The Life Cycle Energy Performance of *Monomur* in Australian Residential Construction

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**Abstract:** Brick veneer is the most dominant construction type in Australia; however it is not necessarily the most advantageous for the climate. Mass wall types, where massing is evident on the interior of the building, can help to achieve greater thermal performance. Monomur thermal blocks are a thermal mass system, based on single leaf construction. They are resistant to compression, transfer of heat, and are made from natural clay. Monomur has shown to benefit construction in Europe, most predominantly France, where the push for low energy buildings is high on the national agenda. This study aimed to determine the life cycle energy performance of the use of the monomur system in Australian residential construction. A life cycle energy analysis (LCEA) was used to quantify and compare the life cycle energy performance of two case study houses, one built from monomur and one from brick veneer. It was shown that there is minimal difference in the performance of these two construction approaches, paving the way for the potential use of monomur in the Australian context.

**Keywords:** life cycle energy analysis; monomur thermal blocks; Australian residential construction

**Introduction**

The construction industry uses significant volumes of material resources and energy. Lowering a building’s energy profile is an integral part of achieving more sustainable societies and reducing the global dependency on non-renewable energy and material resources. Increased stringency in building standards in relation to energy performance has resulted in an increased demand for sustainable or ‘eco’ building designs and components.

In Australian residential construction, clay brickwork is the most widely used external cladding and structural wall medium. Australia wide, brick veneer (BV) represents 45% of the domestic market, followed by double brick at 24%, timber cladding at 13% and fibre-cement at 8%. In Victoria and the ACT the use of BV is higher than the national average, at 61% and 74%, respectively [1]. Framed and clad buildings however are not always optimal in terms of climate responsive design. In particular, brick veneer places the mass of brickwork on the external face of a building where its thermal inertia contributes little to the thermal performance of a building. Additional insulation must be added to bring it to the minimum building regulation requirement of R2.8 [2]. While innovative performance cladding alternatives exist (to replace the BV skin), they are usually highly processed and often plastic- or polymer-based.
Monomur thermal blocks are a single walled tectonic structure, which are highly resistant under compression and have inherently high insulating properties, due to the nature of the material (natural clay), their structure and the firing process during manufacturing. The blocks are resilient, inert, insusceptible to fire, condensation and mould.

The monomur system is a complete catalogue of prefabricated building components; all made using moulded fired clay, which due to their low-tech materiality can be easily modified on site using hand saws and other hand held tools. The monomur thermal block market has become heavily competitive, especially across Europe, and most producers have developed and trademarked their own products. This study considers data relating to one brand, the Calibric® 37.5, as it represents the benchmark for its class of product (Figures 1-4).

Monomur thermal blocks meet the requirements of the Building Code of Australia (BCA) and Australian Standards. One of the most crucial performance factors for building materials in Australia is fire resistance (AS3700-2011) and monomur has a resistance of 240 minutes (single leaf wall un-rendered) which is double the accepted minimum standard.

There is a lack of knowledge in terms of the application of the monomur system in Australian conditions, as well as a lack of test or comparative data for the monomur system versus the single most utilised Australian system, brick veneer. One of most critical areas lacking knowledge is in relation to how this system performs from a life cycle energy perspective. The aim of this study is therefore to determine the life cycle energy performance of the monomur system within Australian residential construction, as compared to traditional BV.
Background
France is one example where efforts have been made to improve the market for low-energy domestic buildings. In 2009, the *Grenelle I* package [3] set new targets and legislation for the construction industry. Under the *Grenelle* standards, housing must have a maximum primary energy demand of 50 kWh/m²/annum (modulated for region and altitude) [4].

In the Australian context, the government has set similar goals, and new houses must reach specific energy performance targets which are defined through a star rating system outlined by the Nationwide Housing Energy Rating Scheme (NaTHERS). The star rating depends on the predicted thermal energy demand of a house [5]. While the star rating system is a step in the right direction it does not consider full life cycle energy performance.

Life cycle energy analysis (LCEA)
*LCEA*, a streamlined version of a life cycle assessment (*LCA*), is used in order to facilitate decision making processes concerning energy efficiency, as it considers environmental impact solely in terms of energy. A *LCEA* considers initial embodied energy (*IEE*), recurrent embodied energy (*REE*), operational energy (*OPE* – thermal and non-thermal) and demolition and disposal energy (*D&DE*) throughout a building’s life. This life cycle perspective is necessary as it helps to avoid shifting energy use across the various stages of a building’s life.

Embodied energy
Initial embodied energy is the energy required in the production of materials or products used in the initial construction of a building. Recurrent embodied energy is the energy associated with manufacturing the building materials and products used in the maintenance of a house over its life. Of the methods available for quantifying embodied energy, hybrid analysis is considered to be the most comprehensive, despite a margin of error of ±30% [6].

Operational energy
Operational energy includes the mechanical heating and cooling-related demands (thermal operational energy - *OPE*T) as well as non-thermal operational energy (*OPE*NT), for lighting, cooking and appliances. Due to the recognised benefits of passive thermal performance, Australia, like many countries has a requirement for new houses to achieve a minimum R-value of 2.8 (R = W/m².K) in an effort to lower thermal operational energy. This R-value relates to thermal inertia or the degree of slowness with which the temperature of a body approaches that of its surroundings. *Monomur* has an R-value of 2.95 (unclad) and a thermal dephasing time of 15 hours (for a 375 mm wide block). A standard clay brick has an R-value of 0.54, with a thermal dephasing time of 3 hours. For a BV wall to meet the minimum Australian standard, it must have insulation added to slow the conductivity of heat. Previous studies of *monomur* show that it has the potential (even in colder climates) to assist in minimising thermal operational energy demand [7].

The main questions to be answered in this study are whether the potential thermal benefits of the *monomur* system are outweighed by an increase in the embodied energy demand associated with its production and how it compares with the performance of BV construction.
Method
This section describes the approach used to determine the life cycle energy performance of the monomur and BV construction methods for a case study house.

The case study house
To generate comparative data for both monomur and BV, a case study approach was used. The case study house selected was a three bedroom single storey BV dwelling with a total habitable floor area of 201.93 m$^2$ (not including garage and decking), located in Melbourne, Australia (Lat. 37°47’S, Long. 144°58’E). The scope of the building elements and materials stayed the same during the comparative analysis, in all aspects except for the wall structure, where BV was substituted for monomur. The functional unit chosen for comparative purposes was one square metre (m$^2$) of floor area. The case study house floor plans are shown in Figures 5 and 6, for monomur and BV, respectively.

![Figure 5 Floor plan of case study house in monomur](image1)
![Figure 6 Floor plan of case study house in BV](image2)

Life cycle energy analysis (LCEA)
The LCEA of the case study house included both initial and recurrent embodied energy, thermal and non-thermal operational energy and demolition and disposal energy (Equ.1). The analysis was performed for a period of 50 years, the average life of a house in Australia.

$$LCE = IEE + REE + (OPE \times building\ lifespan) + D\&DE$$  

(1)

Where $LCE$ is the life cycle energy of the house; $IEE$ is the initial embodied energy of the house; $REE$ is the recurrent embodied energy of the house; $OPE$ is the total annual operational energy (thermal and non-thermal) of the house; and $D\&DE$ is the end-of-life energy associated with the demolition and disposal of the house.
Initial embodied energy (IEE)
An input-output-based hybrid approach [8] was used to calculate IEE using the quantities of the materials in each house. Each material quantity was multiplied by its respective hybrid embodied energy coefficient [8] and then summed to determine the total IEE of the house.

As the monomur system has not yet been used in the Australian context and therefore an embodied energy coefficient for monomur not available, one had to be determined for the use of monomur in Australia. European process data was used as the basis for this value, which was determined to be 1.0764 GJ/m$^2$ [9]. However, this value carries certain complications as the approach used to arrive at it is not completely transparent, so the completeness of the system boundary is unknown. However, when compared to the Australian energy coefficient for a standard clay brick (0.56 GJ/m$^2$), the monomur value is roughly double, and was considered realistic considering that one monomur block is just over double the volume of clay used within a standard clay brick. Furthermore, monomur blocks undergo virtually the same manufacturing processes as bricks.

Recurrent embodied energy (REE)
Recurrent embodied energy was calculated as per the IEE and based on average material service life figures [10]. This considered the number of replacements required for each material within the 50 year life of each house.

Non-thermal operational energy (OPE_{NT})
The non-thermal energy requirements were assumed to be identical for each house and were based on data for the average household in Melbourne, Australia [11].

Thermal operational energy (OPE_{T})
The thermal energy requirement depends on the individual house’s thermal effectiveness, as well as parameters such as geographic location, orientation, position of thermal mass, placement and size of doors and windows, and efficacy of ventilation. IES-VE was used to model the predicted thermal operational energy demands for each house. The R-values assumed for each house were R8 and R2.95 for BV and monomur, respectively. HERS values such as temperatures and occupancy patterns were taken from standardised data sets, reflective of local conditions and user patterns.

Demolition & disposal energy (D&DE)
While there is little reliable information available on the amounts of energy associated with the demolition and disposal of materials at the end of a buildings service life, what is available shows that the amount is likely to be very low, when compared to the total energy demand of a house over its life. A study by Crowther [12] estimates that the D&DE is likely to be less than 1% of a building’s total LCE. The D&DE figure used in this study is thus 1% of the total LCE of each house.
All energy figures used are in primary energy terms, with operational delivered energy figures from IES-VE multiplied by a factor of 3.4 for cooling components (electricity assumed) and 1.4 for heating components (natural gas assumed).

Results
This section presents and compares the results of the LCEA of monomur and BV.

Initial embodied energy (IEE)
The total embodied energy value for the monomur house was 2620.84 GJ (12.97 GJ/m²) compared to 2619 GJ (12.9 GJ/m²) for the BV house. The difference is negligible considering the potential errors of up to ±30%. The data shows that monomur has a higher energy intensity (1.0764 GJ/m²) compared to standard bricks (0.560 GJ/m²). Therefore, even though the timber-framed structure and wall insulation was removed for the monomur house, the higher energy intensity of monomur meant that it still had an equivalent initial embodied energy to the BV house.

The element level breakdown in Figure 7 shows that monomur has a higher masonry value at 123.25 GJ, while BV showed a value of 73.38 GJ. Carpentry (including hardwood and softwood) was reduced for the monomur system by 28.81 GJ, from 151.19 GJ to 122.38 GJ. Similarly, monomur had a 19.15 GJ lower insulation value than BV (from 51.54 GJ down to 32.39 GJ). The remaining elements, which were considered identical for both houses, remained the same. Similarly, the breakdown by material group (Figure 8), shows that the benefits derived from lowering the amount of ‘other metals’ (i.e. reflective foil insulation) and ‘timber products’ (i.e. softwood framing), was offset by an increase in the value for ‘ceramics’, the category which includes masonry (monomur blocks).
Recurrent embodied energy (REE)
Recurrent embodied energy for both houses was found to be 1,373.12 GJ (6.8 GJ/m$^2$) over 50 years, as there was no difference in the replacement rates for materials that differed between houses.

Non-thermal operational energy (OPE$_{NT}$)
The average Melbourne household uses 76 GJ/annum of delivered energy [11], 55% of this energy is non-thermal. Therefore, the average Melbourne household uses 41.8 GJ/annum of non-thermal energy. Assuming an average primary energy factor, to take into account a fuel mix of coal-fired electricity and natural gas, of 2.4, this equates to 100.32 GJ/m$^2$ or 0.37 GJ/m$^2$/annum. This equates to 74.71 GJ/annum for each entire house.

Thermal operational energy (OPE$_T$)
Based on the IES-VE model, the energy required for heating and cooling the BV house in the Melbourne climate was found to be 0.17 GJ/m$^2$ in primary energy terms. The energy demand for the monomur house was found to be slightly lower at 0.16 GJ/m$^2$. Heating makes up the largest proportion of thermal energy demand for both houses at 18% and 17% for the BV and monomur houses, respectively.

Life cycle energy
The combination of the various energy demands for each house (Figure 9) shows that the life cycle energy of the monomur house is marginally lower than for the BV house (2 GJ/annum or 0.5 GJ/m$^2$/annum). Non-thermal operational energy represents the largest single proportion of life cycle energy demand for both houses (39-40%), however, the combined total embodied energy accounted for 42% in each case.

![Figure 9 Life cycle energy breakdown of brick veneer and monomur over 50 years](image)
Discussion
This study has shown that for the Melbourne climate there was only a very small difference in the life cycle energy performance of monomur and traditional BV construction (when insulated to R2.8). The study revealed that in terms of life cycle energy performance, embodied energy is a critical component. However, despite this, non-thermal operational energy still dominates the energy demand through the operational phase of the houses. This can be further minimised by addressing user behaviours, appliances efficiencies and by considering the energy source. The heating and cooling requirements in both case study houses remained similar based on IES-VE modelling, with the main heat loss occurring through the roof of the house. The monomur house showed a slightly lower range of temperature fluctuations throughout the year. The slower thermal lag of the monomur meant that its more sustained dephasing period (between 12 to 15 hours) allowed a longer intermission between the occurrence of low exterior temperatures and the amplification of mechanical heating, when compared to BV. Greater thermal efficacy could be achieved in both instances by controlling the placement and size of windows and the orientation of the house, as well as improving the roof structure.

Another consideration for optimising energy performance is the orientation and placement of thermal mass, as this affects where the heat is collected and then dumped when the thermal storage capacity of the mass is affected by surface temperature changes. As such, thermal mass cannot be adequately expressed with an R-value alone. If a wall has less thermal lag and mass, even though it meets the minimum thermal resistance of R2.8, heat may transfer through the wall mass (or the brick skin with an R-value of 0.54) and be dumped in the internal environment. It is then a question of whether or not the insulation layer can stop that amount of accumulated heat passing through it. Again, while the insulation element may meet R-value specifications, the reality is that these specifications may not be sufficient. As lightweight structures tend to be less durable than massive structures, elements such as insulation cannot perform optimally forever. At some stage during the life of the house, the insulation will probably have to be replaced. This will augment the REE of the building. Such augmentations have not been included in the modelling of this study, as wall structures have an assumed service life of 50 years.

Conclusion
The main findings of this study show that while the difference between monomur and BV was negligible in terms of life cycle energy performance, there is potential for the use of monomur within Australian residential construction. It is critical that the life cycle energy performance of materials are assessed, especially considering that the embodied energy component of a building’s life cycle energy demand is becoming more significant with the advent of low-energy buildings. The use of a life cycle energy analysis approach to compare the performance of monomur and traditional BV construction has enabled a better understanding of how a more advanced material such as monomur may benefit construction industries outside of where they are currently used.
It is also worth noting that other factors play a large part in the viability and use of particular materials in specific construction contexts, including cost, labour availability and skills and market demands and these too should form part of any analysis into the transferability of materials and construction techniques across countries.

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References