Executive Summary

Research Project for Clay Brick Association

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1 Project Purpose

To develop a rational basis for the selection of thermal capacity and thermal insulation in external walling, and a set of deemed to satisfy requirements for external walling in the SANS 204 series of standards, in order to achieve environmental sustainability, energy efficiency and reduced pollution.

2 Key objective

Developing a proposed set of deemed to satisfy requirements for external walls which will ensure, given other energy efficiency interventions in the building as per SANS 204, that the energy consumed by environmental controls of the building will be at levels required by the Department of Energy, in support of the 2015 energy reduction targets set out in the RSA Energy Strategy.

3 Background information

- Most South African climate regions are characterized by high diurnal temperature ranges and high absolute summer temperatures. The use of thermal capacity in buildings located in such climates is beneficial for reduced space heating and cooling energy.
- For each climatic region an optimum thermal neutrality point (temperature) exists for the occupants of the building, and their activities.
- The primary determinants of the energy performance requirements of an external walling system in any climate is the building Occupancy type – which dictates density, activity levels and heat load in the building, and the desired thermal comfort ranges.
- The thermal capacity of a layer in a (composite) wall can be calculated from first principles as : Specific heat (kJ/kg.K) x density (kg/m3) x thickness (m) = kJ/m2.K ("C"). The thermal capacity of the composite wall is the sum of the capacities of the individual layers.
- The thermal resistance of a layer in a (composite) wall can be calculated from first principles as : Thickness (m) x (1/thermal conductivity) (m.K/W) = m2.K/W ("R"). The thermal resistance of the composite wall is the sum of the resistances of the individual layers.
- The active thermal capacity of a layer in a (composite) wall can be estimated as: Thermal capacity x a weighting factor = kJ/m2.K (“Cact”). The weighting factor is determined by the position of the layer relative to the internal environment, and the thermal resistance of the adjacent layers. The active thermal capacity of the composite wall is the sum of the active thermal capacities of the individual layers, and is a suitable composite measure of the thermal performance of a wall, in that both thermal capacity and resistance are considered.
- The arithmetical product of thermal capacity and thermal resistance (CR product) of a composite wall is the “time constant” or thermal lag characteristic of that wall, measured in time units (h). This is a constant building property that is not influenced by internal or external loads.
- The amplitude ratio (internal temperature range / external diurnal temperature range) within a building structure can be reduced by using appropriate combinations of thermal capacity and resistance in the external walls. A relationship between the amplitude ratio, the active thermal capacity and the thermal resistance of the building shell in the SA climate, was determined from research conducted by the CSIR in 1981, and expanded by E.H. Mathews in the 1990’s, resulting in a set of building physics formulae commonly referred to as the CR Method. The desired amplitude ratio can therefore be selected which will in turn have a required active thermal capacity and / or CR product.
- Average internal temperatures can be maintained within a range of comfort around the desired thermal neutral point by using appropriate combinations of thermal capacity and resistance in the external walls.
- The average internal temperature rise is proportional to the solar radiation transmitted through glazed openings in the external wall, the internal floor area and the specific thermal resistance of the shell of the building. Air leakages will reduce the beneficial effects of C and R.

- The thermal performance of external walls has a direct influence on thermal comfort in the perimeter zone of all buildings, with a greatly diminished effect in the interior zone.
- The specification of external walling requirements is largely independent of building size i.e. the optimal wall parameters are determined from the application of building physics equations and thermal modelling of energy consumption and life cycle cost, and apply equally to small and large buildings of the same occupancy type.

4 Research Methodology

- Simplified versions of the standard 132m^2 CSIR designed building, which eliminate design aspects extraneous to walling, provide a basis for constructing thermal models to assess walling system performance in various climate zones.
- The designs ensure that all of the building area can be considered to be part of the perimeter zone, and the heat flows via the external walls are the predominant varying thermal loads.
- The internal environmental conditions for the various building occupancies are calculated using adaptive theory formulae. The thermal neutrality for various building types can be calculated from Tn =18,9°C+0,225ET_{outd} and applied with the desired temperature range per type of ventilation. Table 1 shows the target indoor thermal comfort ranges.

Building type	Formulae	Acceptability	Range
Air conditioned	$Tn=18,9+0,225ET^*_{outd}$	90%	±1,2K
Air conditioned &	$Tn=18,9+0,225ET^*_{outd}$	80%	±2,5K
Naturally ventilated		90%	
Naturally ventilated	$Tn=18,9+0,225ET^*_{outd}$	80%	±3,5K

- The annual varying adaptive indoor thermal neutralities are shown in Figure 1 for 15 South African locations

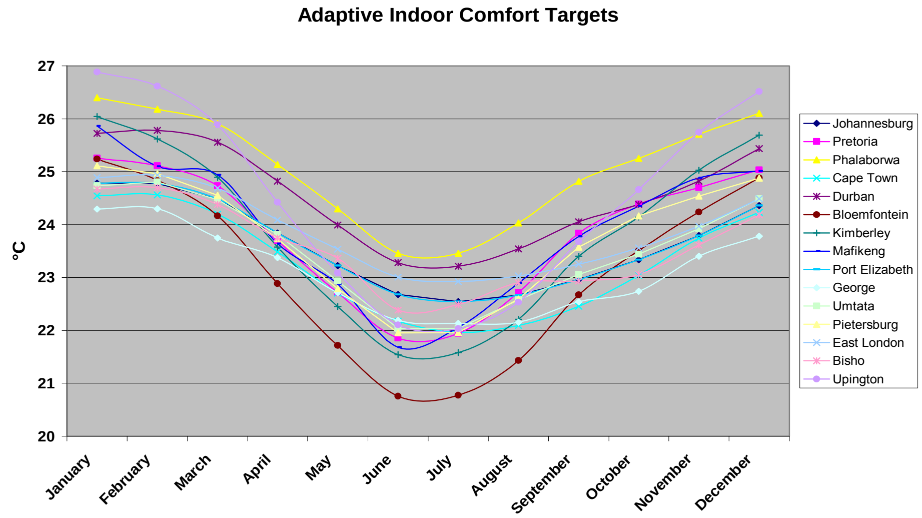
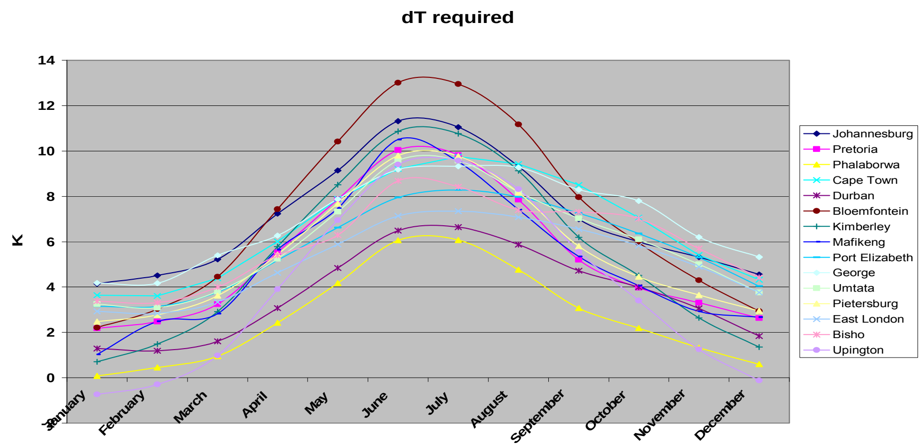


Figure 1 : Thermal Neutrality by Location

- The difference between Tn and the monthly mean outdoor temperature (To_{mean}) is called δT_{reqd} and this is an indication of the average monthly heating (+) or cooling (-) required. These values are shown in Figure 2 below.



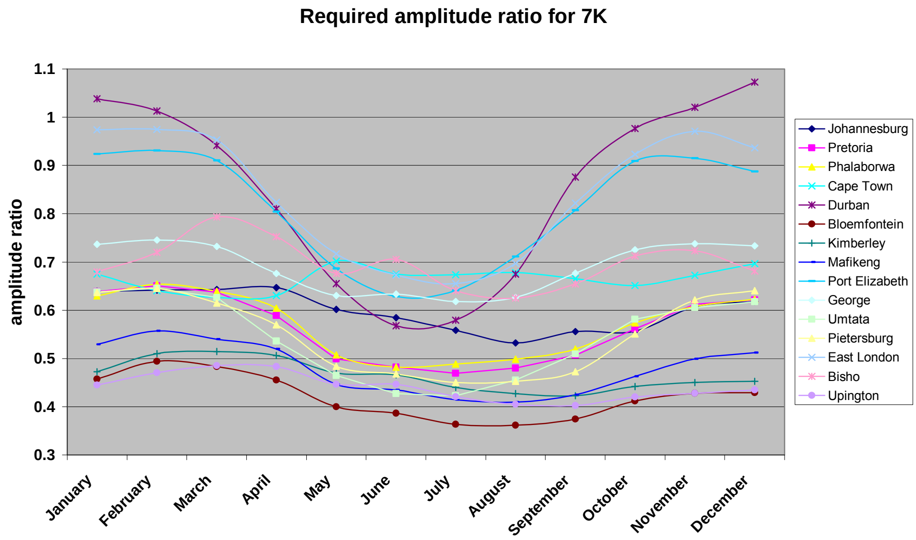


Figure 2; Required amplitude ratio for comfort in a naturally ventilated building

Required active thermal capacity exterior wall [kJ/m²K]			
Indoor amplitude	2.4 K	4 K	7 K
Z1 Johannesburg	1 919	1 151	658
Z1 Bloemfontein	1 727	1 036	592
Z2 Pretoria	1 811	1 087	621
Z3 Phalaborwa	1 475	885	506
Z4 Cape Town	2 147	1 288	736
Z4 Port Elizabeth	1 607	964	551
Z4 George	1 223	734	419
Z5 Durban	1 211	727	415
Z6 Upington	2 243	1 346	769

Table 2 : Target Active Thermal Capacities for Full Passive Response

- The space heating and cooling energy consumption, and present value of the life cycle cost, was modelled for 3 groups of buildings, typified by occupancy type (Commercial & Institutional, Residential and Retail), for 5 existing South African walling systems (standard brick masonry with various levels and positions of insulation), and across 6 climate zones.

5 Research Findings

Increasing levels of thermal capacity and resistance in the external walls result in lower energy consumption. When life cycle costs are considered, an optimum wall system for each climate zone : occupancy type combination can be identified. Figures 4 and 5 below show the values for the Residential occupancy group.

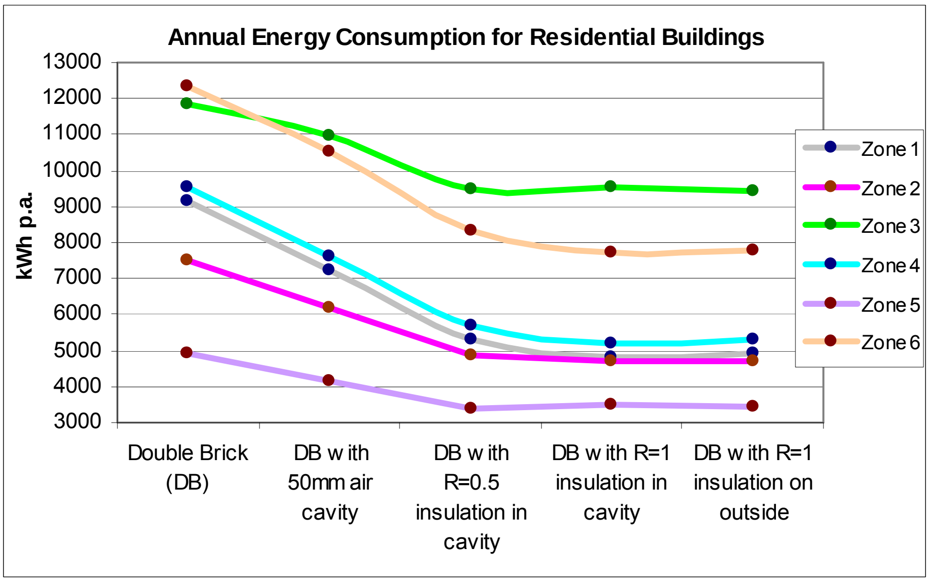


Figure 4 : Energy Consumed in Residential Buildings

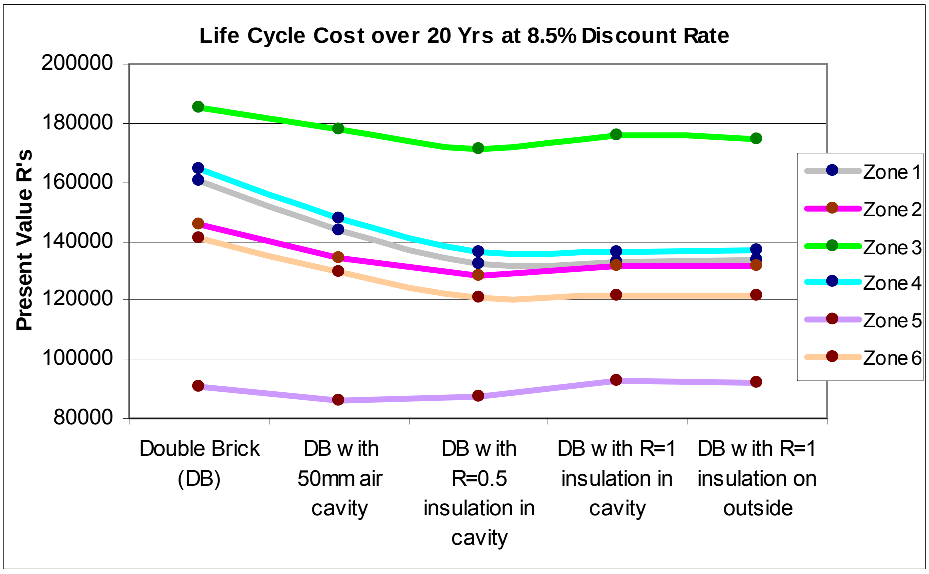


Figure 5 : Life Cycle Costs of Residential Buildings

The statistical correlation between the energy consumption of the building and the CR product of the wall system is greater than 0.88 for 16 of the 18 combinations modelled, with an average of 0.92.

Active thermal capacity (C_{act}) and CR product are easily calculated for existing and planned composite walls if the thermal, and other, properties of the materials are known. Software was developed during this project for this purpose. The calculated active thermal capacities and CR products for the 5 walling systems are listed in Table 3 below in increasing order.

Wall Type	**Double Brick (DB)**	**DB with 50mm air cavity**	**DB with R=0.5 cavity insulation**	**DB with R=1 cavity insulation**	**DB with R=1 external insulation**
C_{act} (kJ/m^2.K)	**139**	**149**	**157**	**162**	**270**
CR (hours)	**40**	**60**	**90**	**130**	**130**

Table 3 : Active thermal capacities and CR product

6 Research Conclusions

- To achieve optimal energy reduction and life cycle cost minimisation goals, a minimum amount of C and R are required for walling in South Africa, which is different for various occupancies and climatic localities.
- These minima can be combined into an easily understood performance criteria – namely the CR Product, which is the product of the thermal resistance and the thermal capacity and whose units are in time units (hours). These are set out in the tables below.
- The positioning of layers with high R values is a critical determinant. Placing a thermal resistance layer on the inside face of external walls is detrimental to active thermal capacity levels and results in higher energy consumption than if the insulation is placed in a mid-wall cavity. Placing thermal resistance on the outside of external walls shows a small reduction in energy consumption, in some cases, over insulation placed in the wall cavity. When considering energy consumption, costs and other practical issues, the optimum position for thermal resistance is in the cavity between two layers of material with high thermal capacity.

7 Deemed to Satisfy (DTS) Requirements for National Standards

- The existing DTS requirements published in SANS 204 parts 2 and 3, make a distinction between walls based on “surface density”, quantified as “kg/m^2”. The DTS requirements are in terms of minimum R values. This research has produced a more scientifically accurate and an optimized approach whereby DTS requirements can be expressed in terms of minimum necessary CR product values.
- The CR product requirements which are proposed for incorporation into regulations and standards are developed from the minimum Life Cycle Cost options. By selecting the walling option which has a CR Product that provides the lowest Life Cycle Cost as the Deemed-to-satisfy proposal, it can be assured that the economic viability of the proposal is not in doubt, for that climatic region and for the occupancy cluster.
- The tendency toward lightweight industrial building systems, using a range of technologies and materials, has facilitated the incorporation of thermal resistance aspects, but not thermal capacity. Much has been made of the thermal efficiency of such systems, but it is shown in this research (and in other studies locally and globally) that when thermal capacity is combined with thermal resistance, optimal results are achieved.
- The assumption that the thermal resistance of the walling is primarily supplied by the thermal insulation and that there is proportionality between the thickness of the materials and the cost, is implicit. The similar presumption that the thermal capacity is primarily provided by the brickwork, and that proportionality exists between the mass and the cost, is also made.
- Most thermal insulation materials are low in mass and most brickwork high in thermal conductivity, but it can be envisaged that for some materials the cost effectiveness is better than others, and for these materials and combinations a rational design compliance route would be more appropriate.
- Wall systems that have low, or no, thermal capacity will not meet the DTS requirements. In such cases a rational design is preferred in order to prevent construction of buildings with wall systems that are unable to achieve the expected energy reduction goals.
- The area of windows relative to high mass walling is similarly important, and should this figure be above 20% of wall area for the residential or retail buildings or above 25% for office and institutional buildings, the benefits of thermal capacity will reduce, and rational design requirements should be invoked. For residential buildings the deemed to satisfy rule assumes northerly facing windows not exceeding 45% of the northerly facade, with 5% mutatis mutandis for southerly windows. For non-residential buildings it is 45% north and south.

The following table of CR Products is developed as a proposed replacement for the present SANS 204 external walling DTS requirements in parts 2 and 3 :

Minimum thermal capacity & resistance CR product, in hours, for external walling						
Occupancy Group / Climate Zone	***1***	***2***	***3***	***4***	***5***	***6***
Residential E1-3,H1-5	*100*	*80*	*80*	*100*	*60*	*100*
Office & Institutional A1-4,C1-2,B1-3,G1	*80*	*80*	*90*	*80*	*80*	*80*
Retail F1-3,J3	*80*	*120*	*120*	*90*	*80*	*120*

Table 4 : Minimum Thermal Capacity & Resistance Products by Region and Occupancy

- To relate the above DTS values to existing wall systems, note that the above DTS requirements can be achieved with a range of standard high mass walls such as a 106mm double brick construction e.g. face brick externally and plastered internally, with a minimum thermal insulation as provided by a 50mm air-cavity, through to a similar wall with 30mm of extruded polystyrene in the cavity, in order to achieve higher CR values. See Table 3 above.
- These findings are similar to that of earlier research by Holm, Johannsen and Harris for the Department of Minerals & Energy in support of SANS 204, which showed that the Life Cycle Cost of additional thermal resistance to typical brick walls, would have optimal levels between the range of a solid wall through to an added thermal resistance of R=1.0, in ten types of buildings, across six climatic regions.
- In order to achieve the deemed to satisfy active thermal capacity requirements, the external wall system must contain a minimum level of thermal capacity (C) and thermal resistance (R). Some materials that have high thermal capacity also contain some thermal resistance, such as clay masonry. However, to meet the minimum CR product requirements, existing clay masonry walling requires additional thermal resistance. Walling systems with low, or no, thermal capacity will not meet the deemed to satisfy requirements. The optimal energy consumption and life cycle cost cannot be achieved through only thermal resistance or by thermal capacity alone.

8 Recommendations

- It is recommended that the Deemed-to-satisfy proposals are built into standard (SANS204) and regulation (SANS 10-400X) in order to progress energy efficiency and comfort in buildings.
- This research project has re-affirmed the benefits of external walling systems containing thermal capacity and thermal resistance in appropriate quantities. In most South African climatic zones, this thermal lag or “thermal battery” effect provides the most effective means for the building shell to positively affect energy consumption through all seasons.
- Low thermal capacity systems tend to have higher levels of thermal resistance, and are more suited to climates with extreme absolute temperatures and lower diurnal ranges. Caution should be exercised when using low thermal capacity external walls in South Africa. Should they be chosen as a preferred walling system, it would be sensible to require a rational energy usage building design by a competent person.
- Software tools for the calculation of active thermal capacity and CR product of composite wall systems should be provided to all interested and affected parties. Manufacturers of wall systems components should be educated, where needed, with regard to the method of calculation and application of the results.
- SA test facilities and international standards for the determination of specific heat capacity of materials and assemblies need to be identified.
- Where the active internal heat capacity of exposed high mass indoor materials (heavier than standard walls, ceilings and floors) occurs, this is considered to be a bonus that cannot be relied upon for legislation or standard purposes, as the thermal capacity value may be lost with carpeting, wall coverings, suspended ceilings etc.

After a limited survey of builders, the above recommendations appear readily achievable in South Africa (e.g. a cavity wall with insulation) and do not demand a substantial (re-) learning of skills, but they do require some attention by designers, manufacturers, specifiers and competent persons.

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