ENERGY EFFICIENCY –

The case for incorporating thermal mass in sustainable house construction

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ENERGY EFFICIENCY – THE CASE FOR INCORPORATING THERMAL MASS IN SUSTAINABLE HOUSE CONSTRUCTION

A review of research shows that the R-value that lightweight walling envelopes rely on for energy efficiency is not the all-important thermal performance property and that 'optimal' energy efficiency in South Africa's six major climatic zones is advanced through the use of thermal mass in the external walling envelope and internal partition walls. Clay brick construction is able to provide this superior energy efficiency through the combination of thermal mass and the thermal capacity clay brick walls provide, and resistance as provided by the air in the cavity this supplemented as may be necessary with insulation materials with a somewhat lower R-value than required for lightweight walling.

Confirming the case for the inclusion of thermal mass in walling envelopes for defining more energy efficient houses in South Africa is the correlation in the findings of a plethora of research both in Australia and South Africa. This research comprised empirical measurement of building modules under 'real world' conditions, parametric and thermal modelling using ASHRAE and Agrement SA compliant software plus Lifecycle Assessment (LCA) to determine how building materials and building systems compare in providing thermal comfort and lowering operational energy consumption of houses. The correlation in the research findings consistently reaffirms clay brick construction outperforming comparable lightweight. Fundamental to this outcome is the contribution of thermal mass, how heat diffuses through mass, how it is slowly absorbed, stored and released to moderate internal temperatures for longer.

Thermal mass reduces the quantum of heat reaching the inside.

Figure 1 below, as referenced from research reported on by Think Brick Australia – www.thinkbrick.com.au [3], demonstrates the extent thermal mass reduces the heat passing through the walling envelope during long hot summers.

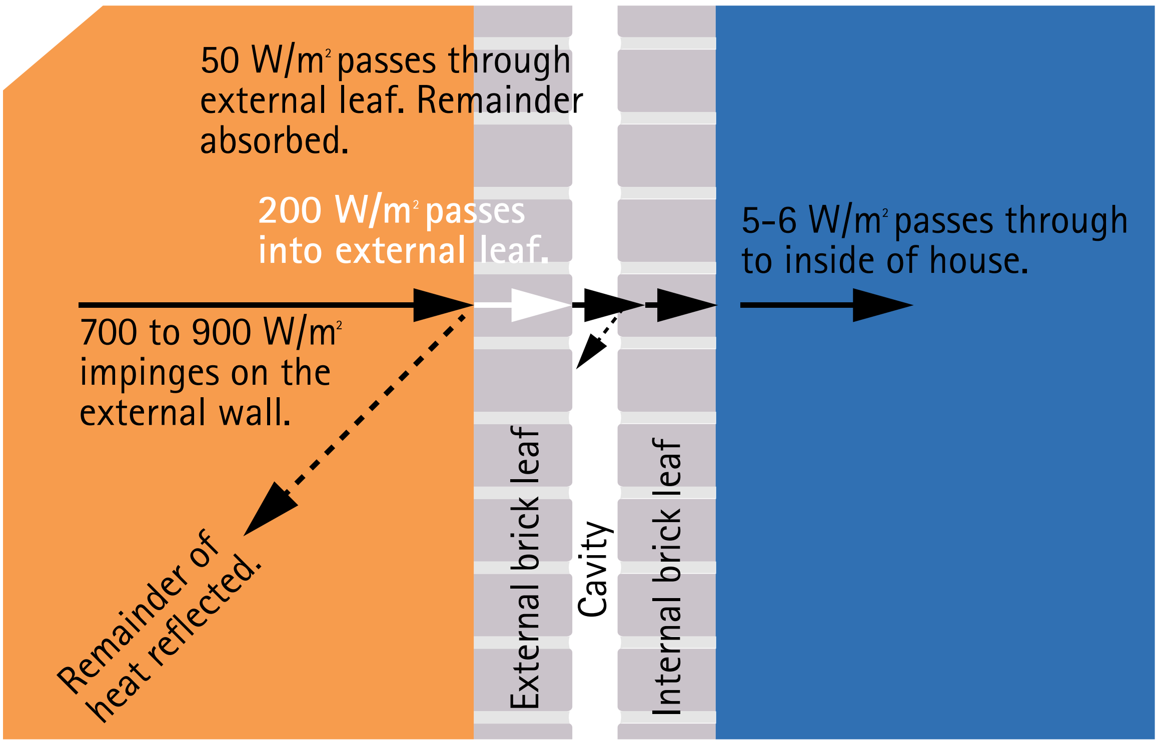


Figure 1: Heat flux through west walls in Summer.

As depicted in Figure 1 above, the amount of heat energy on the surface of the west wall in summer is 700-900W/m² which falls to about 200W/m² entering the external wall. The attenuation of heat reduces to just 50W/m² passing across the cavity with finally only 5-6W/m² of heat energy on average passing into the internal space. The amount of heat energy penetrating the west wall was thus minuscule.

Thermal mass extends the time of heat transfer to the inside

While reducing the quantum of heat, the thermal mass also provides the requisite 'thermal lag' that is of considerable value in the summer months. Table 1 below represents information from research into "The Influence of the Wall R-Value on the thermal characteristics of Australian housing" (Reference 1) depicting the comparison of Australian walling systems with different R-values and the time heat takes to pass through the different wall types.

Wall Type	Thermal Transmittance (U)	Lag (Hours)	Thermal Resistance (R)
Clay Brick Cavity Wall (Un-insulated)	1.22	5.8	0.82
Weatherboard Wall (Un-insulated)	1.82	0.8	0.55
Clay Brick Cavity Wall (Insulated)	0.38	7.5	2.63
Weatherboard Wall (Insulated)	0.38	1.3	2.63

Table 1 - Time comparison of heat movement through walling envelopes

Thermal mass is the essential differentiator between the performances of the two walling options both insulated and un-insulated. The thermal mass rendered both clay brick walling options approximately 5.8 to 7.2 times more effective in slowing the transfer of heat through the wall than the lightweight walling alternates. Insulating the lightweight wall increased the thermal lag a relatively insignificant 0.5 of one hour to 1.3 hours. Consequent to a lag of between 5.8 and 7.5 hours for the brick alternates heat only impacts on the inside after the hottest part of the day when external temperatures would have started to drop and heat flows begin to reverse. The insulated lightweight modules on the other hand have little thermal lag, the light thermal exhibiting the greater variations in internal temperature with internal daily temperature swings of more than twice that of insulated cavity brick during hot conditions.

Thermal mass helps maintain comfort conditions for longer

Depicting the comparable energy consumed to achieve thermal comfort conditions of actual buildings in real world conditions, Table 2 from "A Study of the Thermal Performance of Australian Housing" – Priority Research Centre for Energy, University of Newcastle, Australia [2], shows that the Insulated Lightweight (Ins-LW) module (R1.69) with 14% higher R-value walls used 117% more energy to maintain a comfortable living environment within 18 and 24°C range than the Insulated Brick (Ins-CB) (R1.48) module.

Wall Type	R-Value (m^2K/W)	Heating Energy (MJ/m^2)	Cooling Energy (MJ/m^2)	Total Energy (MJ/m^2)	Normalised to Ins. CB
Ins-CB	1.48	28.3	0.3	28.6	1.0
CB	0.62	56.3	0.1	56.2	2.0
Ins-BV	1.72	32.5	10.4	42.9	1.5
Ins-LW	1.69	48.4	13.7	62.1	2.2

Table 2: Comparison of Energy Usage – Controlled Interior

Both study's [1 & 2] demonstrated that the greater time in the comfort zone and resultant less heating and cooling energy consumed by both the Clay Brick cavity (CB) and Insulated Clay Brick (Ins-CB) modules relative to both Insulated Lightweight (Ins-LW) and Insulated Brick Veneer (Ins-BV) modules (R1.72) was due to the internal thermal mass "smoothing" the internal temperature fluctuations.

This research highlights that in climates akin to South Africa:

- The R-value is not the sole predictor of thermal performance.
- There is no correlation between the R-value of a wall and energy usage.
- The emphasis on R-value as the principal parameter influencing the thermal performance of walling systems is flawed.

The capacity of clay brick walls to absorb a large quantity of heat energy for a small rise in temperature combined with the thermal lag effectively increases the R-value performance over a complete day night cycle. This resulted in greater time spent in the comfort zone and lowest heating and cooling energy usage.

The sum total of the findings of empirical research of the thermal performance of building modules comprising different wall construction types at the Priority Research Centre for Energy, University of Newcastle, Australia [2 & 3] were unambiguous:

- *The lightweight [walled] building was the worst performing in all seasons.*
- Brick veneer performs better than lightweight.
- The insulated cavity brick building performs the best.
- Thermal mass in floors alone, while being essential, is not sufficient to reduce extremes in temperature.

Thermal mass improves the Dynamic Thermal Response

"The concept for a potential metric to characterise the dynamic thermal performance of walls" [4], published in the Energy and Building Journal August 2012, found that the data base of temperature measurements made on the test modules over the eight years showed a consistent pattern for the dynamic responses of walls [T-values] comprising different construction types. The heavy walling systems exhibit small T-values and a relatively small variation in internal surface temperature. In contrast the insulated lightweight walling systems exhibit much larger T-values where the larger temperature changes on the internal surface almost linearly follow the external temperature variations. This was found to be consistent with the behaviour of test modules under real weather conditions in moderate climatic zones, where the modules with walls having lower thermal resistance but higher thermal mass performed better than their lightweight counter parts. The trends of dynamic temperature response for the heavy and lightweight walling systems corresponded and were found to be consistent for both the summer and winter periods.

The thermal mass of internal partition walls add to thermal efficiency

The paper (4) shows that when applying the 'T-value' concept to comparisons of the thermal performance of houses with the same R-value external walls, the cavity brick houses with brick internal partition walls used the least energy of all and had the lowest T-value. Further endorsement of the added value thermal mass [thermal capacity] provides to walling envelopes and internal partition walls for moderating the indoor temperature within the required comfort range is found and explained in the document "Energy Efficiency and the Environment - The case for Clay Brick – Edition 4" [3], www.thinkbrick.com.au where the inclusion of clay brick internal partition walls led to energy consumption reductions in all four construction types. For the 6mx6m modules comprising slab-on-ground, significant north wall glazing, the following reductions in energy consumption was shown when internal bricks walls where added:

- Insulated cavity brick minus 6%
- Insulated 'reverse' brick veneer minus 8%
- *Insulated lightweight minus 20%*

The energy reduction resultant from the addition of internal brick partition walls was most significant in the case of the insulated lightweight module. The effect of this additional thermal mass was less prominent in the case of insulated cavity brick and 'reverse' brick veneer because they were already benefitting from the lower energy demand that the thermal mass provided.

A higher CR Product with greater mass equates with lowest amplitude ratios

Comparable to the T-value research findings are those of the CR Product study [5]. In this South African research a higher CR Product [combination of thermal capacity 'C' and resistance 'R' of a wall] consistently equated to smaller amplitude ratios [lower fluctuation of temperature indoors in response to external temperature movement]. The net benefit of reduced indoor temperature fluctuations was more time within the required comfort range.

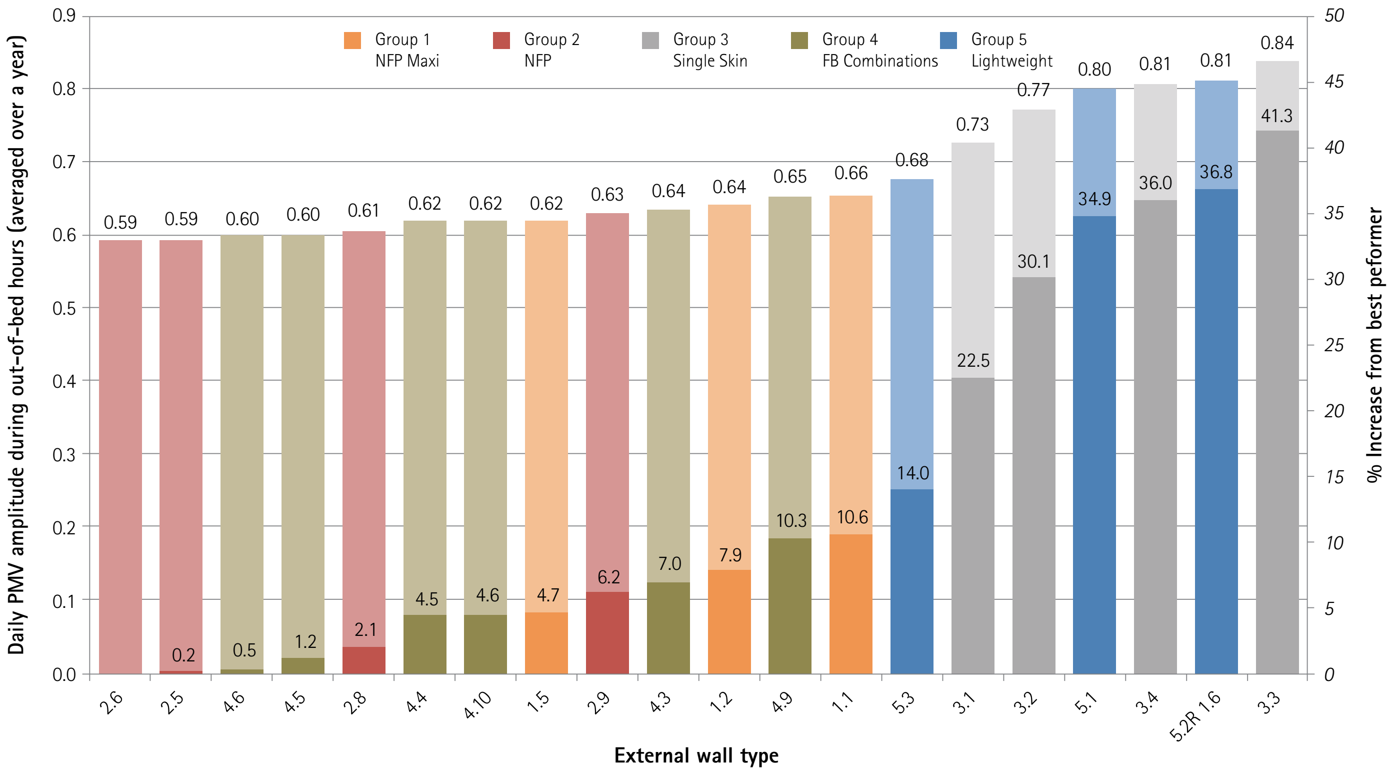


Figure 2: Daily PMV amplitude (max PMV - min PMV, during a days out-of-bed hours averaged over a year), Johannesburg

The CR Product research found that placing insulation between brick skins rendered the 'active' thermal capacity of the internal leaf seven times more effective than the outside leaf, providing the wall with the necessary propensity to self-regulate and better maintain the internal environment within the required comfort range [5].

Dr Alec Johannsen of Alec Johannsen Consulting Engineering on reviewing the WSP Energy Africa, CR Product study commented; "*There is an additional advantage of heavier walls (not discussed in the CR Product report as it is outside its scope), namely a reduction of the building peak cooling and heating loads. This is the combined result of (a) a reduction in the peak heat gain of the wall itself (compared to a light weight wall with the same R-value), and (b) a time lag of the peak heat flux on the inside of the wall in relation to the heat flux on the outside, which makes the heat load from the wall out of phase with the other heat loads, resulting in a lower combined peak total heat load. The result is a smaller and less expensive cooling and heating plant and a lower electrical demand. The above would indicate that greater 'Cs' (thermal capacity) should be favoured over 'Rs' (resistance) when selecting a required CR Product.*"

As depicted in Figure 2 above extracted from the WSP Green by Design 130 m² house study [7], the houses with double skin clay brick walls supplemented with insulation i.e. walls with higher CR Product values, afforded comparatively lower PMV amplitudes and superior thermal comfort to those houses with highly insulated walls (in compliance with SANS 204) but no or little thermal mass and/or single skin masonry walls with lower thermal mass and resistance. This finding for the Johannesburg climatic zone was mirrored in all other major climatic zones of South Africa.

In climates like South Africa, characterised by long hot summers and large diurnal swings – particularly in the interior of the country and at elevated locations, and which are pronounced in-between seasons i.e. in spring and autumn, the importance of the self regulating attribute of thermal mass becomes accentuated in the energy efficiency equation.

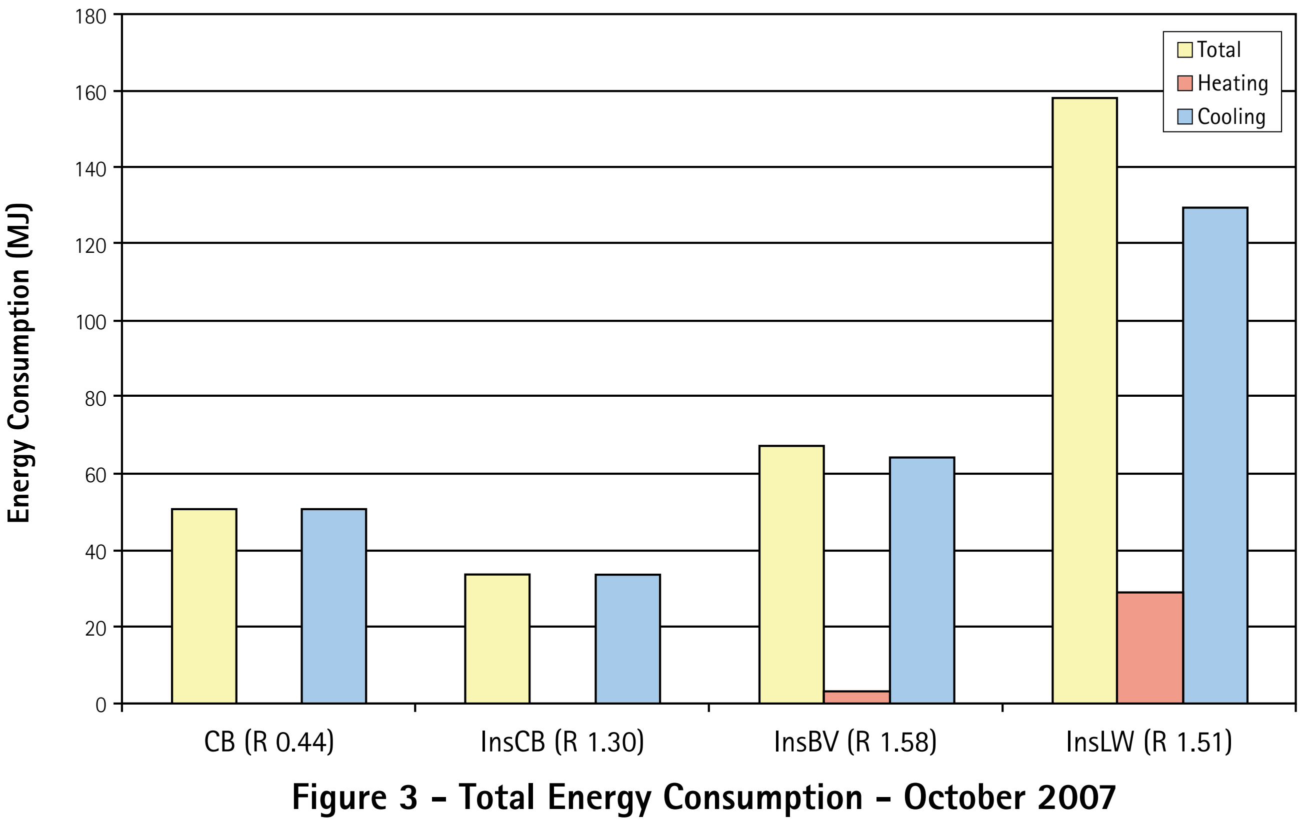


Figure 3: Total Energy Consumption - October 2007

Highlighting the implications of no thermal mass and the inability of lightweight walls to self-regulate [inspite of a high R-value] on hotter days are the comparative findings of the Australian Housing study [3] . As shown in Figure 3 above the insulated lightweight (R1.51) with over three times the R-value of cavity brick (R0.44) used over three times the energy to maintain the temperature in the comfort zone during October 2007.

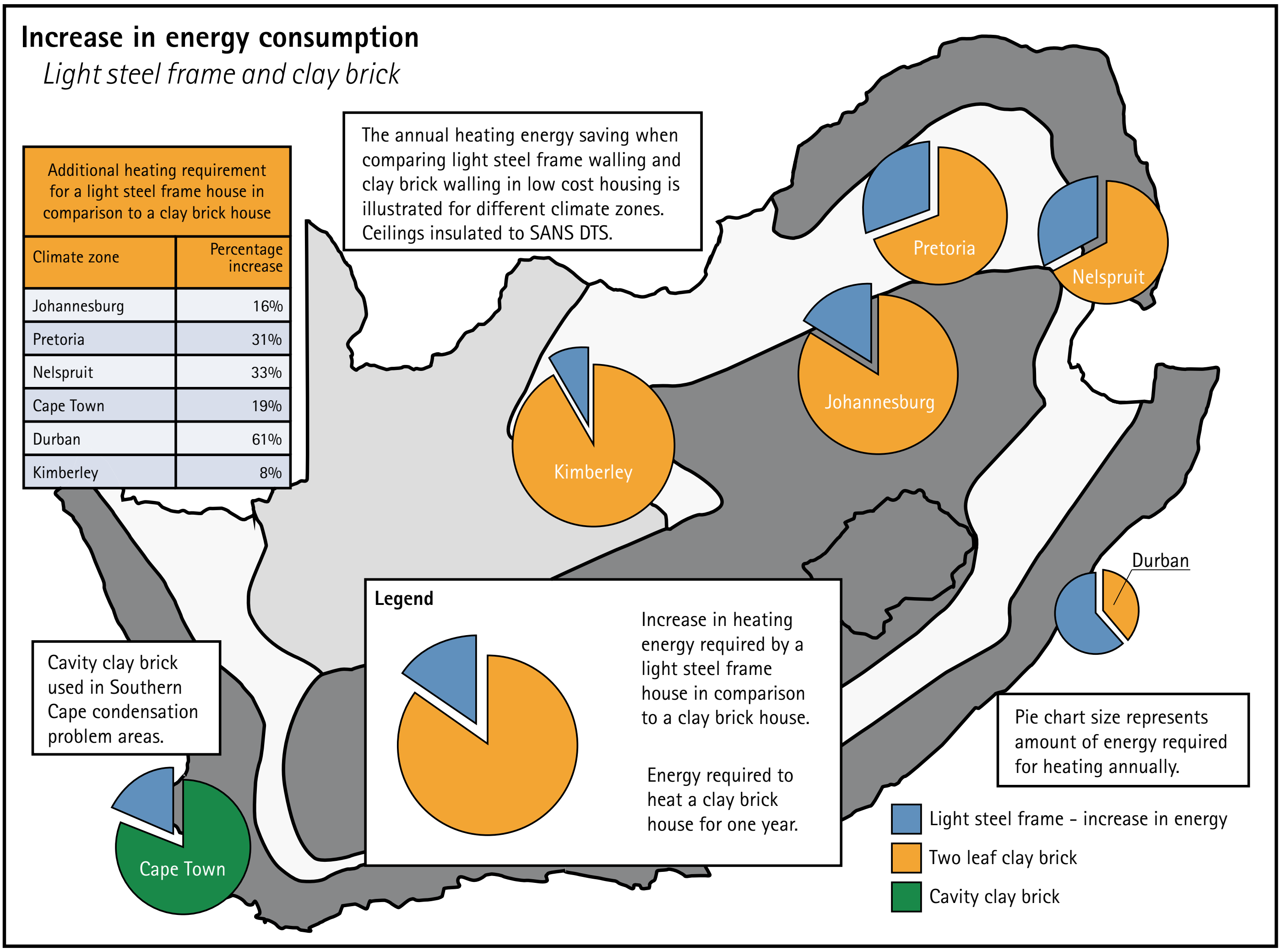
All studies consistently demonstrate the comparably poorer thermal performance of lightweight walling as associated with alternate lightweight building systems such as LSFB during our long summer months and their propensity to overheat, creating 'hotbox' conditions internally and necessitating a greater use of cooling energy [2, 3, 7, 8 & 9].

As a way of explanation, the thermal mass and the thermal capacity it provides helps bricks perform like thermal batteries, slowly absorbing, storing heat during the day over a 6 to 8 hour period, and then releasing that heat when it is needed most [1, 2]. This time lag for the sun's heat to pass from the outside to the inside, referenced as 'thermal lag', is what helps moderate internal temperature conditions for longer during the hottest periods of summer days. In winter the thermal mass of the inner skin brickwork and brick partition walls that have slowly absorb radiant and ambient heat during the day, release that stored heat to the cold evening air helping keep internal thermal conditions comfortable for longer.

The correlation in the findings of all the studies [1, 2, 3, 4, 5, 6, 7, 8, 9 & 10] is consistent in confirming that conventional clay brick construction - double skin with appropriate levels of insulation between the brick skins for the climatic zone - affords superior thermal comfort with lower heating and cooling energy usage than comparable lightweight walling envelopes with the same or higher steady state R-values [resistance].

In the South African modelling studies of 130 m² [7], 40 m² [9] house types using DesignBuilder EnergyPlus and the 132 m² CSIR standard house [8] using Visual DOE software, the SANS 204 compliant clay brick house generally afforded greater thermal comfort and lower heating and cooling energy consumption compared to SANS 517, SANS 204 DTS lightweight walled alternates.

In the 40 m² study of a low cost house [9] the SANS 204 LSF house - see Figure 4 below - incurred higher annual energy costs compared to the clay brick houses in all major climatic zones.



Additional heating requirement for a light steel frame house in comparison to a clay brick house	
Climate zone	Percentage increase
Johannesburg	16%
Pretoria	31%
Nelspruit	33%
Cape Town	19%
Durban	61%
Kimberley	8%

This was mirrored in the findings of the thermal modelling done as part of the full LCA by Energetics. Per Table 3 below of Verdant and Sirocco houses, as compiled from data in the Energetics full LCA [modelled using ASHRAE accredited DesignBuilder software], the comparative thermal efficiency of conventional double skin clay brick cavity wall construction and the same with insulation is endorsed. On average the insulated timber frame used the most heating and cooling energy resulting in 7.01% more HVAC GHG emissions than un-insulated cavity brick and 14.28% more than insulated double brick (R1.3) over a 50 year life cycle. As reflected in Table 3 increasing the R-value of brick walls enhances the thermal efficiency in those climates that have colder winter periods. In the hotter and milder climates such as Brisbane (climate similar to the KZN Coastal areas), insulation applied in the cavity of a brick wall offered no energy savings over cavity brick and may be considered an unnecessary cost. This is consistent with the finding of WSP Green by Designs research in respect of 130 m² and 40 m² house types in South Africa's six major climatic zones [7 & 9].

Table 3

THERMAL MODELLING OF VERDANT AND SIROCCO HOUSE TYPES COMBINED AVERAGE HVAC GREEN HOUSE GAS (kg CO_2-e) EMISSIONS OVER 50 YEARS Tabulated from Energetics Full Life Cycle Assessment						
Location	**Orientation**	**Uninsulated Double Brick**	**Insulated Double Brick (R1.3)**	**Insulated Timber Frame**	**Insulated Timber more/(less) GHG than Double Brick**	**Insulated Timber more/(less) GHG than Double Brick Insulated R1.3**
Newcastle Climatic Zone	East	53174	50007	59802	12,46%	19,59%
	North	55192	51956	61891	12,14%	19,12%
	South	51073	49340	57749	13,07%	17,04%
	West	57107	53640	62385	9,24%	16,30%
Melbourne Climatic Zone	East	71057	65080	70510	-0,77%	8,34%
	North	75560	65049	76341	1,03%	17,36%
	South	69414	59557	68960	-0,65%	15,79%
	West	76169	64878	74469	-2,23%	14,78%
Brisbane Climatic Zone	East	65533	65173	73175	11,66%	12,28%
	North	64970	65308	73700	13,44%	12,85%
	South	62014	62758	69118	11,46%	10,13%
	West	67179	66801	74225	10,49%	11,11%
Combined Total Average GHG		64037	59962	68527	**7,01%**	**14,28%**

Thermal mass and financial payback for insulation applied

Studies specific to South Africa [7, 8 & 9] go further confirming that clay brick construction not only provides superior thermal comfort and lower energy usage but does this more cost effectively [with best payback for the insulation applied] than alternate building technologies such as Light Steel Frame Building, SANS 517 and SANS 204 compliant, over a 50 year lifecycle.

This superior performance provided by clay brick in house construction is also reflected in the 10 Show House development [10] in Perth for developers to demonstrate the environmental compliance of their houses. The double skin clay brick house of Jade Projects, the one and only show house in brick, was awarded an "8 Star" Energy Rating per the Building Energy Rating System [BERS] of Australia. The other nine Show Houses, of which seven comprised steel frame with different insulated lightweight walling composites, some also being designed on passive solar design principles, achieved energy ratings of 5 or 6 Stars, the difference in rating essentially defining the added value of well-placed thermal mass and insulation in the building envelope.

The "8 Star" clay brick house has since been superseded by a "9 Star" house [11] pictured below. Using a 'Carbon Neutral Design' this "9 Star" house shown above achieved a 119% reduction in energy making it beyond carbon neutral.

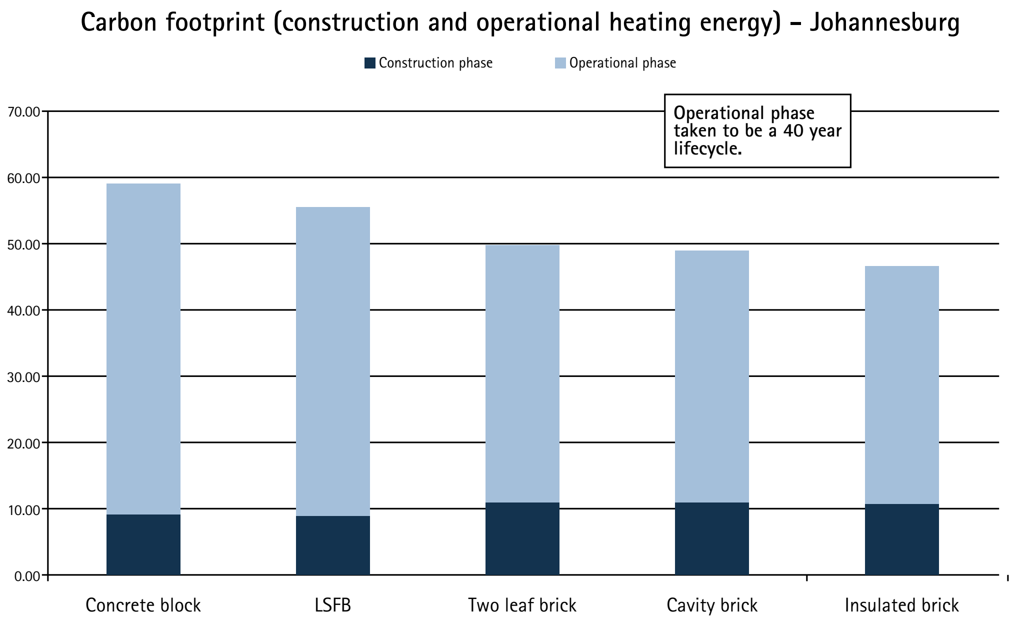
The consistently superior energy ratings achieved by the clay brick houses highlight how combining Solar Passive Design principles [orientation, shading, insulation and ventilation for the climatology of the location] with the use of correctly placed thermal mass in the building envelope, the latter enhancing the propensity to take best advantage of the suns energy, opens the way for optimal thermal efficiencies to be achieved cost effectively. The application of SANS 204 Deemed to Satisfy Standards for masonry construction [currently voluntary] is a step in the right direction towards greater energy efficiency of brick constructed residential buildings throughout South Africa. Rational design incorporating thermal modelling however presents the opportunity to best place insulation of different R-values in the building envelope to assure greatest energy efficiency at the lowest cost.

The value of thermal mass in the "total" energy equation

Moving to total energy consumed [embodied plus operational energy] and the total greenhouse gasses [GHG] emitted for different construction types over a hypothetical 50 year lifecycle, the full Life Cycle Assessment (LCA) [6] by Energetics in Australia puts the benefits of the superior thermal efficiency of clay brick construction in perspective. The LCA found that the savings in operational GHG emissions provided by the insulated brick alternates offset the higher embodied energy of the brick houses to afford lower total [embodied plus operational] GHG emissions than the Timber Frame insulated weatherboard house over 50 years. The LCA notes the timber frame weatherboard house as having the lowest embodied energy and that carbon sequestration, that was still being studied and debated, was not taken into account (as per Kyoto accounting rules) in the LCA.

This finding is mirrored in South African desktop research of a 40 m² house [9] see Figure 5 below where the clay brick house afforded a lower total energy outcome over a 40 year lifecycle than the SANS 204 compliant LSF alternate.

Figure 5



Sustainability with energy efficiency

While the full Life Cycle Assessment of Energetics established the heating and cooling energy benefits and the low lifecycle impacts clay brick construction provides, it also highlighted that a comprehensive approach to sustainability requires that we continue to build houses able to endure, with little maintenance and definitely no materials replacement, way beyond a 100 year lifecycle. Clay brick is the one man made walling material that has proven to be more than up to the task with the thermal efficiency benefits enduring way beyond the limited lifecycle of less durable alternate building lightweight walling. In South Africa masonry construction is the widest used construction method with research showing clay brick construction being price competitive and/or more cost effective than alternate lightweight building [LSFB] as built and with lower life cycle costs.

The thermal efficiency case for including thermal mass in external walling envelopes and internal partition walls is clear as is supplementing clay brick cavity walls with insulation appropriate for the climatic zone for assuring optimal energy efficiency cost effectively. Add such performance to the basket of other sustainability attributes that clay brick in construction provides such the low maintenance qualities of face brick that mitigate future carbon debt associated with a lifetime of maintenance, the longevity and the robustness of brick that mitigates future carbon debt associated with refurbishment and replacement of less durable materials and that clay bricks are reusable as masonry or pavers and/or recyclable as aggregate for concrete manufacture and high thermal mass clay brick finds itself in a unique space for defining an energy efficient future with low lifetime environmental impacts.

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Research Review by Peter Kidger – As published in 'The Sustainable Energy Resource Handbook South Africa Volume 5 – The Essential Guide'.

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7. 130 m^2 Standard House Energy Modelling Project – WSP Green by Design (2010) using DesignBuilder Energy Plus software

8. Thermal Modelling of a 132 m^2 CSIR house by Structatherm Projects (H. Harris 2009) using Visual DOE software

9. 40 m^2 Low Cost House Energy Modelling Project – WSP Green by Design (2009/2010) using DesignBuilder Energy Plus software

10. LandCorp Western Australia 10 Show House development at Verdant Circuit Seville Grove incorporating Jade Projects 8 Star Perth House (www.righthomes.com.au Jade 808)

11. www.righthomes.com.au – Jade 909 on display at "The Vale", Wesley Way Avely, Perth Western Australia

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