

Forum Paper # 5: Transport, Planning and the Built Environment

Executive Summary

Improving energy efficiency across transport, planning and the built environment is a key component to achieving Australia's climate change policy objective to reduce its carbon emissions by 60% of year 2000 emissions by 2050.

Think Brick Australia represents the clay brick and paver manufacturers of Australia and has a large research program, co-funded by the Australian Research Council and being undertaken by the University of Newcastle, that specifically examines the energy efficiency and overall performance of typical Australian housing using full-scale test modules.

This submission outlines the results of that research and its implications for policy; specifically the need to remove thermal resistance (R-value) as the single measure for energy efficiency because of the perverse impacts it is having in the market around building material innovation and substitution.

The thermal performance research demonstrates that, contrary to popular belief, higher insulation does not always reduce maximum temperatures within a building nor reduce energy demand from artificial heating and cooling. Instead, the research indicates, high R-value materials could increase energy demand by over 450% if current market trends continue.

There are several reasons why R-value doesn't deliver the highest energy efficiency outcomes: first, its calculation is based on unrealistic assumptions, and, secondly it traps heat entering a room via a window and forces artificial cooling to work harder.

Overcoming these problems requires removing R-value as the single measure for energy efficiency and replacing it with a new indicator and methodology that rates walling systems based on their thermal mass *and* resistance.

The development of an indicator to combine thermal mass and resistance has been attempted before but because of the complex interactions between controlling variables and the lack of real-time analysis of how thermal mass operates, no conclusive outcomes have been achieved.

This submission argues that a Thermal Performance Indicator (TPI) is now achievable based on the University of Newcastle research and that this should be implemented within legislation in conjunction with life cycle analysis to improve the energy efficiency of the built environment.

Recommendations

1. That the limitations of R-value to achieve energy efficiency and its legislative implications are recognised and no new policy is created without rigorous understanding of the impacts these implications have.
 2. That a Thermal Performance Indicator be developed to replace R-value within legislation.
 3. That all tools used to rate energy efficiency be upgraded so that they use a Thermal Performance Indicator (TPI) to determine building performance.
 4. That government rate building products and construction types according to their life cycle cost/benefit and publish the implications of their use.
 5. That the Federal Government monitors Local Council guidelines to ensure they do not promote building products with high life cycle costs that increase long term energy demand in the built environment.
 6. That Australia's carbon policies include careful use of complimentary policy measures that promote building product innovation and adoption across the market.
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Forum Paper # 5: Transport, Planning and the Built Environment

Full Submission

Energy efficiency in the built environment is an extremely important component of Australia's suite of carbon policies. According to the Australian Greenhouse Office, the average Australian home's energy use is responsible for approximately 8 tonnes of carbon dioxide per year, and of this, the largest component is artificial heating and cooling at approximately 39%.¹

Think Brick Australia represents the clay brick and paver manufacturers of Australia and focuses on the benefits provided by good use of building materials and design across the built environment. We have a large research program co-funded by the Australian Research Council and being undertaken by the University of Newcastle that specifically examines the energy efficiency and overall performance of typical forms of Australian housing.²

The Issues Paper recognises and examines barriers to cost-effective low emission alternatives and the low up take of energy efficiency opportunities given the financial benefits these options provide users. While Think Brick Australia doesn't disagree with any of the possible barriers outlined, our research program indicates that legislative barriers with potentially far-reaching and perverse implications have been overlooked.

Introduction

Current legislation across Australia outlines minimum energy efficiency requirements of all buildings. In the residential sector this function is achieved through star ratings that are primarily derived from simulation software based on the thermal resistance (R-value) of building materials.

Although materials with high R-values (predominately insulation materials) have a large role to play in reducing heat entering or leaving a building, the assumption that higher R-value equals higher energy efficiency is incorrect because during summer, when energy demand is greatest, high R-value materials actually trap heat entering a room via the window and force artificial cooling to work harder.

The Thermal Performance Research Program (the research) has started to quantify the limitations of depending on R-value as the single indicator to measure energy efficiency and have data that indicates a superior methodology would include both thermal mass and thermal resistance.

Thermal mass, unlike resistance, absorbs energy and stores it for release once the environment it is interacting with cools down. This provides different benefits during summer and winter, but overall, thermal mass acts to reduce temperature fluctuations which cause building occupants to regularly switch from cooling to heating, especially during the autumn and spring seasons.

This submission is divided into two sections. Section One – *The unknown quantity in building performance: thermal mass* – provides preliminary results from the University of Newcastle and argues that more work needs to be done to understand these findings and their impacts, especially as they relate to long term demand and management of energy

¹ Commonwealth of Australia, *Your Home: Design for Lifestyle and the Future*, Technical Manual www.yourhome.gov.au/technical/fs40.htm

² Sugo, H.O., Page, A.W., Inglis, C.M., *Thermal Performance Studies at The University of Newcastle* Proceedings of the 45th ANZSES Conference, Alice Springs, Australia, October 3-5, 2007.

used by the residential sector to regulate temperature during periods of both hot and cold weather.

Section Two – *Unintended consequences and perverse outcomes of policy making* – analyses the potential impact of the research findings within the residential market and argues that energy efficiency legislation needs to be updated with a methodology that recognises the benefits of heavyweight construction using both thermal mass and thermal resistance.

Section One – The unknown quantity in building performance: thermal mass

The old saying “*there’s nothing like bricks and mortar in these times of uncertainty*” seems like an adage that has been forgotten in the battle for energy efficiency. Despite this oversight, bricks, and their rapidly growing heavyweight competitor concrete, provide a key ingredient to improving the energy performance of the built environment.

This section provides an overview of the research and outlines four key benefits of thermal mass which thermal resistance alone cannot provide:

- delaying and reducing maximum internal temperatures
- removing heat entering a building through a window
- reducing the energy demand from artificial heating and cooling, and
- absorbing and storing energy to heat a room during winter.

Although the research includes four different types of housing construction, this submission concentrates on the insulated cavity brick and insulated fibre-cement modules because they provide a similar comparison and represent current market trends moving away from heavyweight and toward lightweight forms of construction.

Overview of the Research

The research was established to examine the real-time performance of typical forms of Australian housing under all weather conditions. It includes the construction of four full-scale test modules – two heavyweight and two lightweight - each with over 100 sensors, to measure heat flow into and out of the buildings, external and internal air temperatures, and humidity. Table 1 outlines the module construction types and their thermal resistance (R-values.)

Heavyweight	Lightweight
Cavity brick (“Double brick”) (R=0.47)	Insulated brick veneer (R=1.83)
Insulated cavity “double” brick (R=1.32)	Insulated fibre-cement (R= 1.52)

Table 1: Thermal performance research module construction types

Data was first collected in 2003 and has since been taking measurements every 5 mins, 24 hours a day. Over that time a number of Experiments have been conducted using the modules including

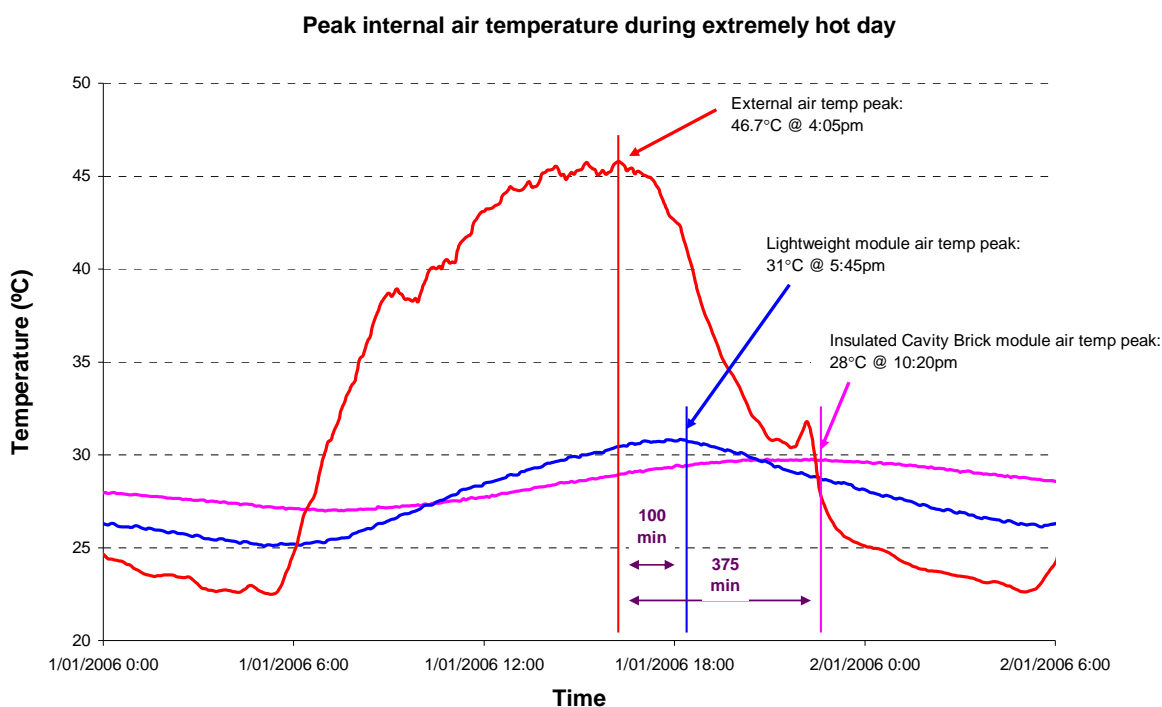
1. passive behaviour
2. impact of windows
3. fixed internal temperature range moderated by artificial heating and cooling
4. impact of insulation in walls
5. impact of internal walls
6. impact of ventilation.

Experiments 1, 2 and 3 are referred to in this submission. Under Experiment 1, there were no windows, internal walls or artificial heating and cooling. Experiment 2 introduced

windows and Experiment 3 (which maintained the windows) measured real-time energy requirements to heat and cool the modules using a fixed internal temperature range and artificial heating and cooling.

Benefit of thermal mass #1: maximum internal temperatures are delayed and reduced

Experiment 1 demonstrated that in the absence of a window external thermal mass delayed and reduced maximum internal temperatures experienced by building occupants. As illustrated in Graph 1, on 1 January 2006 when the external temperature reached 46.7°C, there was a 375 minute delay (6 hours 15 minutes) before maximum temperature was reached inside an the insulated cavity brick module (R=1.36), as compared to a 100 minute delay (1 hour 40 minutes) for the lightweight module (R=1.56).



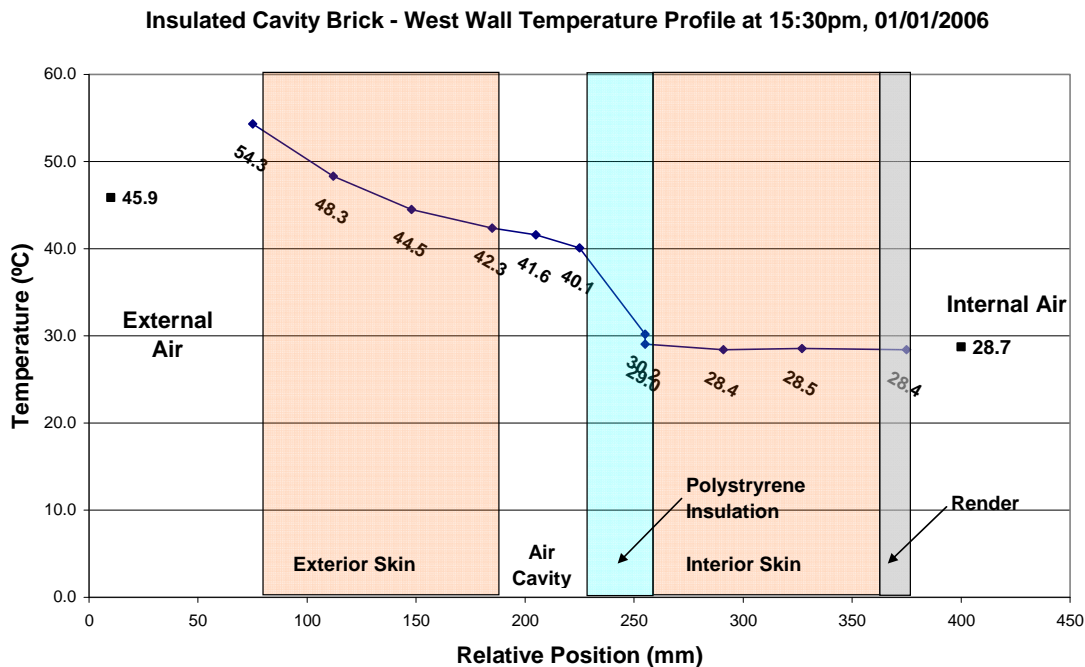
Graph 1: The time delay benefit of thermal mass

This delay occurs because thermal mass constantly interacts with its environment to absorb energy. Furthermore it also expels heat not only toward the inside of a building, but also into the external environment.

Based on the principle that heat energy flows from hot to cold, the research is demonstrating that because the external temperature of the bricks (which can be seen in Graph 2) is hotter than the outside temperature (even during extreme heat), the inside of a building is not receiving 100 percent of the energy absorbed by the brick. Instead heat flows in two directions, reducing the overall amount of heat entering the building.

Despite the ability of thermal mass to delay maximum temperatures, Graph 2 provides real-time data demonstrating the ability of insulation to reduce the amount of heat entering a building. The reduction through the insulation between the two layers of bricks is approximately 11°C which plays a large part in reducing the internal temperature to 29°C while the external temperature is above 45°C.

This is consistent with the patterns observed during other periods of the research and highlights the need for an energy efficiency indicator and methodology that combines both thermal mass and thermal resistance.



Graph 2: The benefit of insulation

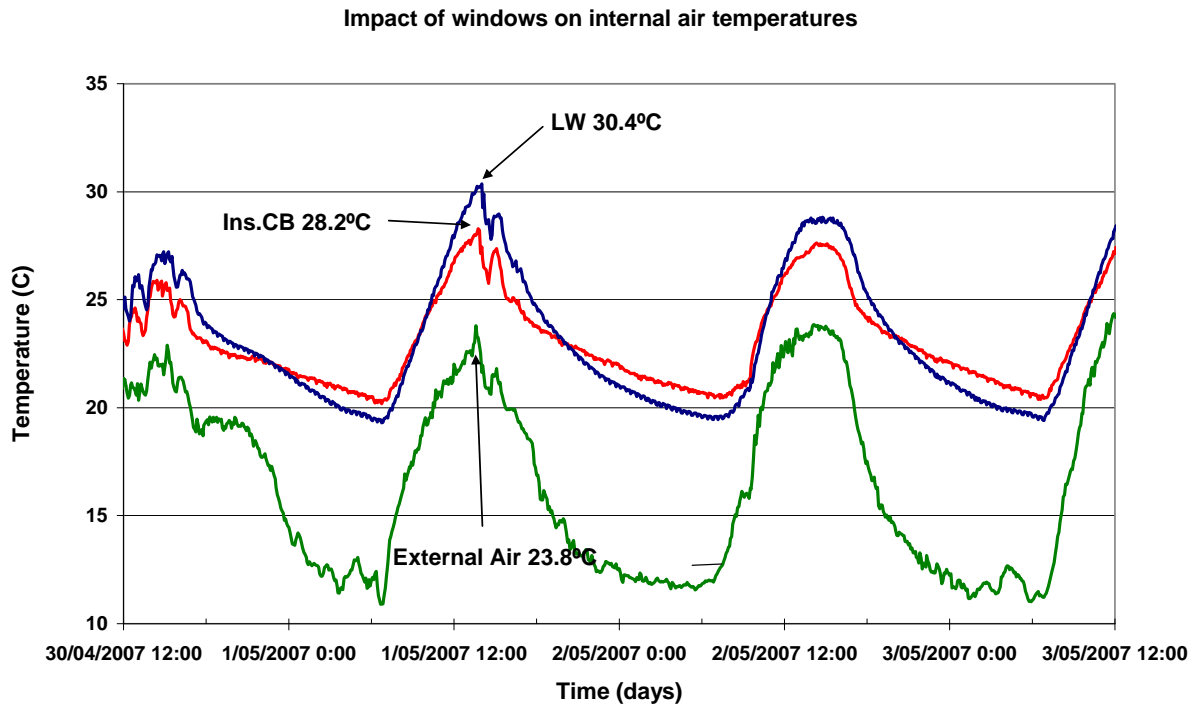
Benefit of thermal mass #2: internal thermal mass removes heat entering a building through a window

Graphs 1 and 2 are drawn from Experiment 1 before windows were included in the modules. Experiment two demonstrated that windows let the largest amount of energy into, and out of, a building, and that they removed the temperature delay provided by thermal mass shown in Experiment 1 as well as the overall heat reduction properties of thermal resistance in the walls.

Graph 3 shows the temperature comparison of the buildings with windows and the reduced thermal mass time delay. Despite this, the insulated cavity brick still performs better despite its lower R-value. Table 2 shows that during this period the insulated fibre cement had higher maximum and average temperatures: 2.2°C and 0.9°C respectively.

	Insulated cavity brick	Insulated fibre cement	Difference
Maximum Temp.	28.2°C	30.4°C	2.2°C
Average Temp.	21.3°C	22.2°C	0.9°C

Table 2: Comparison of temperature difference with and without thermal mass

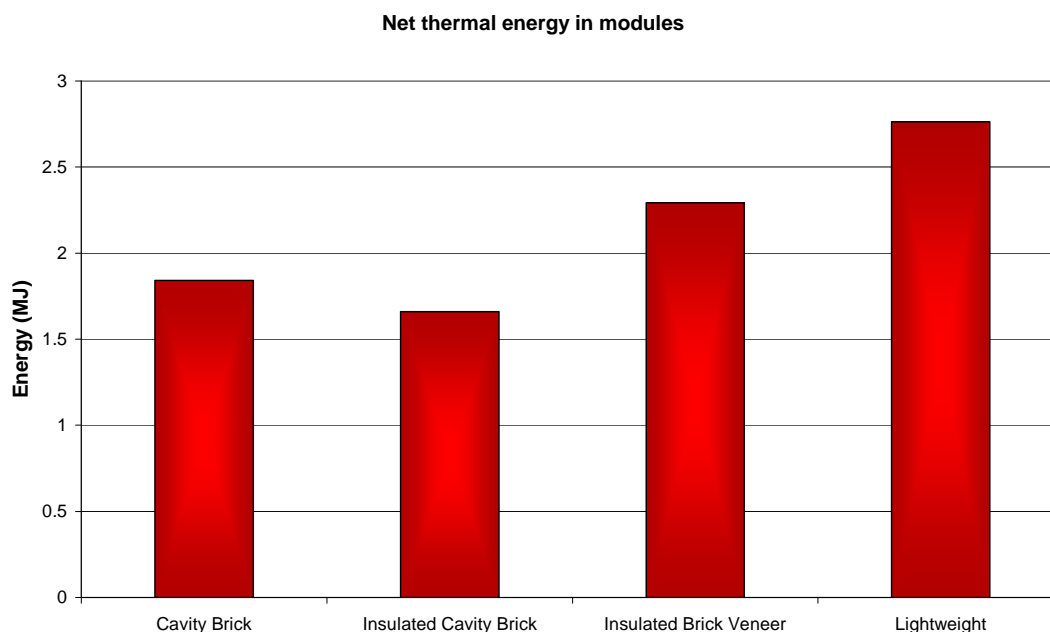


Graph 3: The impact of windows

The insulated cavity brick module performs better than fibre cement module because not only is the heat entering the building reduced by the insulation in the walls, but also as the heat entering the room via the window (which can be 70-80 percent of total heat entering a room) is being absorbed by the internal brick wall³.

Graph 4 quantifies this benefit by showing the heat remaining in a room after the internal thermal mass has absorbed energy. The lightweight and insulated brick veneer modules have more remaining energy because they have no internal mass to absorb heat, whereas the insulated cavity brick has the lowest remaining energy because the mass is absorbing incoming heat entering via the window and the insulation is reducing energy flowing through the walls.

³ H.O Sugo, A.W Page, B Moghtaderi *The study of heat flows in masonry walls in a thermal test building incorporating a window*, Canadian Masonry Symposium, Banff, Alberta, June 8-12, 2005



Graph 4: Remaining heat after thermal mass absorption

Benefit of thermal mass #3: internal mass reduce artificial heating and cooling energy demand

Experiment 3 compared heating and cooling requirements for each type of building construction to maintain a thermally comfortable temperature range of 18-24°C.

For this Experiment each test module was installed with a commercial 5kW heating/cooling fan unit and control system to measure real-time energy requirement to meet standard thermal comfort ranges of 18-24°C⁴. Heating energy was provided by electric resistive elements whilst cooling was performed via a chilled water heat exchanger system coupled to an external chiller.

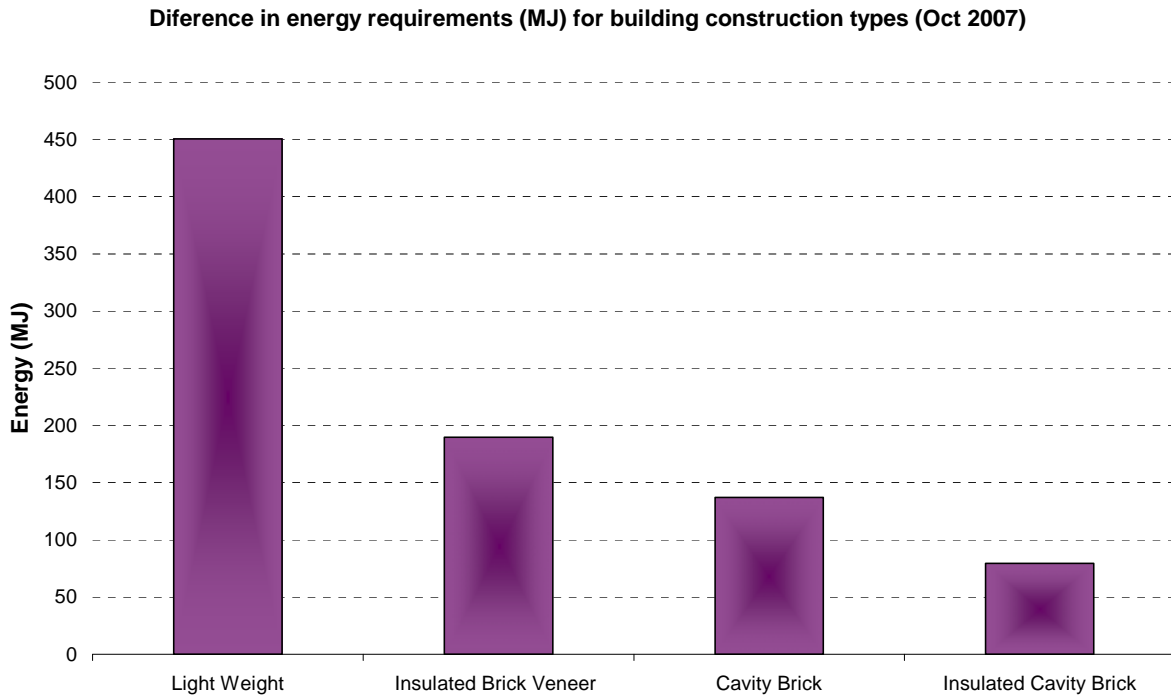
Heating is activated when the internal air temperature fell below 18°C and operated until 20°C was reached at which point the heater was turned off. The building free-floated without heating or cooling between 20-24°C and cooling was turned on above 24°C and operated until the internal temperature reached 22°C.

Within these parameters, and under typical spring conditions, Graph 5 shows that the insulated fibre-cement module used 468 percent more energy than the insulated cavity brick module. This is during a relatively mild period where 85 percent of the time the temperature was less than 25°C (see Graph 6 for temperature distribution and ranges).

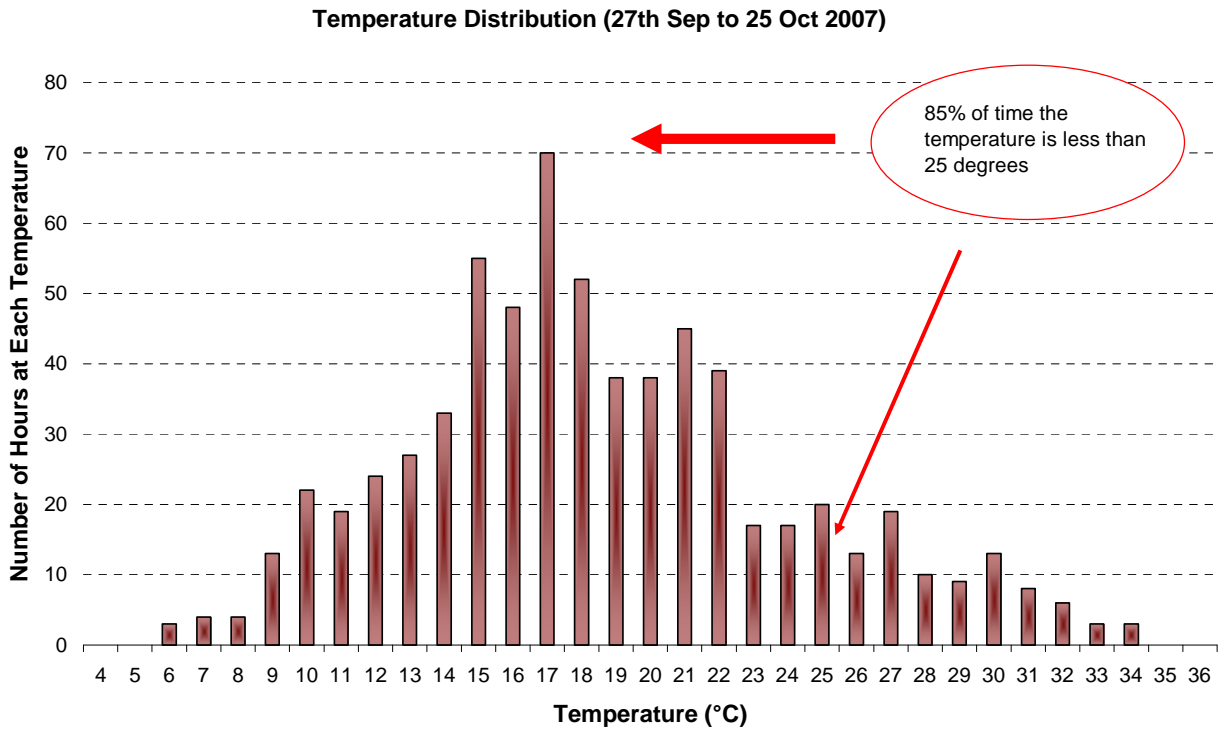
This outcome occurred because the amount of energy (heat) within the lightweight module was substantially higher without the benefit of thermal mass absorption and the air conditioning unit had to remove this additional heat before it could start to cool the room.

Fundamental to improving energy efficiency in the built environment is reducing the amount of energy above or below that naturally required to maintain the level of thermal comfort. To this end, while insulation materials with high R-value can reduce the amount of energy entering a building, once the energy is in the room, they also work to prevent the energy leaving.

⁴ H.O Sugo, S.A Hands, A.W Page *Thermal performance of Australian masonry housing – heating/cooling demands under spring conditions*, 14th International Masonry Conference, Sydney, Australia, February 18-20, 2008



Graph 5: Difference in energy requirements observed for Experiment 3



Graph 6: Temperature ranges for Experiment 3

Benefit of thermal mass #4: absorbing and storing energy to heat a room during winter

While this submission has concentrated on the benefit of thermal mass in conjunction with thermal resistance during summer conditions, thermal mass also has a significant role to play during winter.

During winter good housing design⁵ can maximise the amount of heat entering a building. During the day internal mass works to remove heat through absorption, but at night, as the internal temperature reduces, the mass releases the energy back into the room effectively operating as a self-regulating heater.

Although significant attention is paid to summer time energy demand caused by air conditioning, the impact of heaters cannot be overlooked (in particular the increasingly popular reverse cycle air conditioner/heater). The benefit of combining thermal mass with thermal resistance is that during cold winter nights heat is not lost to the external environment because the insulation provides a preventative barrier.

Section Two – Unintended consequences and perverse outcomes of policy making

The Thermal Performance Research has identified some significant issues that need to be resolved if Australia is to use energy efficiency in the built environment as a source of carbon emission reductions.

Section One has outlined a number of insights into the real-time thermal performance of buildings, however ultimately, they all lead to the same conclusion and problem: that higher insulation does not necessarily reduce maximum temperatures within a building or the energy demand from artificial heating and cooling.

Unfortunately for the long term intentions of Government policy, this problem manifests itself in different way across multiple parts of the economy. These include legislation, rating tools, market behaviour, entrenched beliefs about insulation, and consumer preferences.

Overcoming this problem will not easy but is imperative given the implications if new policy to increase minimum energy efficiency standards is introduced. As demonstrated in Experiment 3, the lightweight insulated fibre-cement module used approximately 468 percent more energy for heating and cooling than the equivalent heavyweight construction method which had a lower R-value.

Extrapolated over the entire residential sector and the 42 years until 2050, a 468 percent difference has the potential to create a massive and unwanted increase in energy demand. Furthermore, this amount may be larger given this test was conducted on a single story, single room module that was perfectly aligned to maximise solar passive benefits, whereas in reality, consumer trend is toward larger, multi-level homes without consideration for solar passive design.

Given alternatives to Australia's coal-generated electricity supply are still someway into the future and the long term life of carbon emissions in the economy, the risk of unintended consequences and perverse outcomes of well-intentioned policy making are significant. To assist reduce this risk the remainder of this section considers specific policy options to improve the energy efficiency of the built environment.

⁵ Solar passive design includes the use of factors such building products, orientation, ventilation and shading to maximise heat gain during winter and minimise it during summer. Given the potential improvements in building energy efficiency using solar passive design strategies, Think Brick Australia have also commissioned research that aims to make solar passive design more accessible. For more information see Upadhyay, Anir Kumar (2008) or visit www.thinkbrick.com.au/climatic-zones.cfm to view the outcomes of this work targeted at architects.

Legislative barriers to energy efficiency

To overcome the problems identified in this submission the legislated requirement for minimum R-values, without consideration of thermal mass, needs to be removed and replaced with an indicator and methodology that combines the benefits of both thermal resistance *and* thermal mass.

As outlined in *Market behaviour and barriers to energy efficiency*, this legislated minimum R-value is influencing building material innovation, large builders, and developers.

Without overstating the limitations of R-value, its measurement and function work on the assumption of a constant temperature difference between the inside and outside of a building. This limitation should be recognised because it not reflective of the actual environment buildings operate within and it favours fibrous and foam insulation products which the real-time research at the University of Newcastle has demonstrated are inferior if not used in conjunction with thermal mass.

Unfortunately a combined indicator and methodology for thermal mass and resistance is not easily achieved because external temperature constantly changes and within this environment simple assumptions cannot be made. Rather it is a complex interaction of many controlling variables which vary from climate to climate.

Australia is well placed to simplify this complex problem as a result of the Thermal Performance Research. Phase 2, set to commence in October 2008, seeks to analyse the real-time data collected from University of Newcastle to define the methodology and indicator to evaluate the performance of walling systems (ie the combined benefit of resistance & mass). This task has been attempted before, but the lack of real-time data has resulted in unsuccessful attempts because all modelling software is based on assumptions, those of which for thermal mass have never been defined.⁶

The Phase 2 outcomes – A Thermal Performance Indicator (TPI) – is hoped to provide a solution that removes the legislative barrier that is causing builders and developers to substitute mass for insulation to meet minimum legislative requirements at the cheapest cost. Think Brick Australia and the University of Newcastle are seeking to get this recognised in appropriate Standards and implemented by the Building Code of Australia as part of its on-going reviews.

Nevertheless, the introduction of a TPI to determine the energy efficiency of buildings may prove difficult if political will does not exist to overcome vested interests. The outcomes from the University of Newcastle need to be properly tested and given a 'fair hearing', and support may be needed to ensure that the methodology is achieved prior to the commencement of any major climate change policies.

Recommendations

1. That the limitations of R-value to achieve energy efficiency and its legislative implications are recognised and no new policy is created without rigorous understanding of the impacts these implications have.
2. That a Thermal Performance Indicator be developed to replace R-value within legislation.

Rating tools as barriers to energy efficiency

As part of legislation, all buildings are rated by tools such as AccuRate or FirstRate. Unfortunately the pervasive nature of R-value has evolved to the point where these rating tools themselves are barriers to energy efficiency because they have all been developed

⁶ See: USA Department of Energy www.ornl.gov/sci/roofs+walls/research/detailed_papers/dyn_perf/thermal.html

using R-value and assuming that the higher the R-value, the higher the energy efficiency of a building.

Therefore, not only has the sole use of R-value to determine energy efficiency created legislative barriers to energy efficiency, but it has also created barriers within the tools used to determine outcomes.

Overcoming this barrier does not necessarily require developing new rating tools, but rather replacing R-value with a measure like the TPI that combines the benefits of thermal mass and thermal resistance.

Recommendation

3. That all tools used to rate the energy efficiency be upgraded so that they use a Thermal Performance Indicator to determine building performance.

Market behaviour and barriers to energy efficiency

As a result of the highly competitive housing market, shortage of land supply and high government taxes and regulations on the development industry, builders and developers have sought cost reductions from a number of areas, including building materials. While historically this is not unusual (given that most construction represents availability of cheap supplies at the time), the legislation has laid the ground work for innovation in building materials that do not improve upon their predecessors, but rather just provide opportunities for the market to meet its legislative requirement at the cheapest possible cost.

Cost comparison⁷ (\$/m²)	Lightweight (Fibre cement)	Heavyweight (Double brick)
Frame <ul style="list-style-type: none"> • Timber (75x50mm @600mm centres) • Clay brick 'commons' (110mm thick) + facing & clean 	\$32.30	\$95.40
Insulation (Glasswool batts R1.5)	\$8.20	\$8.20
Cladding <ul style="list-style-type: none"> • Fibre cement (6mm panelclad Stucco sheeting) • Clay brick veneer (110mm thick) + cleaning & pointing 	\$45.60	\$108.60
Total	\$86.10	\$212.20

Table 2: Average cost comparison of lightweight v heavyweight materials

As indicated in Table 2, the cost to build equivalent insulated homes with lightweight and heavyweight materials is substantially different. An extra \$126.10m² to use the heavyweight construction from Experiment 1, when extrapolated over a small family home of 180m², adds approximately \$22,700 to the price of the home. When combined with other costs and the competitive market, it is understandable that such business decisions are made against the benefits of improved energy efficiency.

Despite this cost difference, legislating the use of thermal mass is not necessarily the best option given that the full consequences of regulation can never be predicted and quantified.

⁷ *Construction Cost Guide*, edited by Rawlinsons Construction Cost Consultants & Quantity Surveyors, Perth, Rawlinsons Publishing, 2008, pp 45-46

Other options include using life cycle analysis to measure the cost/benefit of all materials and construction methods, and the use of 'name and shame' methods to assist the market decide which products it wants to use based on the known implications their use carries.

Recommendation

4. That government rate building products and construction types according to their life cycle cost/benefit and publish the implications of their use.

Entrenched beliefs about insulation and heavyweight building products

Improving energy efficiency in the built environment will be difficult if the Government attempts to change the current market understanding of particular products because these are entrenched beliefs that have been developed over long periods of time.

For example, attempting to convince people that insulation in buildings should be replaced by thermal mass would be difficult because consumers intuitively understand the benefits of insulation and would be uncomfortable trying to turn away from it (Fortunately the research clearly indicates we do not need to do this!).

Nevertheless, a new set of ideas and guidelines are emerging which are not necessarily based on fact and to which the research casts serious doubt. "Embodied energy" and the perceived belief that lightweight is better than heavyweight are ideas still not commonly understood by average Australians. Nevertheless these terms are being increasingly used incorrectly and if not addressed, could make the integration of thermal mass and resistance difficult because of an entrenched belief.

At this stage embodied energy is primarily driven by Local Council guidelines to use low embodied energy materials and various green movements. While this may appear to make the building 'greener', this is another example of an isolated measure and rigorous life cycle testing has not been conducted to prove it.

An example of this is Moreland City Council's "*Moreland Greenlist*", based on their Sustainability Tools for Environmental Performance Strategy (STEPS) Program⁸. The aim of the program is to factor the impact of building material manufacture in the building approvals process. STEPS rates building materials across five categories, including embodied energy without regard for the material's ability to reduce operational energy demand.

Within the guide, especially when rating walling systems, it specifically discourages the use of bricks in preference for timber cladding and other lightweight alternatives because they have lower embodied energy.

To prevent increased energy demand over the long term it is necessary that the Government use rigorous life cycle analysis to test the claims about embodied energy and increase the controls on the information provided in guidelines being developed by Councils that impact the built environment.

While the extent of Council influence over the development process and built environment is beyond the scope of this research, anecdotal evidence suggests Local Councils have a significant impact on the shape and operation of the built environment.

Recommendation

5. That the Federal Government monitors Local Council guidelines to ensure they do not promote building materials with high life cycle costs that increase long term energy demand in the built environment.

⁸ See: Moreland City Council www.moreland.vic.gov.au/services/sustainabledesignassessment.htm

Consumer preferences

Within the current residential and commercial markets the trend toward buildings made of multiple products (brick, timber, glass, concrete etc) will actively work against the effectiveness minimum standards for higher energy performance of buildings. As the research has demonstrated, adding a glass to a wall completely changes the dynamics of how the building operates.

As more new materials enter the market and consumer preferences continue to adopt the mixed-product look, there will be a need for ways to ensure they are not working against the carbon policies of the Australia.

Given the unlikely event that trends will reverse, there is a need for governments to work with industries to support new product research, innovation, and adoption across the economy. This is particularly true for industries such as glass where there is product innovation yet adoption is still at relatively low levels because short term costs outweigh long-term benefit.

Achieving this kind of innovation and adoption needs careful incentives aimed at manufacturers, builders and developers, and end users. It is important to recognise the different leverage each of these groups have, and as such, incentives aimed at end users are likely to have less impact than those targeted at developers.

Recommendation

6. That Australia's carbon policies include careful use of complimentary policy measures that promote building product innovation and adoption across the market.