	41632	39414
House 7	131967	142414	138740	145781	137948
House 8	44649	46876	46091	47595	45922
House 9	38857	42320	41102	43437	40839
House 10	18334	19263	18934	19564	18863

Table 5: *Percentage Difference in Embodied Energy Relative to Stud Partition Walls*

Partition Wall System	*Minimum Improvement*	*Maximum Improvement*	*Average Improvement*
10 PB/ 90 Block/ 10 PB	+ 5.0 %	+ 12.1 %	+ 7.9 %
10 PB/ 90 Softwood/ 10 PB	+ 3.2 %	+ 9.1 %	+ 5.4 %
10 PB/ 90 Hardwood/ 10 PB	+ 6.6 %	+ 18.6 %	+ 11.0 %
110 Softwood	+ 2.9%	+ 8.1 %	+ 4.8 %

CARBON SEQUESTRATION

Each house modelled to examine the carbon sequestration contributions for each of the different partition walling systems. The mass hardwood partition wall variation provided the greatest carbon sequestration and the concrete block variant produced a reduction in carbon sequestration, as shown in Table 6. When this data is further analysed, as shown in Table 7, the relative difference for each system is significant. The concrete block partition walls provided an average reduction in carbon sequestration of –14 % whilst the mass hardwood partition system provided an average increase of +180 % in carbon sequestration.

AUSTRALIAN PLANTATION TIMBER RESOURCES

A significant portion of softwood and hardwood plantation solid timber product is not meeting market performance requirements for durability, strength or appearance resulting in a much lower than planned market value (Innes 2007). Desiring to provide additional value to this growing quantity of low grade timber product research has been undertaken to explore new and innovative harvesting and processing methods (Farrell 2012). Much of this is basic research, with limited immediate commercial application. Softwood and hardwood plantations, which meet the Kyoto Agreement protocols, encompass 1 million hectares of Australian agro-forestry's land-use, accounts for 22 million tons of carbon storage and provides 4% of Australia's greenhouse gas abatement activities. There is a need to provide new value and uses for the hardwood and softwood plantation timber, to secure Australia's ongoing greenhouse gas abatement and carbon sequestration requirements. The development of mas-timber products could utilise the growing supply of low grade softwood and hardwood plantation timber within the construction sector. If the initial focus for the use of mass-timber was for its ability to significantly increase the thermal capacitance within Australian homes, this may radically improve the thermal performance of lightweight and medium weight construction systems and provide long term carbon storage within Australian homes.

Table 6: *Carbon Sequestration Values for Each Case Study House*

House	*E CO2(-e) Stored Table 1n timber products (kg)*				
	10 PB/ 90 Stud/ 10 PB	*10 PB/ 90 Block/ 10 PB*	*10 PB/ 90 Softwood/ 10 PB*	*10 PB/ 90 Hardwood/ 10 PB*	*110 Softwood*
House 1	2014	1365	7280	9278	8594
House 2	8056	6662	21634	26693	24961
House 3	13215	12094	24295	28418	27006
House 4	4142	3425	10898	13423	12559
House 5	1878	1485	5593	6981	6506
House 6	8996	8190	17765	21002	19893
House 7	23173	19936	53743	65168	61256
House 8	10612	9897	17119	19559	18723
House 9	14393	13310	24523	28313	27015
House 10	3630	3313	6334	7360	7010

Table 7: *Percentage Difference in Carbon Sequestration relative to Partition Walls*

Partition Wall System	*Minimum Improvement*	*Maximum Improvement*	*Average Improvement*
10 PB/ 90 Block/ 10 PB	- 21 %	- 7 %	- 14 %
10 PB/ 90 Softwood/ 10 PB	+ 61 %	+ 261 %	+ 131 %
10 PB/ 90 Hardwood/ 10 PB	+ 84 %	+ 361 %	+ 180 %
110 Softwood	+ 76 %	+ 246 %	+ 163 %

CONCLUSION

Through the use of CSIRO developed AccuRate Sustainability software thermal performance, embodied energy and carbon sequestration simulations have been performed on many house designs. Ten of these house designs have been discussed in this paper. In all ten house types, the thermal performance of the houses has improved when compared to the standard stud partition wall system by between 9% and 11% . In all cases the three mass-timber systems provided a better result than the normally adopted concrete block walling system. The embodied energy simulations documented an increase in CO2 (-e) between 4.8% and 11% for the mass wall

systems when compared to the standard stud partition wall system. The mass softwood wall systems had a significantly lower increase, (2.5% to 3.1%) when compared to the concrete block wall system. Alarmingly the mass hardwood system provided the greatest increase in embodied energy. The values for the mass hardwood walling system require further investigation as hardwood processing for mass timber construction may be significantly different to standard hardwood processing systems.
The carbon sequestration properties of the mass timber construction systems were significantly higher than the values for the standard stud partition and concrete mass wall systems. The concrete mass walls provided and average of 14% less carbon sequestration, while the mass-timber wall systems provided between 131% and 180% greater carbon sequestration. This research and analysis has revealed potential significant thermal performance, embodied energy and carbon sequestration benefits for the use of mass-timber partition walling systems in new Australian homes.

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