



Manual 8
Sustainability
and Energy
Efficiency

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Cover and Inside Back Cover: *Apartment House* by

Kerstin Thompson Architects, winner of the Horbury Hunt Residential Award 2018, continues an interest in the brick vernacular of suburban Melbourne and the capacity for masonry to be detailed as opaque wall or transparent screen. A white clay brick is the primary material for the exterior and interior walls. Contrasting with the chalky matte finish of this is the reflectivity of a glazed brick, in the same colour, used in wet areas and to form a datum line to the base of the exterior walls. Glass inserts within the vertical joints of the front facade filter the western sun. This brings a play of light – dazzling at times, aqueous at others – to the interior; its dynamism and changeability enliven the firmness of the rectilinear geometry of the plan and section.

Manufacturer: Bowral Bricks

Brick collection: Bowral Dry Pressed - Chillingham White

Builder & Contractor: ATMA Builders

Photographer: Trevor Mein

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Tiger Prawn
by **WOWOWA.**
Horbury Hunt
Residential
Award 2018 High
Commendation.



1. Introduction

The existence of brick and brick masonry dates back to ancient times, with records of its use in construction found in historic writings and religious texts. Bricks have been used to build the most prolific and awe inspiring constructions that shaped the ages, some of which still stand today. This serves as a testament to the material's longevity and durability and its ability to stand the test of time. Edifices such as castles, churches, houses are still in use hundreds of years after their completion!

In addition to their long life, bricks naturally maintain their aesthetics, technical properties and character. The material composition of bricks is comprised of clay and shales, which are abundantly available throughout the world. Bricks are also impervious to chemical leaching and are naturally fireproof which adds a further dimension to their durability, without the need for further surface treatments or protection.

This manual provides guidance on the selection, design and use of clay brick masonry in construction from a sustainability perspective. Sustainability is generally defined as the development that meets the needs of the present without adversely affecting the needs of the future. Issues such as global warming, deforestation, over consumption and pollution have resulted in growing concern for energy conservation, the reduction of greenhouse gases and sustainability. Think Brick Australia has lead the research in brick design aiding architects, engineers and manufacturers by providing sustainable design methods to maximise thermal comfort and energy efficiency in a household. As a result, brick has regularly been commended for its environmental soundness in all aspects of its life cycle, from its extraction and manufacture to the role it plays in Ecological Sustainable Development (ESD) and to its post life recyclability and uses (cradle to grave). It has been consistently recognised as an ideal building material under many environmental or 'green' design certifications, studies and system reviews by exceeding various criteria and performance protocols across numerous categories.

Sustainability in the built environment considers the

material, design, thermal comfort and energy efficiency of a structure. The operational energy required for heating, cooling, ventilation and lighting contributes to most of the emissions produced in a household over its lifetime. By considering sustainability in buildings, there is potential to substantially reduce the dependency on operational energy, consequently reducing greenhouse gas emissions and energy expenditure.

Even before the introduction of energy efficiency requirements into the Building Code of Australia (now called National Construction Code or NCC) in 2003, the brick industry lead Australian research into thermally efficient buildings. In 2001, Think Brick Australia, in collaboration with the University of Newcastle, undertook a comprehensive research program to investigate thermal behaviour in real structures. This confirmed that clay bricks have the potential to keep a household cool in summer and warm in winter. Built projects that incorporate thermal mass coupled with passive design have shown the superiority of clay brick as a building material. In terms of NCC compliance measures, clay masonry inherently fulfils and satisfies various clauses and recommendations that fall under fire safety in bushfire areas, termite risk (for cavity brickwork), sound insulation and energy efficiency.

Parallel to this work, a detailed Life Cycle Assessment (LCA) of the brick industry has been performed. Previous LCA methods only consider the energy used through extraction & manufacture, transport & construction to demolition & disposal. Think Brick Australia adopted a new methodology to analyse the full environmental impacts of a material, by also considering emissions from operating the structure over a lifetime of 50 years. Bricks are presented as the preferred building material, due to the low operational energy required for comfortable living.

Sustainability requires a reduction of lifetime greenhouse gas emissions and the economic benefits are obvious. A reduction in operational building energy implies a reduction in energy costs and the easier attainment of energy self-sufficiency.

2. Sustainability

Sustainability is defined as, “Meeting the needs of the present without compromising the ability of future generations to meet their own needs.”(3) The three main pillars of sustainable development include economic growth, environmental protection and social equity.

2.1 Elements of Sustainability

For building materials, sustainability has generally been simplified into the areas of embodied energy and thermal resistance. These aspects form just a fraction of the total life cycle considerations of a material. If decisions are made solely from that narrow perspective, the outcome can be consequential and can actually work against the objectives of sustainability.

Sustainability in the construction industry means balancing and improving environmental, social and economic needs. Sustainable buildings require selection of materials that have a lesser or reduced effect on the environment when compared with alternatives that serve the same functional purpose. That means, when comparing alternatives, it is not as simple as ranking characteristics based solely on mass, cost or embodied energy. It may be popularly claimed that materials with a lower embodied energy do their part in fulfilling the elements of sustainability. However, low embodied energy products may reduce sustainability because of high maintenance needs or short life spans leading to early or frequent replacement. This leads to a rise in processes that encourage further wastage, carbon emissions and use of resources. Bricks offer long life, low maintenance, durability and recyclability. These characteristics alone enhance the industry’s contribution to sustainable building materials and out perform any other competing products.

It is important to differentiate between bricks and brickwork. It can be misconstrued that because brick has a near endless service life that a brick wall should also share the same rate of durability. It must be mentioned

that bricks have to be used in conjunction with the correct mortar mix for its application. Tables found in AS 3700: Masonry Structures (2) provide the performance design requirements for bricks, mortar, built-in components and reinforcement to achieve the required levels of strength and durability.

Section 4 of this manual provides detail to the Life Cycle Assessment of bricks in buildings, below is an overview of the sustainability elements for clay brick masonry.

2.2 Manufacture

The steps of manufacturing a brick are:

- Extraction
- Crushing and grinding
- Shaping
- Drying
- Firing
- Packaging

2.2.1 Extraction

Clay and shale are two of the most abundant natural materials on the planet. They are extracted from pits located at the site of a brick manufacturing plant so as to minimise the energy used in transporting raw materials. The process of clay extraction, also known as winning, is highly efficient so that virtually all the material extracted from a pit is used. The clay shale is extracted and layered in blended stockpiles. There is no need for elaborate chemical processing. When the resource has been depleted, the pit is repurposed for landfill, housing, industry, agriculture or parkland.



Figure 2.1 Typical clay pit

2.2.2 Crushing and grinding

The raw materials are processed in primary crushers to reduce the particle size. The material is then transported by conveyors for finer grinding and screening, to reduce it to the desired particle size.

2.2.3 Shaping

After the clay is mixed with water, it is shaped by pressing or extrusion. Pressed bricks are produced by compressing clay in a steel mould (or die box) to form the finished brick shape. Extruded bricks are the most common brick type and are produced by forcing clay through a tube to a die (Fig 2.2). The clay column is cut into individual bricks with a wire. Any off-cuts are re-introduced into the manufacturing process to be mixed and extruded again.

It is common to meet the brick plant's water needs solely from rainwater collected on site rather than using town water.



Figure 2.2 Shaping

2.2.4 Drying

Before bricks are fired, the water must be removed by forced drying. Air drying is rarely used as it can take months for the bricks to dry, and that is not practical in modern production facilities. Bricks may set directly on kiln cars that pass through drying and firing (Fig 2.3). In some cases, bricks are dried on racks before setting. To add to the energy efficiency of the manufacturing process, all plants in Australia now utilise waste heat from the kilns to dry the unfired 'green' bricks.



Figure 2.3 Drying of extruded bricks prior to firing

2.2.5 Firing

Bricks are fired at temperatures between 1000 and 1200 °C depending on the clay. There are many different types of kilns with tunnel kilns being the widely used in Australia, mostly fired on clean natural gas. Many of the beneficial properties of bricks are result of firing, such as strength, durability and longevity. Broken and damaged fired bricks can be crushed (commonly referred to in the industry as “grog”) and fed back into the production process.



Figure 2.4 Tunnel kiln



Figure 2.5 Recycling of waste heat

2.2.6 Packaging

The regular shape of bricks enables efficient packaging, usually in packs strapped together which in many cases eliminates the need for a pallet.



Figure 2.6 Packaging of bricks for transportation

2.3 Use

Bricks, because of their relatively small unit size, offer great flexibility in design with minimal waste material on site when detailed properly. The small unit size of bricks promotes safe and effective use of manual labour and allows easy accommodation of site dimensional variation.

2.4 Functionality

Clay brick masonry addresses multiple performance needs. In fact, no other building material delivers such a broad range of functions, attributes and aesthetics. Some are listed below:

- Face brickwork is finished and durable, requiring little if any maintenance over its design life of 50-100 years.
- Weather tightness. The cavity construction of cavity brick, brick veneer and reverse brick veneer construction prevents water ingress to the inner wall.

- Bricks can be made to meet exposure grades for high durability in adverse environments such as coastal areas and areas with high level of ground salts.
- Bricks are capable of supporting relatively high loads, for example in three to four storey buildings with suspended concrete floors.
- Fire resistance – brick walls meet all bushfire attack levels including flame zone, and provide fire separation in multi-unit buildings.
- High level of acoustic resistance.
- Versatility – modern brick styles allow great freedom of design expression, being available in a wide range of shapes, colours, textures and finishes.
- Bricks provide a high level of thermal mass for smoothing out the temperature range in a dynamic diurnal cycle.
- Bricks are chemically inert and classified as low-Volatile Organic Compound (low-VOC) building products providing a safe and healthy indoor air quality
- Bricks do not contain organic matter that supports mould growth.

2.5 Potential Energy Savings

The Australian brick industry has always been devoted to energy savings in brick manufacturing. Figure 2.7 shows the national average energy consumption of the brick manufacture, in which 'Energy' includes, gas, electricity and other fuels. Thanks to the energy efficiency improvements that the Australian brick industry has been undertaking for a decade, the drop in energy consumption is quite noticeable. The industry average energy per single brick equivalent (SBE) has been cut to less than 90% compared to what it was 8 years ago, and is continuing the downward trend by introducing further efficiency initiatives. Many plants have reduced energy consumption significantly more than this average.

Energy efficiency improvements are a result of plant machinery upgrades particularly on the kilns and dryers. Examples include high efficiency burners, improved kiln sealing, entry chambers, heat recovery and fans, all reducing the energy required for firing.

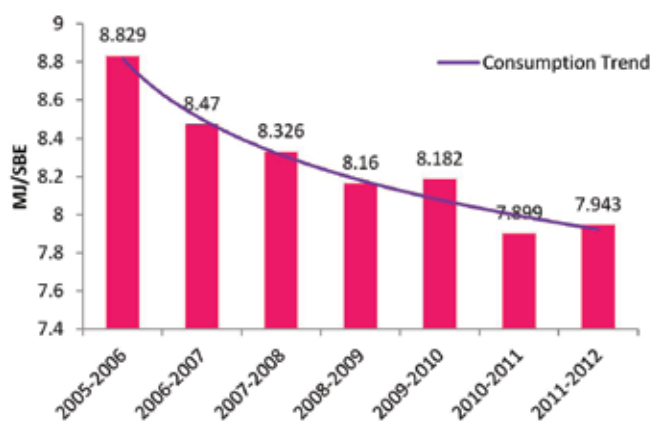


Figure 2.7 National average energy consumption of the brick manufacture

While these gains in efficiency are impressive the industry is undertaking extensive research into using renewable energy sources and the reuse of materials. Innovations have the potential to reduce energy consumption.

2.6 Re-Use and Recycle

Bricks recovered from demolition are reused extensively in structural and aesthetics applications. Bricks can be re-used if care is taken in their removal and cleaning. Where masonry is damaged it is common to recover the whole bricks and reuse them blended with new bricks to maintain the aesthetic of the original masonry. Recovered bricks are sometimes available to use in new walls or extensions to match existing structures. Occasionally recovered bricks are used in new masonry to create a uniquely rustic aesthetic. One of the most common reuse options is to reuse bricks from demolition as common bricks in new structures. These bricks are hidden under render or other cladding so a variety of

different looking bricks in one wall is acceptable. Bricks delivered to sites that are not used can be removed to other sites where they are used as commons.

Recycling of bricks starts in brick manufacturing plants. Broken and damaged bricks are often crushed and added back into the brick making raw materials. Crushed brick is called 'grog' and is very useful in opening the body allowing faster drying of the green brick. Unused bricks on building sites and bricks from demolition can be crushed for use as concrete aggregate and as sub-base for pavements and roads. After sorting to achieve selected colours crushed bricks can be used as a decorative surface in paths, driveways or in landscaping as mulch.



Figure 2.8 Re-used brick facade

If bricks do end up in landfill they are nontoxic, inert, and stable and as such will not leach harmful substances to the environment.

2.7 Chemical Emissions Compliance

Bricks are made from abundant naturally occurring material and are fired at temperatures between 900-1200°C. Consequently they do not produce harmful off-gas/vapour and are non-toxic. When tested to EN 13419: Building Products – Determination of the emission

of volatile organic compounds Part 1: Emission Test Chamber Method, clay bricks constructed with cement based mortar are classified as low-VOC emitting building products.

Due to its inert nature, there is also no need for additional coatings or chemical treatments to ensure optimal serviceability of clay masonry. This ensures a healthy environment in which people can safely live.

2.8 Energy Efficiency Opportunities

The Energy Efficiency Opportunities (EEO) Program is an Australian Government initiative encouraging large energy-using businesses to increase their energy efficiency by improving the identification, evaluation and implementation of cost-effective energy saving opportunities.

At the end of June 2009, the clay brick manufacturing industry identified initiatives that could reduce energy consumption by 20% with 15% having been implemented and commenced. By June 2010 73% of those initiatives had either been completed, realised or had been commenced. The industry is committed to continuous improvement in areas of energy efficiency and sustainability.

2.9 National Greenhouse and Energy Reporting Scheme

The National Greenhouse and Energy Reporting (NGER) Scheme was introduced in 2007 with the objectives of providing data for carbon pricing and public policy setting, to meet Australia's international reporting obligations, and to provide a single point for consolidated industry reports. The scheme is administered by the Department of Environment.

Think BrickAustralia and member organisations have been collecting and analysing data since the inception of the scheme and the industry is committed to the ongoing recording, collection and reporting of data.

2.10 Eco-Labeling

Eco-labels identify the credentials of a product against one or more particular environmental impact categories. The International Standards Organisation (ISO) has created the standards ISO 14024 (3) and ISO 14025 (4) for eco-labelling generally, and ISO 21930 (5) which concerns product specific to building construction, with the purpose of creating an objective method of assessing a product's environmental attributes.

There are three classes of eco-labels as follows:

- Type I – Voluntary environmental labelling, usually based on a relatively simple assessment of preference under one or more impact categories
- Type II – Self-determined environmental claims
- Type III – Voluntary environmental declaration, based on a detailed life cycle assessment and verified by a third party

Think Brick Australia and its member organisations have contributed data suitable for Type III eco-labelling, as is described in Section 4 Life Cycle Assessment, and is working with National Standards to create an industry platform for its support.

2.11 Summary

The Australian brick manufacturers are achieving high standards of sustainability in the production process; incorporating, economic, environmental, and social equity. The industry is committed to continuous improvement in all areas of sustainability. To date, significant gains have been made in both waste and energy efficiency. Waste has been minimised to a very low level for most brick plants by recycling waste material and heat in the production process. Long standing energy efficiency programs have resulted in continuous reductions in energy consumption.

3. Thermal performance and Energy Efficiency

Over the last decade, there has been growing worldwide concern for the reduction of greenhouse gases and an increased awareness in energy conservation and sustainability. In Australia, it is estimated that 40% of end energy usage in domestic buildings is consumed for space heating and cooling (1). The design and construction of energy efficient buildings has the potential to substantially reduce the dependence on artificial heating, cooling, lighting and ventilation with consequential reduction in greenhouse gas emissions and energy expenditure.

To maximise sustainability in building design it is imperative to understand that the key factor is the use of the most appropriate material in all aspects of that design. The sustainability of the whole is much greater than the sum of its parts. This section outlines key research findings of clay masonry from a sustainability perspective.

3.1 Solar Passive Design

Solar passive design is energy efficient design which considers the local conditions to maximize thermal efficiency in a building. Good solar design uses natural heat and natural cooling to keep temperatures within a comfortable range (typically 18-24 degrees Celsius) and should not cost more when included at the planning stage. Solar design has the ability to reduce the need for expensive mechanical heating and cooling.

Key considerations of passive design are illustrated in Figure 3.1 and are as follows:

- Orientation and solar access
- Shading and glazing
- Sealing and ventilation
- Insulation
- Thermal mass

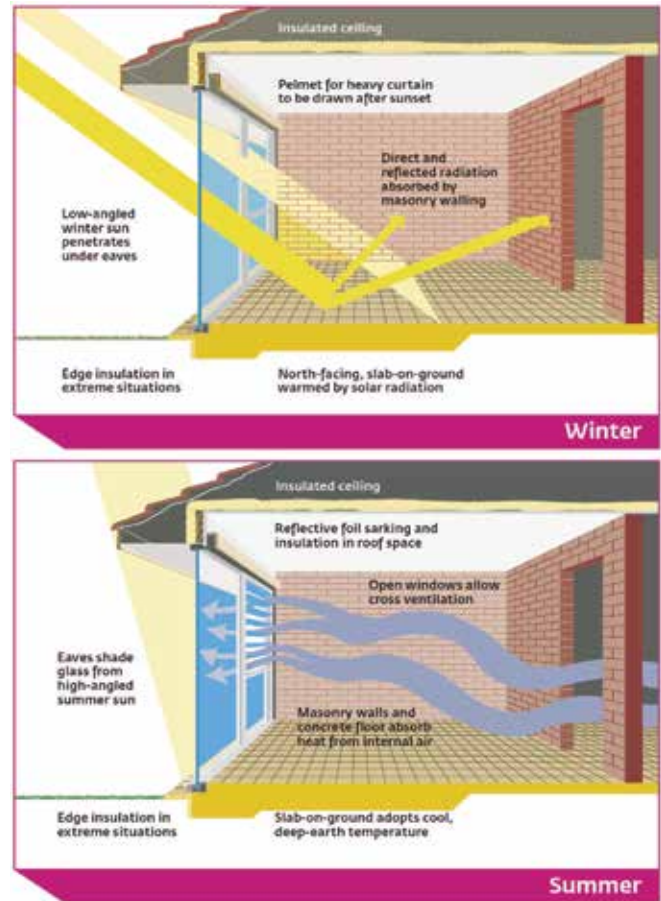


Figure 3.1 - Principles of Solar Design for temperate climates

When considering passive design, it is important to tailor design features of structures to each climate. In southern parts of Australia, prominent north-facing shaded windows with overhanging eaves restrict the entry of summer heat and permit the entry of winter warmth. Contrastingly, in Northern Australia, only shading is required but on different walls at different times of the year, together with well-designed ventilation. Properly sealed doors and windows to allow cross-ventilation and heat restriction when required are essential.

3.2 Thermal Mass in Building Design

Thermal mass is the ability of a material to retain heat energy when subjected to a temperature differential and to slowly release it back into the environment as the conditions change. Structures with high thermal mass can reduce the transfer of heat by absorbing the heat energy flowing in from the outside. This process is slow and results in a delay called thermal lag. The ability to absorb large quantities of heat energy combined with the thermal lag effectively increases the thermal performance of a material. Heavy walling systems like brickwork coupled with concrete floors combine to produce relatively high thermal mass. From a sustainability perspective, high thermal mass is ideal such buildings need less dependency for artificial heating and cooling, meaning less energy use and improved thermal comfort for building occupants.

The maximum external air temperature is usually reached between 12pm and 2pm. A thermal lag duration of six hours (typical for full brickwork construction), means the maximum heat flow would not reach the interior until six hours later. By then external air temperature will usually have dropped and thermal flow will reverse, allowing the building to cool for the following day.

The National Construction Code (NCC) acknowledges the contribution of the mass of a cavity brick wall to its thermal capacitance by including separate deemed-to-satisfy provisions for walls having at least 220 kg of wall mass per square meter.

Thermal mass should not only be incorporated in external walls but in other areas:

- Solid partition walls (as opposed to stud walls) add significantly to the thermal mass. (With the additional benefit of reducing noise transmission between rooms).
- A concrete slab is beneficial as it increases mass significantly.

3.3 R-value

The thermal resistance value or R-value of brick contributes to the thermal efficiency of a building or structure.

It is calculated by dividing its thickness by its thermal conductivity (K-value) resulting in units of $\text{m}^2\text{K}/\text{W}$. While insulation in external walls is essential, the R-value is a static parameter which alone does not predict the energy used in maintaining internal temperature in real-life dynamic temperature environments. Consequently it also does not reflect the true superiority of clay masonry which is to its inherent thermal mass. With a clearer understanding of the importance and role of thermal mass in energy efficiency, one of the key outcomes of the first phase of the University of Newcastle research was the confirmation that the R-value does not directly correlate with thermal performance of real buildings, under dynamic conditions (7).

3.4 A Study of the Thermal Performance in Australian Housing

Think BrickAustralia, in collaboration with the University of Newcastle's Faculty of Engineering and Built Environment undertook a 16-year study on the thermal performance in Australian housing, to better understand the role of clay masonry in achieving sustainable design. The research program provided hard experimental data on thermal performance of various walling systems used in domestic construction. Key goals of the program were to provide a sound understanding of thermal performance of walling systems using both experimental and theoretical techniques and to provide a credible communication strategy to the industry and community. Though the program is still ongoing, to date, the research has shown that clay brick is superior in producing thermally comfortable, energy efficient environments for people to live, work and play (8).

The research was carried out using two methods of testing. The first test uses full scale housing modules, each fitted with 105 temperature sensors to measure the thermal performance of typical Australian walling systems when subject to climatic conditions over all

Hot Box Apparatus

A Hot Box is a testing apparatus consisting of two chambers, separated by the test material.

One chamber will be set to a predetermined temperature while temperature sensors in the second chamber calculate how well the material can resist the transfer of heat from one side to the other (thermal resistance), producing an R-value. The test is performed in accordance to ASTM C1363-11, Standard Test Method for the Thermal Performance of Building Assemblies by means of a Hot Box.

seasons. The following five walling systems were built in accordance to Australian Standards and tested; cavity brick (CB), insulated cavity brick (InsCB), insulated brick veneer (InsBV), insulated reverse brick veneer (InsRBV) and insulated lightweight construction (InsLW). Each module is built to allow for adaptation to design changes, such as the inclusion of windows and partition walls.

The second method uses a **Hot Box apparatus**, the widely recognised testing method for determining **R-values**. The test was reproduced in accordance to ASTM C1363-11, Standard Test Method for the Thermal Performance of Building Assemblies by means of a Hot Box- however, the temperature was set to simulate typical Australian climatic cycles instead of using a constant temperature.

3.4.1 R-value Tests

Over the 12 year period of research, various walling systems have been tested; cavity brick (CB), insulated cavity brick (InsCB), insulated brick veneer (InsBV), insulated reverse brick veneer (InsRBV) and insulated lightweight construction (InsLW). The walling systems were first tested in a guarded hot box apparatus (ASTM C1363-11) to determine their R-values under standard conditions, (see Table 3.1) followed by cyclic (dynamic) tests under a varying temperature regime.

R-value

A materials ability to resist the transfer of heat is represented by a number known as an R-value. This is obtained using a Hot Box Apparatus, exposing one side of a material to a constant temperature while measuring the transferred heat on the opposing side.

R-values are used to determine the energy efficiency of a building – however, the study shows there is no direct correlation between the two under realistic climatic conditions.

Table 3.1 Wall Type, Element Thickness and R-Values (surface-to-surface)

Wall Type	Element Thickness (mm)	R-value (m ² .K/W) ΔT=18°C
Cavity Brick + Internal Render	280	0.44
Insulated Brick Veneer	260	1.58
Insulated Cavity Brick + Internal Render	310	1.30
Insulated Reverse Brick Veneer	240	1.57
Insulated Lightweight	110	1.51

3.4.2 Full Scale Housing Module Testing

Full scale housing modules were constructed to monitor performance under Australian seasonal conditions. The research was conducted in suburban Newcastle, which has a typical moderate Australian climate. Each module was studied with the interior space either being in a **free-floating** state or with the interior being artificially heated or cooled to maintain a **comfortable temperature range**. The energy consumption that resulted from heating and cooling was recorded.

The modules were progressively altered to gain an understanding of the significance of various design features. The following features were tested under free-floating and controlled internal conditions:

Free Floating

The internal temperatures are left to freely adjust to temperature changes with no artificial heating or cooling used to maintain a set internal temperature.

Comfortable Temperature

Heating and cooling was based on the assumption that a comfortable temperature range is 18-24°C for the study.

- Windowless design,
- North facing windows,
- Internal lightweight partition walls, and
- Internal heavy partition walls.

3.4.3 Windowless Modules

The windowless module study highlighted the significance of including thermal mass in housing construction as it helps to reduce the extremity of internal temperature variations through **thermal lag**.

Thermal lag is approximately 6 hours for typical cavity brick, resulting in a living space temperature dampening effect caused by warmer walls during cool nights and cooler walls during the heat of the day. These opposing temperatures result in less extreme temperature changes, decreasing the energy demand of appliances used for heating and cooling.

These dampened internal temperatures are evident in figure 3.2. It is important to note that there is a time delay between peak external temperatures (red line) and peak internal temperatures (blue line).

Temperature sensors throughout the walling systems of windowless modules showed that the external leaf in cavity brick construction absorbs and stores heat energy, then radiates a large amount of it back out into the external environment, thereby reducing the amount of heat entering the living space.

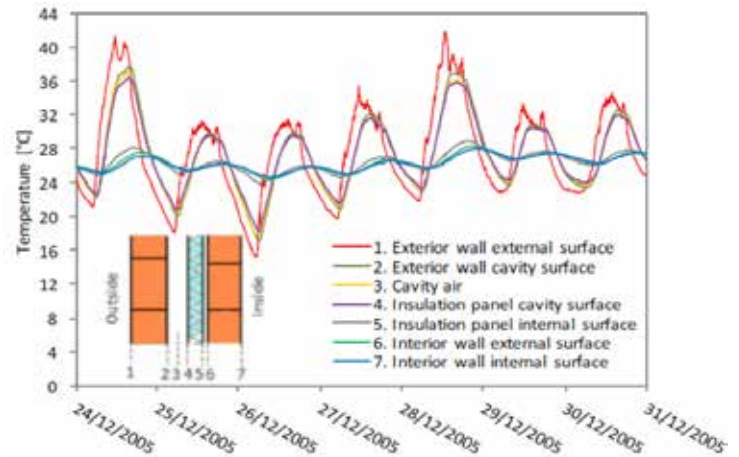


Figure 3.2 - Temperature profiles of InsCB layers in summer

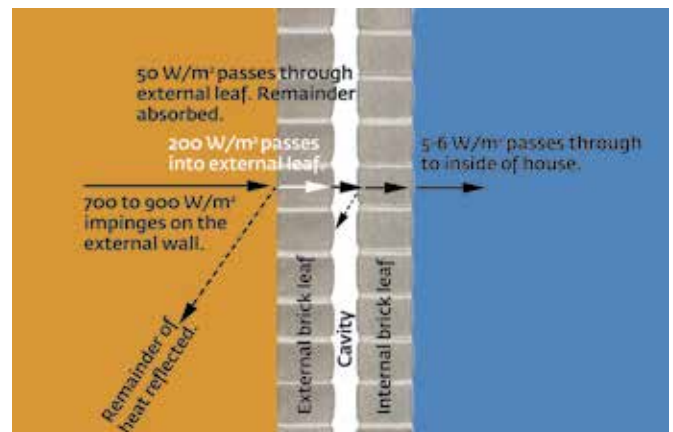


Figure 3.3 - Heat energy transfer through cavity brick wall

Thermal Lag

Materials with high thermal mass absorb and release heat energy to equalise with the ambient temperature of its surroundings.

During the day, the sun slowly charges the bricks with heat energy, then at night the bricks release this energy as it equalises with the cooler external air.

This process is slow – resulting in what is known as thermal lag.

3.4.4 Modules with Windows

Large north facing windows were introduced to the housing modules to monitor their contribution to internal temperatures.

Single pane glass windows are a weak link when constructing for energy efficiency as they offer no thermal lag. This masks the benefits provided by walls of high thermal mass as they allow for living space temperatures to be directly influenced by external conditions. Figure 3.4 demonstrates the influence of installing components with no thermal lag.

To optimise the energy efficiency of a building; small, double glazed windows paired with walls consisting of an appropriate combination of thermal mass and insulation would be ideal.

Although windows were found to be a weak link in designing for energy efficiency, the study also found that windows can be used in favour. The additional solar energy entering a house through windows can be harnessed by strategically placing thermal mass within the living space. Using high thermal mass floors such as concrete slabs and heavy partition walls can assist in maintaining thermal comfort as the components contribute with thermal absorption and later release of the heat energy, as seen in figure 3.6. The study compared the two modules shown in figure 3.5, demonstrating that the use of heavy partition walls and floors helps reduce the temperature variation (figure 3.7).

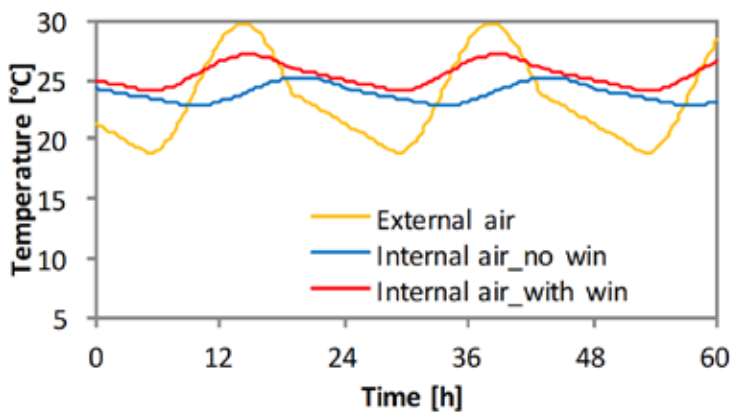


Figure 3.4 - Temperature comparison of cavity brick modules with and without windows in summer

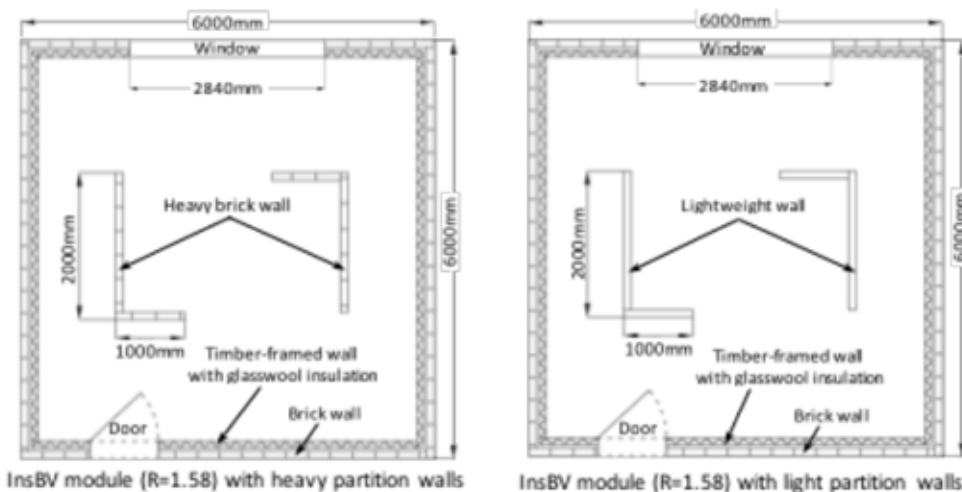


Figure 3.5 - Plan view of modules incorporating heavy partition walls (HPW) and lightweight partition walls (LPW)

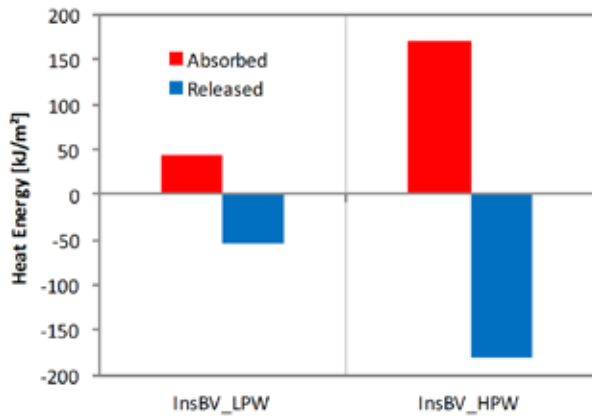


Figure 3.6 - Heat absorbed and released by the HPW and LPW components

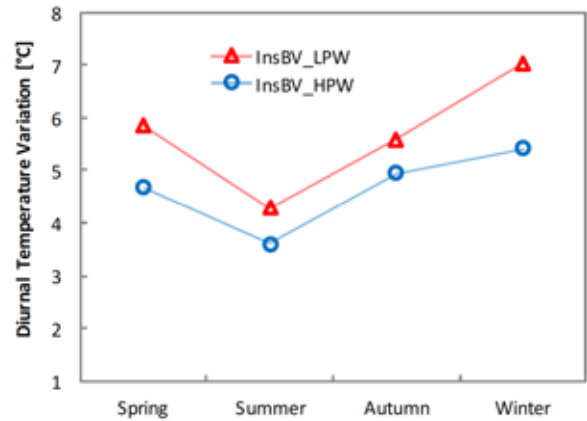
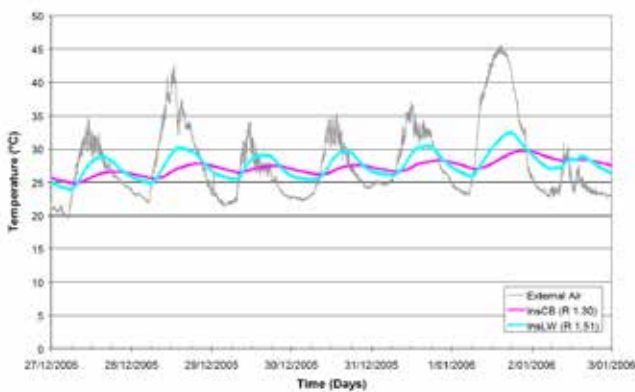


Figure 3.7 - Comparison of the effects of LPW and HPW on internal temperatures

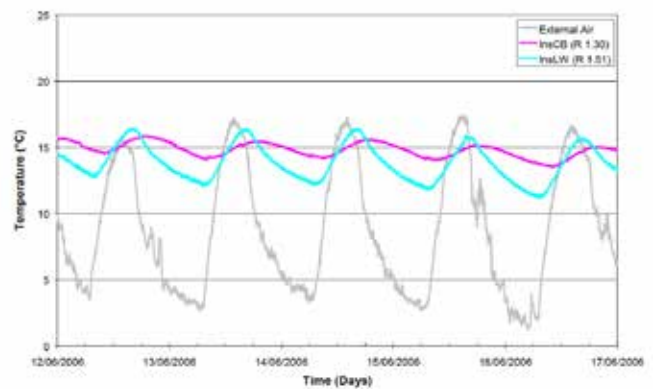
3.4.5 Comparison of Lightweight and Cavity Brick Modules

This was not the case for the insulated lightweight walling system which had a higher R-value but little thermal mass. As a result, there was a greater variation in internal temperatures and no thermal lag, as shown in Figure 3.8, with the insulated lightweight module also being on average warmer during summer and cooler during winter when compared to the insulated cavity brick module.

Note: under the National Construction Code (NCC), the energy efficiency of a building is based directly on R-values. However, the study shows that this assumption is far from accurate. Figure 3.8 (a) and (b) demonstrated that the insulated lightweight wall (R 1.51) would require significantly more heating and cooling than the insulated cavity brick (R 1.30) – despite the insulated lightweight module being regarded under the NCC as being more energy efficient.



a) Hot Conditions in Summer



b) Cool Conditions in Winter

Figure 3.8 - Internal and external temperature for insulated lightweight and insulated cavity brick modules

3.4.6 Seasonal Energy Demands for Full Scale Housing Modules

The energy consumption required to maintain a comfortable temperature within each module was monitored over a twelve-month period and was carried out on modules with north facing windows to demonstrate seasonal variations.

The current R-value system suggests that thermal resistance of a building is directly related with its energy efficiency. However, the study found that their relationship is not so straight forward.

For example, the cavity brick construction required half the energy when compared to insulated brick veneer during the autumn period, despite having an R-value more than 2.5 times greater. This is shown in figure 3.9 (b).

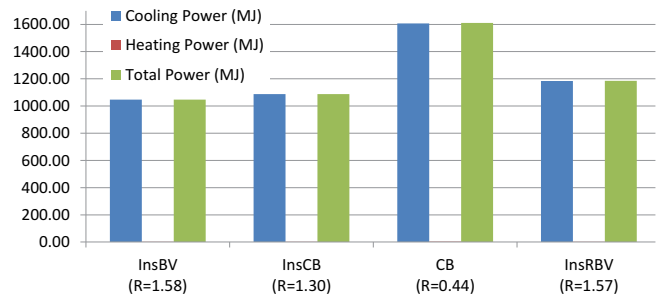
Comparing the energy demand of each construction type indicates that there are three main factors to consider:

1. Thermal mass,
2. Thermal resistance, and
3. Positioning of each

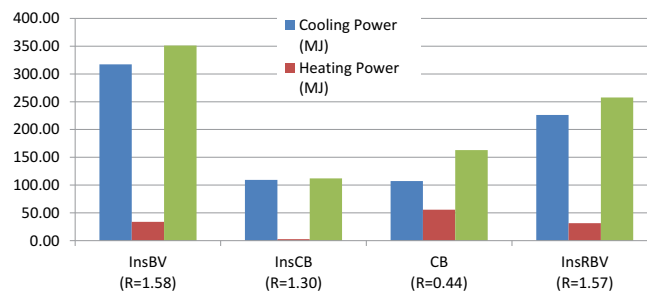
Not only is it important to incorporate both thermal mass and thermal insulation when designing for energy efficiency, the order that they are positioned also plays a contributing factor and will be discussed in more detail in the following section – *Hot Box analysis*.

Overall, the insulated cavity brick provided the most energy efficient results over the course of a year, even though the two walls that incorporated lightweight components had higher total R-values.

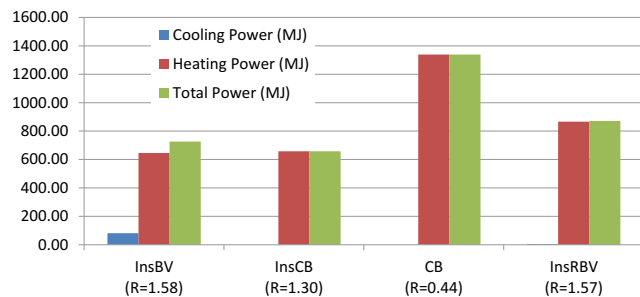
Figure 3.9



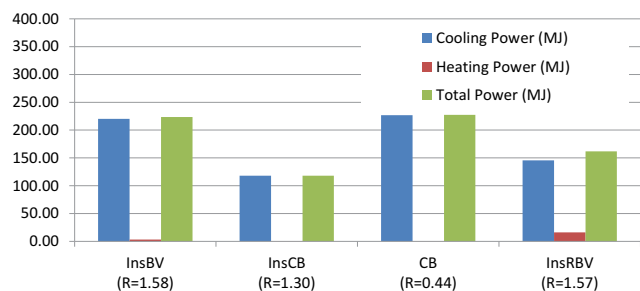
(a) Total energy consumption for a 4 week summer period.



(b) Total energy consumption for a 4 week autumn period.



(c) Total energy consumption for a 4 week winter period.



(d) Total energy consumption for a 4 week spring period.

3.4.7 Hot Box Analysis

The Hot Box apparatus was used during a separate study to test the thermal performance of walling systems under controlled conditions. The testing was performed in accordance to an industry recognised testing method (ASTM C1363-11) – the same method typically used to identify R-values. The only difference was that the temperature was controlled to simulate typical daily temperature exposure, rather than having it set to a constant temperature.

This modification to the testing method demonstrates that R-values are not a credible indicator for predicting energy efficiency. Masonry and polystyrene were used to test internally and externally insulated walling setups, both making up a total R-value of $R_{0.786}$ (figure 3.10). According to the NCC, two materials having the same R-value should perform equally; however, this was not the case.

Figure 3.10 – Hot Box testing configurations of externally and internally insulated masonry

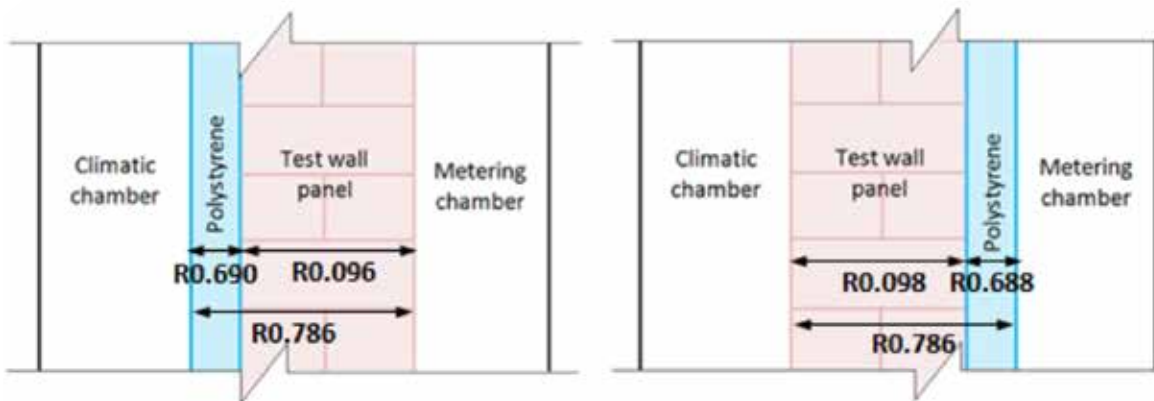
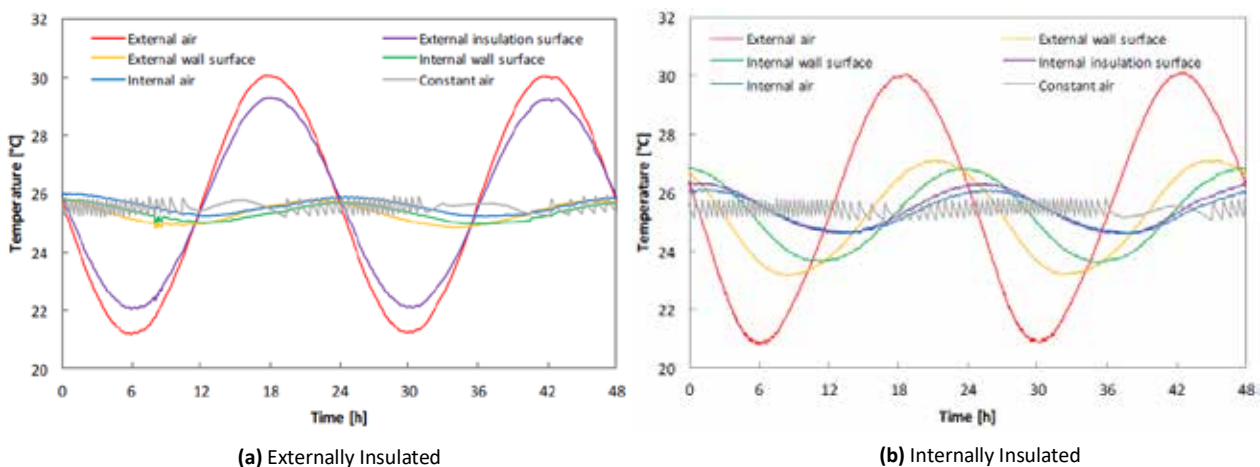


Figure 3.11 demonstrates that placement of materials plays a significant role in achieving energy efficiency. Both walls consisted of the same materials with equivalent total R-values; however, the externally insulated wall achieves greatly reduced internal temperature fluctuations. This means that less artificial heating and cooling is required, making it a more energy efficient option.

Note: The peak internal temperatures are delayed in figure 3.11 as a result of thermal lag.

Figure 3.11 – Hot Box testing results of externally and internally insulated masonry configurations



3.4.8 What Does It Take to Build Energy Efficient Housing?

If R-values are not an accurate indicator of energy efficiency, then how can we build to ensure that energy consumption is minimised?

There are many contributing factors that need to be considered to achieve an energy efficient building. Some of these are listed below:

Thermal Mass

Materials with high thermal mass offer a delayed transfer of heat known as thermal lag. This delay can be utilised to minimise the temperature variations within a living space. In contrast, lightweight components allow for immediate heat transfer – allowing heat to radiate into the living space during the warmest part of the day. Thermal mass is an essential aspect when building for energy efficiency.

Thermal Resistance

Incorporating components with insulating properties significantly reduces the transfer of external temperatures on living space conditions. It is evident that thermal resistance alone does not dictate the energy efficiency of housing; however, large reductions in energy consumption are seen when comparing two of the same construction types with and without insulation.

Material Positioning

Placing insulation material between two leaves of high thermal mass was found to provide the most energy efficient design. Positioning insulation material on the external face was found to be most beneficial when a single leaf of high thermal mass was used.

Windows

Windows are an essential part of a building's external envelope and help to reduce energy bills by providing

natural lighting. However, they also provide little resistance to external temperatures. Windows are a weak link when constructing for energy efficiency, therefore double glazing or small sized windows should be considered to maximise energy efficiency of your building's external envelope.

3.4.9 Findings

The common perception is that a higher R-value is desirable when attempting to achieve occupational comfort within a dwelling, translating to lower energy consumption and costs. The results above challenge this perception. If the R-value were to be considered as the sole indicator of thermal efficiency, the InsBV system (R 1.58), which has an R value 21.5% larger than that of InsCB (R 1.30), should give greater periods of internal thermal comfort and, under controlled conditions, consume less total energy throughout the year. However, it was found that the lightweight component in InsBV led to 218% higher energy consumption than the heavy brick component in InsCB, despite the wall having a greater R-value. The above observations of realistic building behaviour obviously refute this perception and illustrate that there are more significant contributing factors to the wall performance.

Not only do the findings demonstrate the importance of combining thermal mass and thermal resistance (insulation), their contribution is also dependant on their positioning (Figures 3.10 and 3.11) – the benefits of using thermal mass was also evident when used independently to the external walls as internal partition walls, as demonstrated in Figure 3.5.

There is no doubt that insulation can play a major role in improving the energy efficiency of a building, but it cannot be assumed that adding insulation to any lightweight configuration will produce the best thermal performance. A better outcome can be achieved by using a combination of insulation to provide thermal resistance and a material with high thermal mass (such as clay masonry) to mitigate the temperature fluctuations that occur with daily temperature cycles.

3.5 Future Design Parameters

It is evident that the thermal mass of clay bricks provides a timely delay for heat transfer through walls known as thermal lag. This in turn aids in Ecological Sustainable Design (ESD) as the costs of HVAC and other operational energy is greatly minimised compared to lightweight walling (with equivalent insulation). The thermal lag effect ensures that a cavity brick home will be warmer in winter and cooler in summer as a result of the materials ability to absorb, store and release heat – stabilising the internal temperatures within the building. The R-value does not reflect this effect.

Currently, from detailed analysis of data from past and on-going research at the University of Newcastle, new parameters are being developed to represent more realistically the thermal behaviour in dynamic temperature environments. The “Dynamic Temperature Response” or T-value couples the combined effects of both insulation and thermal mass. The “System Dynamic Temperature Response”, or S-value accounts for the contribution of all the building components and their subsequent influence on the dynamic thermal performance on a building enclosure. Both T-values and S-values are showing significant potential as a future key design parameter for both walls and complete buildings.

The NCC states that a building must achieve an energy rating of 6 stars to reduce heating and cooling loads. Think Brick Australia has completed a case study that easily exceeds this rating when using bricks in a suitably planned design.

3.6 Summary

The research phase 1 (<http://thinkbrick.blob.core.windows.net/media/1374/a-study-of-the-thermal-performance-of-australian-housing.pdf>) and phase 2 (http://thinkbrick.blob.core.windows.net/media/6898/2018_o1_16_thermalreport_hardcopy-3.pdf) analysis have shown that heavy walling systems, such as clay brick, are very energy efficient, sustainable and outperform lightweight construction configurations. Thermal mass, inherently present in heavy walling systems, coupled with solar design can significantly improve thermal performance by reflecting and absorbing solar heat. Accordingly, heavy walling systems perform well in maintaining thermal comfort thus reducing energy expenditure on HVAC. It has also been found that the current measurement of thermal resistance (R-value) does not completely define the energy efficiency in materials or buildings. Clay brick construction offers a more energy efficient and sustainable walling solution compared to other forms of construction.

4. Life Cycle Assessment

To extend the University of Newcastle study, Think Brick Australia commissioned Energetics (13) to undertake the ISO 14040/14044 compliant Life Cycle Assessment (LCA) research on behalf of the Australian clay brick manufacturing industry. The key objectives of this study were:

- to calculate the environmental impacts (in particular energy use and greenhouse gas emissions) associated with the production and operation of a brick house, in Australia, and
- to develop data for a brick include in a national Life Cycle Inventory (LCI) database for building materials, and
- to identify areas within the production and supply of bricks for housing construction, where environmental performance may be further improved.

To understand and mitigate the environmental impact of building and occupying houses, Think Brick Australia has used an internationally accepted total LCA methodology to accurately compare the advantages and disadvantages of different building materials over a 50 year design period. Think Brick Australia undertook a Kyoto Protocol (10), ISO standards 14040:2006 (11) and 14044:2006 (12) fully compliant and peer reviewed total LCA (13) combining both embodied and operational energy emissions.

The research is unique in the Australian construction materials context for its depth and breadth of analysis. The functionality of a house is greater than the sum of its constituents (such as bricks), which should be reflected in the LCA as well when comparing building materials. Think Brick Australia considers that the methodology used in this research is the only fair and appropriate

method for comparative LCA and legislation that targets emission reductions in the building materials sector. Its design recognises that all building materials are different and that the advantages and disadvantages of both heavy and lightweight construction need to be fairly balanced across all four stages of a building's lifecycle.

Stage 1 is the cradle-to-gate manufacturing of bricks. This includes the processes of clay extraction and brick manufacturing for which Think Brick Australia members are directly responsible. Separating these processes from the rest of the life cycle enables Think Brick Australia to communicate their LCI data to third parties such as BPIC and AusLCI. (Shown in Figure 4.1 by green)

Stage 2 encompasses the total life cycle of bricks (cradle-to-grave). Downstream processes, such as transport to building sites, bricklaying, use, demolition and waste treatment, are added to the processes included in stage 1. This is done from a generic perspective, i.e. by following a brick throughout a typical life cycle. (Shown in Figure 4.1 by orange and blue)

Stage 3 looks at the actual application of bricks in assemblies, to build a wall from bricks as a minimum mortar needs to be added. (Shown in Figure 4.1 by blue)

Finally, in **Stage 4**, the building is regarded as a complete entity. Brick walls are combined with other building elements (floors, roof, etc.) to form a house. This includes the operation of a lived-in house over 50 years. (Shown in Figure 4.1 by pink)

The entire LCA takes a holistic approach in analysing the embodied energy of a building product. It can shift the perceptions illustrated by current LCA models (cradle to grave) suggesting that alternative building materials are greener and show how sustainably inferior they are in comparison to clay masonry.

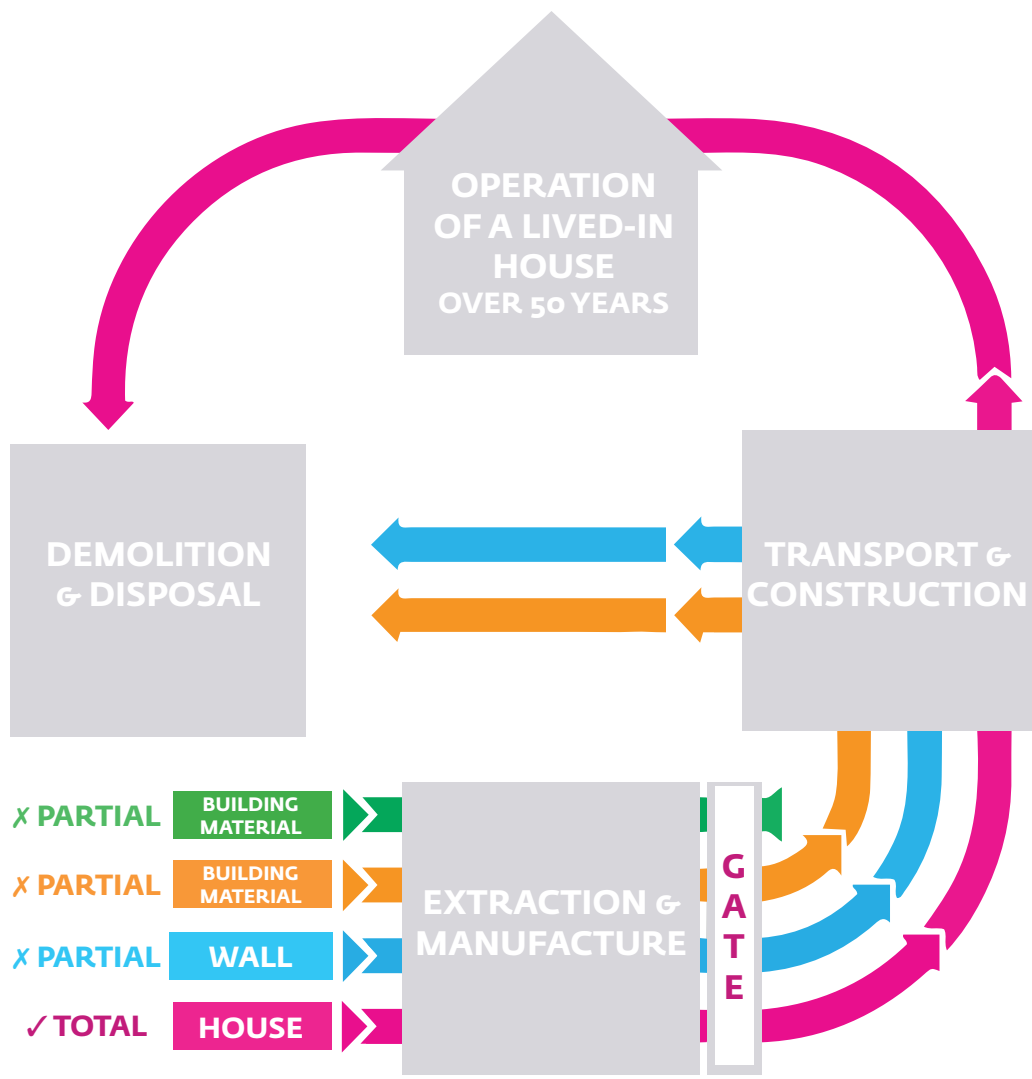


Figure 4.1 Life cycle assessment distinctions

4.1 Life Cycle Impact Assessment Methodology

The main objective of this LCA study is to understand how a brick product performs over its entire life cycle, including consideration of the benefits it may bring to the “use” stage of a house in Australia, with specific reference to a carbon constrained future and increased concern about global warming on the part of stakeholders. Therefore, Energetics focuses on cumulative energy demand (CED) (in MJ) and greenhouse gas emissions expressed in the climate change indicator (in kg CO₂-e).

4.2 Life Cycle Inventory

An integral part of LCA, is a life cycle inventory (LCI) which is a compilation and quantification of all inputs and outputs of a material, product or service measured over a defined time period. Figure 4.2 details a typical LCI process diagram for clay brick. Inventory flows include inputs of water, energy, raw materials and outputs of emissions to air, land, and water and industrial effluent. LCI is developed by creating a flow model of a product’s process, illustrated by a flow chart that includes the activities that are going to be assessed in the relevant supply chain and gives a clear picture of the system boundaries. The input and output data needed for the model are collected for all activities within the system boundary, including supply chain.

4.3 Life Cycle Impact Assessment of Brick

A LCA quantifies the environmental impacts of products across their entire life cycle based on all the inputs to, and outputs from, each stage of that product’s life.

Figure 4.1 shows the study examining emissions associated with:

- A single brick equivalent (SBE). (Green & Orange)
- One square metre of brick wall. (Blue)
- A built and lived-in house over a lifetime of 50 years. (Pink)

4.3.1 Manufacturing, Life Cycle and Wall

Table 4.1 demonstrates that a single brick assessed using “cradle-to-gate” LCA (shown in green) creates 0.61kg of CO₂-e over its life cycle. An additional 0.09kg of CO₂-e is emitted when transported and inevitably disposed in landfill, as per the “cradle-to-grave” assessment (shown in orange). By comparison, a square metre of single leaf brick wall (with the addition of mortar) creates 40kg of CO₂-e (shown in blue). The result shows that brick manufacturing is the dominant process (84.2%) in the greenhouse gas emissions during the life cycle of bricks (natural gas and electricity consumption). Clay extraction and clay transport to brick plant have a combined contribution of less than 4%.

Table 4.1 CO₂-e emissions for brick

	1 SBE	1m ² Wall Assembly
Cradle to gate	0.61 kg CO ₂ -e	n/a
Cradle to grave	0.70 kg CO ₂ -e	40 kg CO ₂ -e

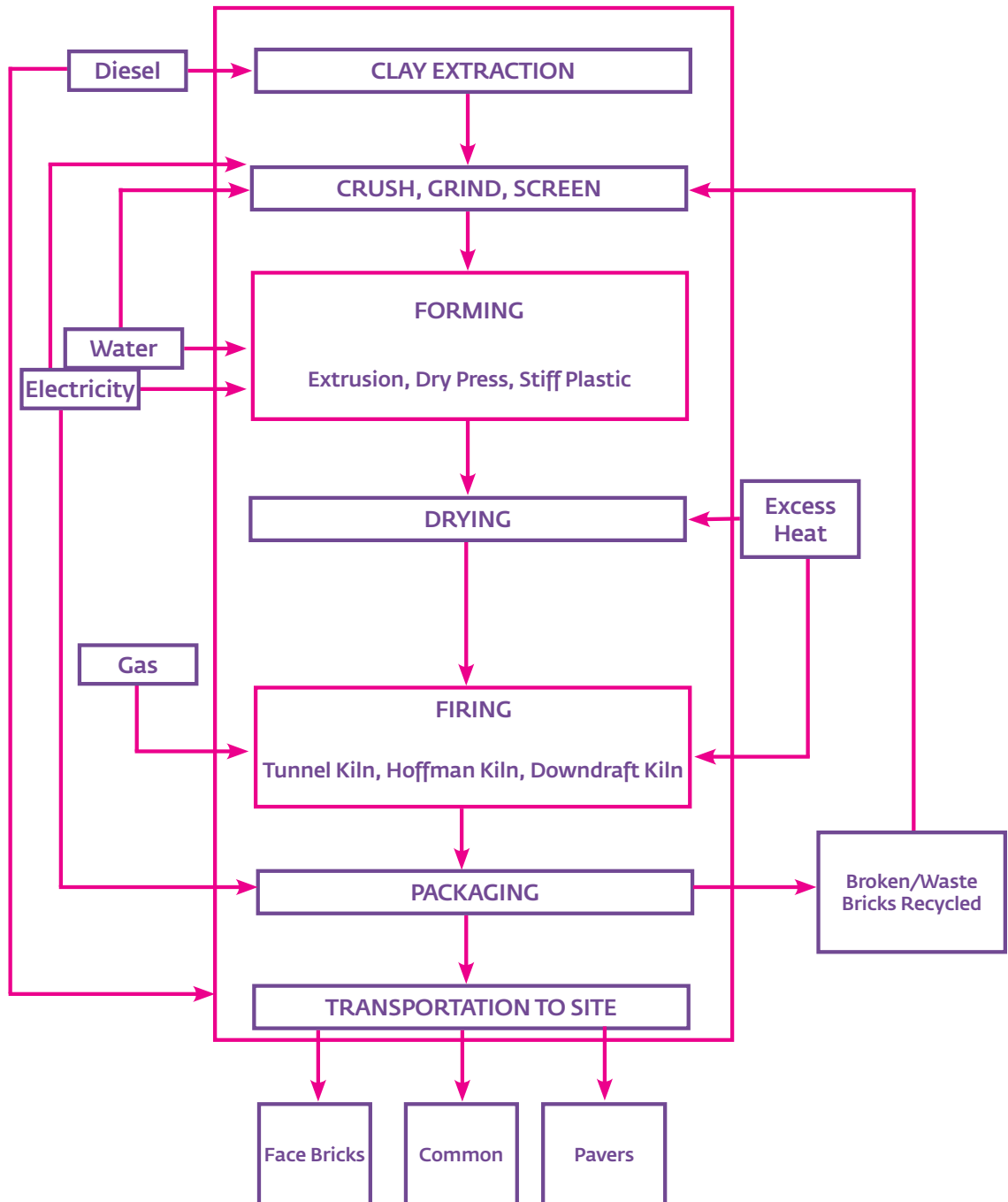


Figure 4.2 Typical Clay masonry LCI flow diagram

4.3.2 House

Using the total life cycle assessment depicted in Figure 4.3, a typical Australian home as modelled (and regardless of external walling material) creates approximately 89 per cent of its emissions over 50 years from the operational energy used to power the appliances, hot water, lighting and HVAC. Only 11 per cent of emissions come from the building materials and construction process (Figure 4.3).

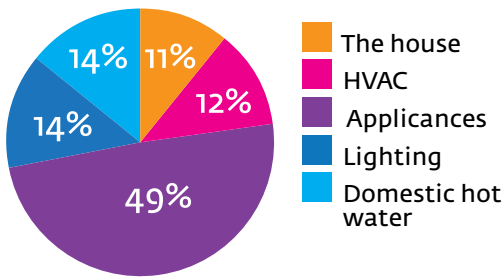


Figure 4.3 Sources of greenhouse gas emissions in a typical Australian home

Figure 4.4 uses the total life cycle assessment but removes the sources of operational energy consumption that are not influenced by the walling materials. Without the operational energy from appliances, lighting or hot water the emissions from the building materials and HVAC energy consumption are more easily examined (11 and 12 per cent in Figure 4.3 respectively). From this it can be seen that the brick wall only represents approximately five per cent of the emissions in a typical Australian home.

Although there are differences between building materials, the study shows that over 50 years they produce minimal differences in the climate change impact. Furthermore this highlights that reducing HVAC energy consumption delivers the most significant emission reductions, and that lowering embodied emissions in all parts of the house will have a more substantial impact than exclusive focus on the external cladding.

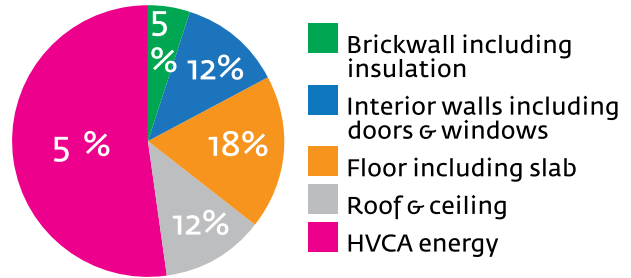


Figure 4.4 Sources of greenhouse gas emissions from HVAC and building materials

4.3.3 Impact of Wall Construction

Table 4.2 and Figure 4.5 compare the differences between a partial cradle to grave LCA and the total LCA used in this study (as represented by the blue and pink paths in Figure 4.2). While Table 4.2 only assesses the emissions from a “cradle-to-grave” life cycle perspective, figure 4.5 shows typical results from all four stages over 50 years.

Table 4.2 Partial life-cycle CO₂-e impacts for different walls

Tonnes CO ₂ -e	Insulated Brick Veneer	Insulated Weatherboard	Insulated Double Brick
House Plan A	67.4	64.4	75.9
House Plan B	63.5	60.3	69.7

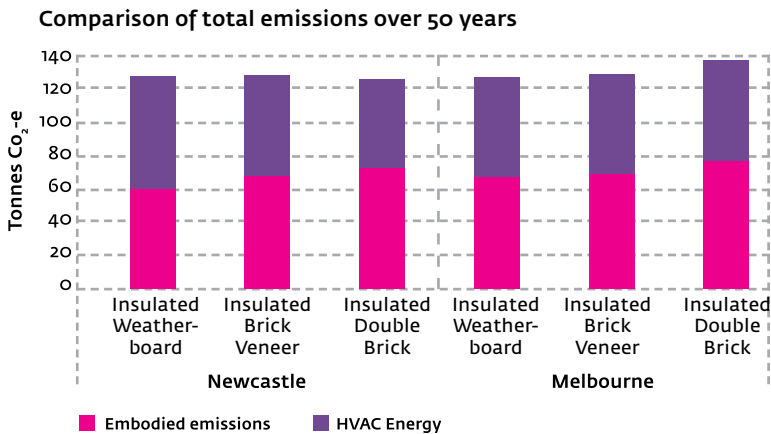


Figure 4.5 Full LCA CO₂-e emissions.

In Figure 4.5, there are no discernible differences in carbon impact between the brick veneer and weatherboard houses. Furthermore, the higher energy efficiency of the double brick house in Newcastle has reduced total emissions below the equivalent brick veneer and weatherboard houses. The Newcastle results can be broadly transferred to Eastern Sydney, Adelaide and Perth.

While the study has highlighted that every case needs to be considered on its own merits, the examples do suggest that lower embodied emissions do not necessarily mean lower carbon impacts, and that the benefits of increased energy efficiency can offset higher embodied emissions.

The difference in embodied impacts between double brick houses and insulated timber houses is 10 tonnes of CO₂-e. This amount of greenhouse gasses equates to 10,000 kWh of electricity consumption in New South Wales and Queensland (and 7,700 kWh in Victoria). Therefore, over a 50 year period, if the double brick houses save more than 200 kWh on HVAC annually, they will become more greenhouse gas efficient than insulated timber houses.

"All assumptions made are precautionary; they are intended to determine the worst case scenario for brick as a construction material in residential housing. This being the case, we find that, over an assumed 50 year life of the building, brick performed no worse than other building materials. When a longer life span was assumed, brick often presented as a marginally preferred material." Energetics 2010 (13)

4.4 Summary

- Improving the design and operation of a house is currently the best way to significantly reduce greenhouse gas emissions.
- Difference in walling systems has very little impact on the overall greenhouse gas emissions caused by a house.
- Correct comparison of building materials requires measuring over the four stages of a building's total life cycle.
- The embodied emissions of a typical Australian house represent only 11 per cent of the total emissions over a 50-year life cycle, regardless of walling materials.

This study demonstrates that the external walling material alone cannot substantially reduce the house's emissions. Rather, emission reductions are achieved by using a total life cycle analysis and understanding how all parts of the house contribute to its total emissions.

In particular this study has highlighted that analysis of emissions based only on the manufacture of building materials and/or the construction of a house does not capture the breadth of information required to properly develop public policy. The best way to capture this information is to use the total life cycle analysis methodology described in Figure 4.1.

The largest limitation of this methodology is the thermal modelling process. Work is already underway by governments and academics to resolve these issues, and once complete, it will be possible to develop a standard Australian LCA methodology to complement current and future carbon policies.

5. Conclusion

Bricks have been used to build the most prolific and awe inspiring constructions that shaped the ages. This serves as a confirmation to the material's longevity and durability and its ability to stand the test of time. But now, people are more concerned about the environmental sustainability of buildings.

Think Brick Australia has led the research in brick design by aiding architects, engineers and manufacturers by providing sustainable design methods to maximise thermal comfort and energy efficiency in a household. As a result, brick has regularly been commended for its environmental soundness in all aspects of its life cycle, from its extraction and manufacture to the role it plays in Ecological Sustainable Development (ESD) and to its post life recyclability and uses (cradle to grave). It has been consistently recognised as an ideal building material under many Environmental or 'Green' design certifications, studies and system reviews by exceeding various criteria and performance protocols across numerous categories.

The Think Brick Australia thermal performance research, in collaboration with the University of Newcastle, had shown that heavy walling systems (such as clay brick) are very energy efficient, sustainable and outperform lightweight construction. This confirmed that clay bricks have the potential to keep a household cool in summer and warm in winter. Concepts such as thermal mass coupled with passive design have shown the superiority of clay brick as a building material. Additionally, heavy walling systems perform well in maintaining thermal comfort and thus reducing energy expenditure from HVAC. It has also been found that the current measurement of thermal resistance (R-value) does not completely define the energy efficiency in materials or buildings. By carefully considering energy efficient and the various aspects of sustainable design, clay brick construction offers a superior walling solution when compared to other forms of construction.

Parallel to this work, the Life Cycle Assessment (LCA) research not only considered the energy used through extraction and manufacture, transport and construction to demolition and disposal but also considered the emissions from operating the structure over a lifetime

of 50 years. Bricks presented as the preferred building material, due to the low operational energy required for comfortable living.

By considering sustainability with one of the aims to reduce lifetime greenhouse gas emissions, the economic benefits are obvious. A reduction in operational building energy implies a reduction in energy costs and the easier attainment of energy self-sufficiency.

6. Definitions and Acronyms

ALCAS Australian Life Cycle Assessment Society.

AusLCI The Australian Life Cycle Inventory Database Initiative.

BCA Building Code of Australia. Part of the National Construction Code (NCC) and published by the Australian Building Codes Board.

Brickwork A type of construction that has units of baked clay and/or shale of uniform size which is laid in courses with mortar joints to various structures.

CO₂-e Carbon dioxide equivalents. There are six greenhouse gases that contribute to climate change which are all normalised to the value and impact of carbon dioxide.

Cradle to gate Cradle to gate measures the environmental impact of a product from the extraction of its raw materials until it leaves the 'gate' of the manufacturing facility. It does not include the transport to the construction site.

Cradle to grave Cradle to grave measures the environmental impact of a product from the extraction of its raw materials until the product is disposed (ie to landfill). This does include the transport to the construction site.

Diurnal Cycle A daily cycle of temperature variation through a maximum and a minimum.

Embodied energy and emissions Embodied energy refers to the energy used to manufacture or construct a product. Until recently embodied energy was used as an easy to communicate indicator, but it is not sufficient to convey the environmental impact given the increased use of renewable energy and other forms of emissions reduction. As such *embodied emissions* is a more accurate representation of the climate change impact.

HVAC Heating, Ventilation & Air Conditioning.

Heat Flux The rate of heat energy transfer through the surface of a material. Units – W/m².

Insulation Material used to reduce the magnitude of heat transfer.

ISO International Standards Organisation.

ISO 14040/14044 The International Standards Organisation (ISO) world-wide standards for life cycle assessment. Although not all LCAs have to follow these standards, it is necessary to do so before publishing any comparative results.

Life Cycle Assessment (LCA) A Life Cycle Assessment measures the environmental impact of products by analysing all the inputs (ie raw materials, water, energy) and outputs (ie the end product, waste, emissions) of manufacture, transport, use and maintenance of the product, and its disposal.

Life Cycle Inventory (LCI) An inventory of flows from and to each stage in the life-cycle of a product, and also across the system boundaries, eg. from and to the natural environment. Inventory flows include inputs of water, energy, and raw materials, and releases to air, land, and water.

NatHERS Nationwide House Energy Rating Scheme. An initiative of the Australian government to ensure consistency across the various house energy rating software tools, so that they can be used in rating building design to meet the requirements of the bldg code.

NCC National Construction Code, a regulatory document, which sets out the minimum requirements for the design, construction and performance of building throughout Australia, published by the Australian Building Codes Board (ABCB).

NGERS National Greenhouse Gas and Energy Emissions Scheme.

Operational energy Operational energy includes all the energy used to power our homes. It includes energy for heating, cooling, lighting, appliances and hot water.

Radiation Is the transfer of heat in the form of electromagnetic radiation. This can occur through space, as in the case of the Sun's energy, or other transparent and translucent media (glass or air). All bodies emit thermal radiation depending on their temperature and emissivity.

R-Value Measure of thermal resistance of a material or building system. Units – $m^2 K/W$.

Range Magnitude of difference between maximum and minimum values.

Recycle The reclaiming, alteration or adaptation of a material for new use without changing the essential form or nature of the material.

Reuse To return a material to serve a function after it has been previously used for a particular purpose.

Solar Radiation Solar radiation emitted by the sun.

Steady State A term describing the state of constant, non-variable temperature input. In the context of building thermal performance, usually refers to a uniform heat load applied to a material for the purpose of determining a material's resistance to heat transfer.

Thermal Capacitance The measure of thermal mass, it is the amount of energy required to increase the temperature of a material by $1^\circ C$. Units – J/kg .

Thermal Lag The time interval between peak temperatures either side of a material, or the outside and inside of a building.

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