A THERMAL PERFORMANCE COMPARISON OF SIX WALL CONSTRUCTION METHODS FREQUENTLY USED IN SOUTH AFRICA

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Abstract

In this paper, we assess the thermal performance of six conventional wall types most frequently used in South Africa. The impact of the energy efficiency of walling can be modelled in terms of heating and cooling energies required to maintain the human environmental comfort condition.

The main impact of the walling component of buildings during their operational phase is the efficacy with which they moderate the external environment and provide thermal comfort to building occupants. If thermal comfort is provided with a minimum of heating and cooling, the walling system can be considered to be more energy efficient. The energy usage for heating and cooling for various relevant walling systems in use are compared using suitable, internationally accepted and Agrément South Africa approved thermal modelling software.

Three different building typologies are analysed; two residential; a standard 40m² house which is typical of subsidised housing in South Africa, a 130 m² house design based on an earlier CSIR study and a small office development of approximately 2000 m², which is intended to represent a wider range of commercial and institutional places of work. Each wall construction type is simulated within each of the six climatic zones in South Africa and each of the three typologies.

The results of this modelling indicate that solid clay brick masonry walling is the most thermally and energy efficient walling system considered for day-time or non-residential occupancy buildings. The clay brick masonry cavity walls are the most thermally and energy efficient walling system considered for all day or residential occupancy buildings. A clay brick masonry cavity wall is a suitable choice for universal application in the South African regulatory built environment (SANS 10400 Part XA) as a first step towards more efficient wall construction in South Africa, particularly as a replacement for the 140 mm hollow concrete block which is found to be universally the worst performer of the wall construction methods that were examined. The low-mass light steel frame and timber frame wall construction methods are not as thermally or energy efficient as clay brick masonry walling methods and the SANS 517 and 10082 standards should be amended to reflect the required increase in effective thermal insulation via reduced heat bridging, and/or greater thicknesses of thermal insulation.

1. Introduction

A Life Cycle Assessment (LCA) of clay bricks in South Africa was conducted by the Department of Architecture at the University of Pretoria (UP) for the Clay Brick Association of South Africa (CBA). The LCA reviewed all environmental impacts associated with the production and use of clay bricks and brick structures from mining of the raw materials through all life cycle stages to the recycling and/or disposal of brick masonry in land-fill – “cradle to cradle” (Vosloo et al., 2015)

The need for a thermal performance study arose from the need in the LCA methodology to determine the environmental impacts that stem from the operational lifespan of clay brick structures. This study addresses the calculation of the energy usage anticipated for clay brick buildings in South Africa during its operational phase. An important consideration is that the necessary detailed assumptions to be made in any such a modelling exercise are numerous; that these are often not fully disclosed and thus a comparison of performance against alternative building systems is made difficult and unreliable.

As a consequence of this difficulty the thermal performance of walling materials in South Africa was not thoroughly and objectively differentiated until the publication of the CR-Method and the publication of SANS 204:2011 that deals with energy efficiency in buildings. It is expected that this Thermal Performance Study (TPS) will add to a better understanding of walling energy efficiency, particularly in relation to the contributions of thermal mass (capacity) and thermal resistance.

The CBA has therefore requested that an exemplary model be developed that can be used by others, and to conduct a comparative study to investigate the thermal performance of clay brick walls as installed in buildings in South Africa and compared with the thermal performance of alternative wall construction methods typically used in South Africa.

1.1 Aim of this study

It is envisaged that the data gathered in this TPS will inform the LCA on the energy requirements of clay brick walls during its operational life, and assist in the development of National Standards for energy usage and energy efficiency in buildings.

2. Methodology

2.1 Rationale for an appropriate TPS methodology

The operational energy usage in buildings attributable to the walling of such buildings is the sum of all heating, cooling and ventilation energies accumulated over the four seasons in a year.

These energies can be estimated by a simulation of heating, cooling and ventilation energy requirements as indicated in an energy model developed with suitable energy modelling software and appropriate climate data file (Holm, 2011). The climate files capture some of the variations which are possible in a particular year in terms of variability of seasonal climates, yet build in the averages of climatic parameters recorded in the longer term.

The comparison between the various walling systems is conducted through thermal modelling using appropriate thermal modelling software. The selection of the correct software tool for the building energy modelling is an important part of this project, as is the development of assumptions appropriate for on-going comparative work.

2.2 Operational environmental impacts of walling

The main environmental impact of the walling component of buildings during their operational phase depends on the efficacy with which they moderate the external environment and provide thermal comfort to building users. If thermal comfort is provided with a minimum of heating and cooling, the walling system can be considered to be energy efficient (Holm & Engelbrecht, 2004).

2.3 Software selection

The accuracy, in absolute terms, of the estimation of heating and cooling energy usage is a pre-requisite for the choice of appropriate software. Hence the physics employed by the various software offerings have been scrutinised by Johannsen through a review of the calculation methods utilized when simulating unsteady-state heat transfer through walling systems in computer based software (2012). This was performed in a separately commissioned study of the different heat transfer functions applied in calculating the energy flows through the walling of three building energy modelling software offerings. This analysis has informed the decisions regarding the choice of most appropriate software to be used to compare the thermal performance of the various selected walling systems (Johannsen, 2012).

2.4 Generating a typical energy usage for walling in South Africa

Three different building typologies are analysed. A standard 40 m² residential building which is typical of subsidised housing in South Africa. A 130 m² residential building based on an earlier unpublished CSIR study and as published in the Green Buildings Handbook Volume 1 (published periodically by Alive-to-Green). An office building of approximately 2000 m², which is intended to represent a wide range of commercial and institutional places of work. All of these typologies have been used as notional buildings for earlier South African energy modelling research for the Department of Mineral and Energy Affairs, with minor alterations. The floor plans, elevations and specifications of these three buildings are set out in Appendix A.

In this study, three different clay brick wall construction methods are compared to three alternative wall construction materials. The walling materials which were compared are listed below and are detailed in Appendices B, C and D.

The walling systems compared in this analysis are:

- Double clay brick solid wall (nominally 220 mm thick)
- Double clay brick cavity wall - un-insulated (nominally 270 mm thick)
- Insulated double clay brick wall (nominally 280 mm thick)
- 140mm hollow core concrete block (150 mm thick with a single external layer of plaster)
- Light steel frame, insulated and cladded with fibre board to SANS 517 (nominally 145 mm thick)
- Timber frame, insulated and cladded with fibre cement board (nominally 145 mm thick)

Each of these construction methods were analysed for each of the three building typologies, and across the six different climatic zones in South Africa, in terms of SANS 10400 Part XA: Energy Usage in buildings, (Figure 1)

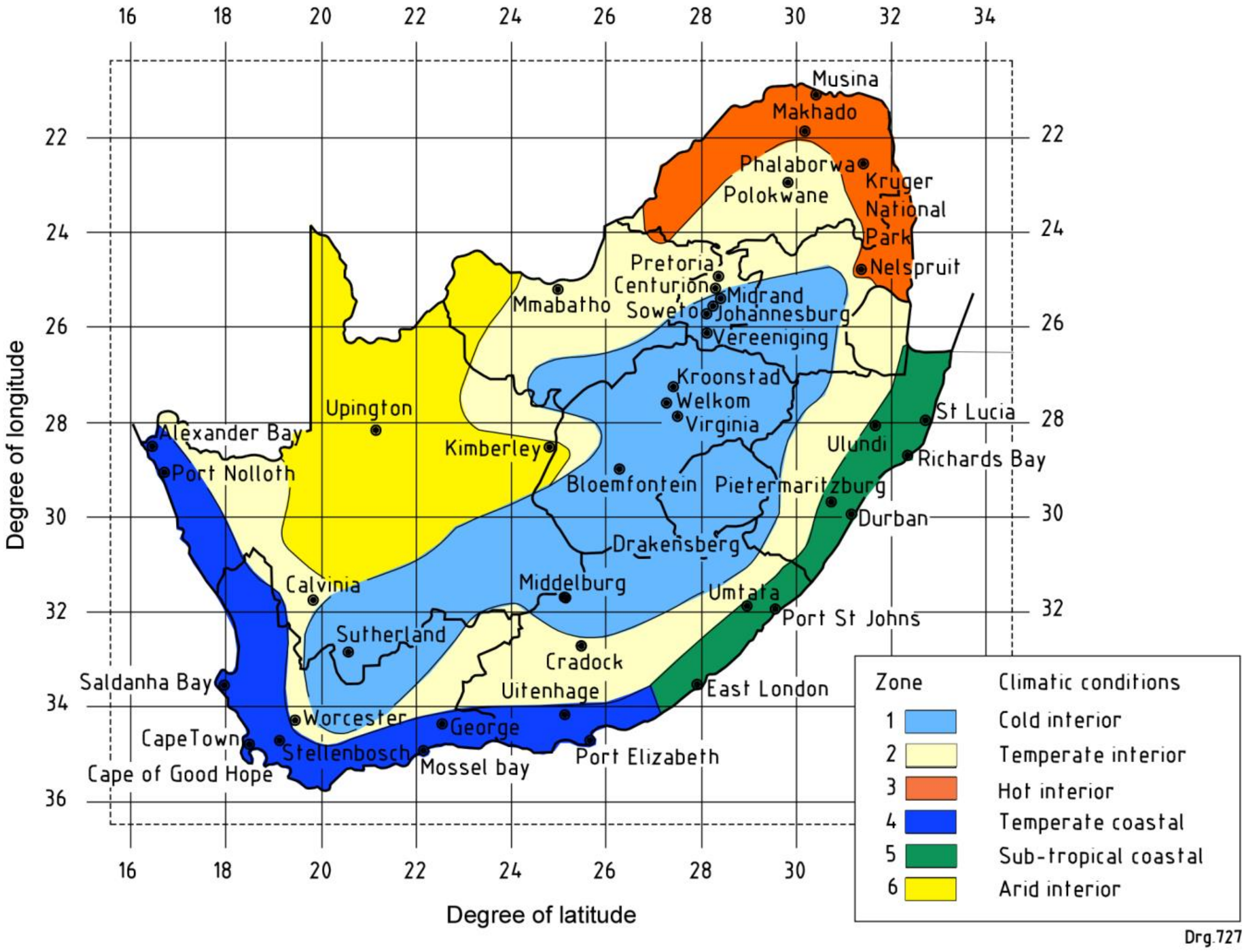

Figure 1 Climate zones of South Africa in terms of SANS 10400 Part XA

2.5 Isolation of walling impacts

All aspects which might affect heating or cooling, other than the walling of each design, are held constant at levels, which are considered to not detract from the walling performance. The comparative references are made only to the building walling systems and the operational aspects studied are confined to the building heating, cooling and ventilation energy consumption response to the climatic variation.

As the focus of this research is on the performance of walling systems, the type of exterior walling construction and the corresponding internal walling are the only variables. The floor, roof, windows, fenestration type, doors, and occupancy patterns of all permutations are kept constant to yield comparable results.

3. STANDARDISATION OF MODELLING

3.1 Review of suitable building physics in modelling software

Thermal performance modelling methodology requires that the different walling systems and their effect on the calculation of annual energy requirements of the residential & non-residential buildings should be taken into account by the selected modelling software.

One of the key requirements for energy modelling software is to accurately simulate the unsteady-state heat transfer through the walling systems under varying external conditions. The so-called unsteady state applies as a consequence of the hourly changes in diurnal temperature, radiation and wind speed in combination with the variations in internal temperature, in part as a consequence of outside air temperature, internal loads and ventilation rates, but also as a consequence of the degree of delay in heat transfer as the heat diffuses into and through the walling systems. Traditional analyses of heat flows were assumed to occur under conditions of steady state where a constant temperature profile exists across the walling system, which is a condition that is not frequently achieved in high mass walling due to the high thermal capacity and attendant low thermal diffusivity.

This Thermal Performance Study has considered the fundamental equations governing heat conduction through walls and different methods of solving these equations for multi-layer walling systems. The suitability of these methods for simulating annual energy performance of buildings was reviewed independently by Johannsen (2012) in a separate report.

3.2 Building energy modelling software selection

The software packages considered for selection for this TPS are confined to programmes which implement appropriate heat transfer functions and which meet other recommended international norms.

International software validation norms and procedures for evaluating software offerings are contained in ASHRAE Standard 140 and the ‘Bestest’ system which are also observed in the software selection. Software packages that have been certified by Agrément South Africa, in terms of the protocol for accrediting energy modelling software, will also satisfy the ASHRAE and Bestest requirements.

The two programmes which were approved by Agrément SA at the time of writing, and which have been confirmed as implementing the Conduction Transfer Function (CTF) method as well as the use of the State Space method, are *Design Builder* Version 3.1 and *BSIMAC* Version 9. *Design-Builder* Version 3.1 was selected for the TPS (Johannsen, 2012).

3.3 Input standardisation

3.3.1 Climate data files

The climate data files selected are those in use in South Africa for building energy usage assessments and rational designs in terms of SANS 10400 Part XA and are as provided for use in Agrément SA approved software. All six climate zones in SANS 10400 Part XA are individually analysed. As the climate data files are in general use, the modelling results could be reproducible and comparable with other similar work. The nature of the climate data files is such that the dry bulb and wet bulb temperatures, radiation levels, wind speeds over all 8760 hours of a typical year are simulated, even to the extent of reproducing the effects of the passage of frontal systems over the African sub-continent and the variability of the weather in the region.

3.3.2 Modelling stipulations

3.3.2.1 Measurement

The gross floor area (GFA) is to be treated as a single zone, and the gross floor area (external dimensions and including internal walling areas) are to be held constant for each typology.

By holding the GFA constant, the effect of wall thickness variations causes the net floor area (NFA) to vary slightly; however, the heat losses and gains then take place over constant and hence comparable external walling areas. The influence on NFA is most acute for the smaller building designs, but this does not invalidate the comparison and could be adjusted for. The differences between energy usages with NFA held constant versus GFA being held constant are of the order 1-2% and are therefore not considered material.

3.3.2.2 Metrics

The Annual Energy Intensity and Average Demand Intensity are the reporting metrics of SANS 204 and SANS 10400 Part XA; these express energy usage per square metre of usable internal area. The Annual Energy Intensity in this report is presented as the Annual Energy Intensity per square metre of external walling area for the building typology. This is in line with the overall objective of arriving at the typical operating energy attributable to the walling of each building model.

3.3.2.3 Air infiltration

The air infiltration rate is assumed to be 0.57 AC/h (air-changes per hour) to be aligned with an unpublished CSIR research project for residential buildings and the 7.5 litre per second per person as per SANS 10400 Part O requirement for offices.

3.3.2.4 Occupancy hours

The buildings are occupied in accordance with Tables 4, 5 and 6 of SANS 10400 Part XA; these occupancy hours are:

- 24 hours per day for a seven day week for residential buildings
- 12 hours per day for a five day week for office and institutional buildings

3.3.2.5 Occupancy density

Occupancy density is taken as two persons per bedroom or 15m² per person for working spaces at 75W per person.

3.3.2.6 Lighting energy

Lighting is assumed at a level corresponding with the requirements of SANS 10400 Part XA & SANS 204, i.e. 5 W/m² for residential buildings and 15 W/m² for commercial and institutional buildings during occupancy hours, and thus will reduce heating energy usage in winter, and increase cooling requirements in summer.

3.3.2.7 Occupant operational energy usage

The occupant driven energy impacts of non-fixed appliances are allowed for as per occupancy stipulations of SANS 10400 Part XA and are assumed to be a constant 5 W/m² for residential occupancies and 15W/m² for non-residential buildings. This stipulation is to compute an influence of the overall daily plug-load, appliance usage and cooking energy which is to be voided via cooling systems or otherwise contributing to reducing the heating requirements of the internal environment. The impact is not modelled on a usage schedule.

3.3.2.8 Set points for heating and cooling

The set points selected for heating and cooling are 19 – 25 °C as per SANS 10400 Part XA.

Heating and cooling are assumed to take place at all times when called for, if the building is operating outside of a dead-band of +/- 2.0 K about 22 °C.

An increase in Relative Humidity (RH) has an effect on human discomfort at elevated air temperatures. Climate zones at low altitude and in proximity to the coastline show high RH values. Thermal Neutrality can account for RH by adopting a TnET (Effective Temperature) rather than TnDBT (Dry Bulb Temperature). Much of the hot regions of Southern Africa experience heat in combination with low RH and this is well known to ameliorate the effects of elevated temperature.

3.3.2.9 Thermal resistances calculation conventions

The conventions applied to the selection of appropriate thermal conductivities of the building envelopes are the coefficients as per CSIR and NBRI publication X-Bou 2.1 are to be used preferentially and thereafter the software data bases as supplied with the software are used.

3.3.2.10 Internal wall selection

Internal walling is an essential part of all designs. In general in practice the use of lightweight internal walling partitioning systems are used with like external walling systems, and masonry partitions are used for structures with external masonry walling. The tendency may be towards light-weight partitioning for rented office construction as a result of the flexibility in catering for tenant fit-out.

The thermal performance of high mass external walling systems is greatly enhanced by the use of internal masonry walling. Lightweight partitioning walling adds little to the thermal performance of buildings built with these systems, as is evident from the sub-study described below.

It has been determined via a sensitivity study within this energy modelling project that the extent of potential energy savings in the RSA by way of using masonry partitioning over light-weight partitioning across the three typologies and building sizes used in this study, and across an equal number of warm and cool climate zones, could lead to a reduction in energy usage of on average 25%.

The range of extra energy usage for light-weight structures over masonry varies from a maximum deterioration of 52.4% for mild to warm climate zone 5 for the 120m² home to the smaller 3.8% premium for office buildings in hot climate zone 6. In general the premium of energy usage as a consequence of using light-weight partitioning is between 20 and 30% over the masonry solutions.

3.3.2.12 Window design and optimisation thereof

The thermal capacity of high mass elements and the optimisation of north facing window sizes can, if used in conjunction with one another, give rise to an improvement in relative performance of pure masonry solutions. However, in order to preserve a comparison of walling which excludes other influences, the window sizes are not varied in this study.

The convention applied is to use a window size as determined by SANS 10400 Part O for ventilation and lighting, i.e. not less than 10% of the net floor area of rooms which are served to be glazed. By placing the living room and bedrooms on the north elevation there is a larger area of fenestration on the north side.

3.4 Building typologies

3.4.1 Blending of walling in different typologies

Data sources provided by Milford (Holm, 2011) indicate that the current stock of South African buildings (expressed in m² built) consists of the following mix of building typologies:

- ±40 m² low income residential: 7%
- ±130 m² middle income residential: 43%
- ±2000 m² non-residential (daytime occupancy): 50%

The operational energy and environmental impacts of the operation phases of the three building typologies are blended in this ratio in order to determine the environmental impact of an average wall on an average built square metre of building structure.

3.4.2 Materials selected

Material selection for the three designs and six walling systems are detailed on the plans for each building and are summarised as follows:

3.4.2.1 All roofs

The modelled roof construction consists of 30 mm concrete tiles with a 38 mm air space created by the battens, a 0.2 mm polyolefin tile underlay, a ceiling airspace of between 0 and 608 mm and with 140 mm fibreglass insulation on a 6.4 mm gypsum ceiling board.

3.4.2.2 All floors

A 25 mm screed on a 75 mm concrete surface bed on compacted soil fill.

3.4.2.3 All windows

Windows are constructed from 4 mm clear glass in aluminium frame casement windows without thermal breaks.

3.4.2.4 External wall Type 1

Nominal 220mm solid clay brick masonry consisting of two 106 mm skins plastered both sides with 15 mm of mortar.

3.4.2.5 External wall Type 2

Nominal 270 mm clay brick cavity masonry wall as above but with 50 mm air-cavity in mid-wall.

3.4.2.6 External wall Type 3

Nominal 280 mm clay brick cavity wall with cavity insulation of R=1.0, as for Type 2 above but with insulation of 30mm extruded polystyrene/ 40 mm of expanded polystyrene.

3.4.2.7 External wall Type 4

Nominal 140 mm hollow concrete block wall plastered and painted externally and bagged internally.

3.4.2.8 External wall Type 5

Light steel frame wall structure in accordance with SANS 517 with 75 mm fibreglass insulation, externally cladded with 9 mm fibre cement, a 0.2 mm polymer vapour membrane, a 20 mm Orientated Strand Board, with 0.8 mm steel studs intruding through the insulation, and cladded internally with 15 mm gypsum board, in climate zones 2, 3, 4 and 5 with attendant heat bridging allowances.

As above, with 100 mm glass wool insulation batts in combination 0.8 mm steel studs with heat bridging for climate zones 1 and 6, with attendant heat bridging allowances.

3.4.2.9 External wall Type 6

Timber Frame construction in accordance with SANS 10 082.The thermal insulation thickness is as for External Wall Type 5 above, with external ship-lapped timber or weather-board fixed to 20mm Oriented Strand Board and internal cladding of 15mm gypsum plasterboard, with attendant heat bridging allowances.

3.4.2.10 Internal wall Type 1

High density 110 mm clay brick single skin wall covered both sides with 15 mm plaster for wall types 1 to 3 and bagged for the 110 mm hollow concrete block in the case of wall type 4.

3.4.2.11 Internal wall Type 2

15 mm gypsum board fixed to 76/102 mm steel studs with 75/100 mm fibre sound insulation.

4. Modelling results

4.1 Graphical presentation of modelling results

The results of the energy modelling of the gross annual energy usage for each of three types of building are presented in graphical format below. The analysis of these results follows thereafter.

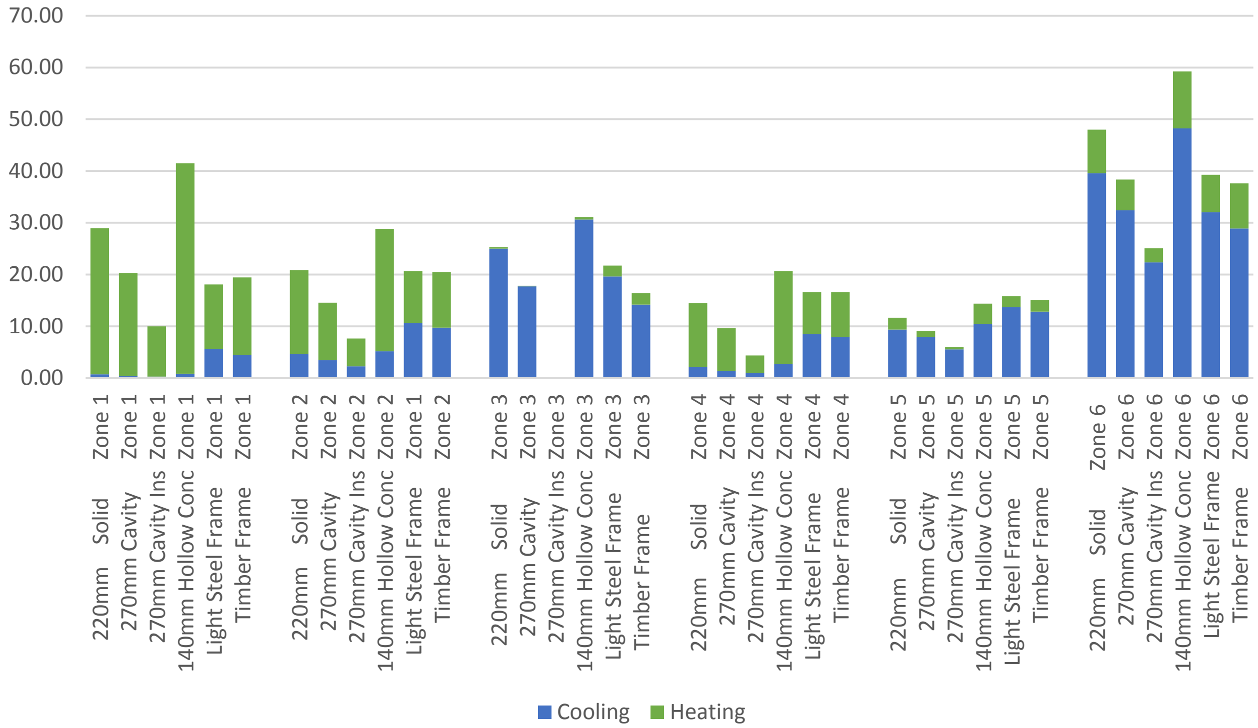

Figure 2 *Comparative annual heating and cooling energy usage in kWh per square metre of walling for a 40 m² house for six walling systems over six climate zones of the RSA*

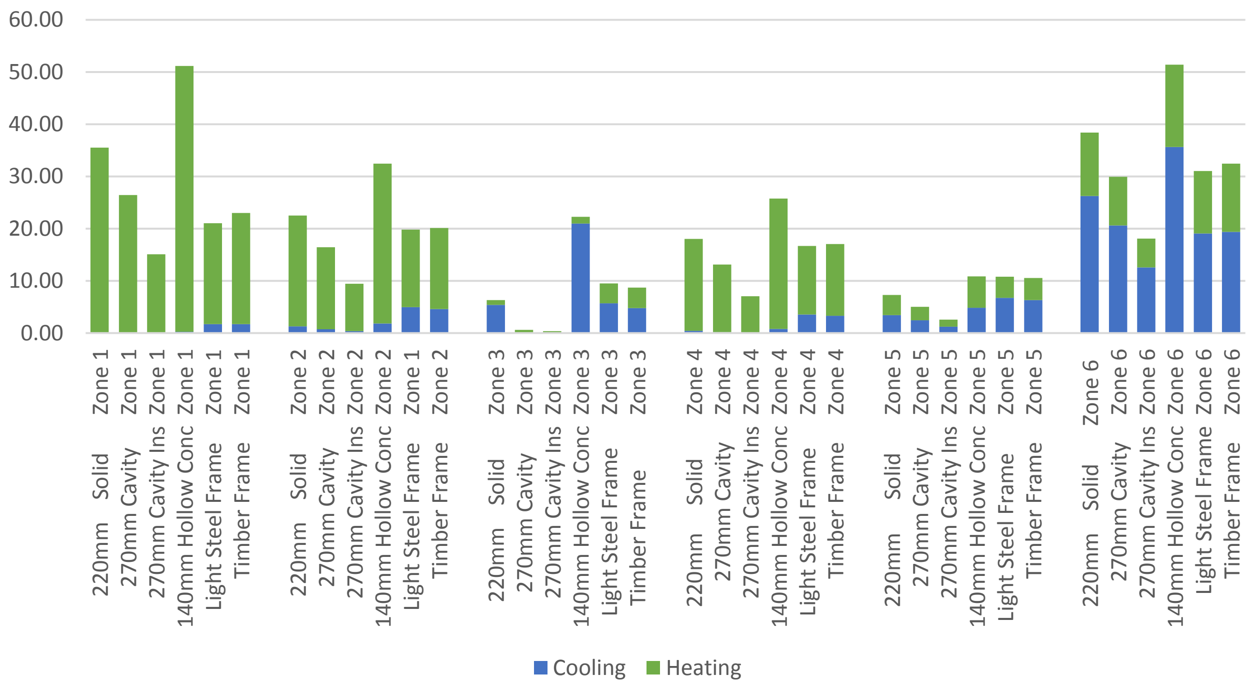

Figure 3 *Comparative annual heating and cooling energy usage in kWh per square metre of walling for a 130 m² house for six walling systems over six climate zones of the RSA*

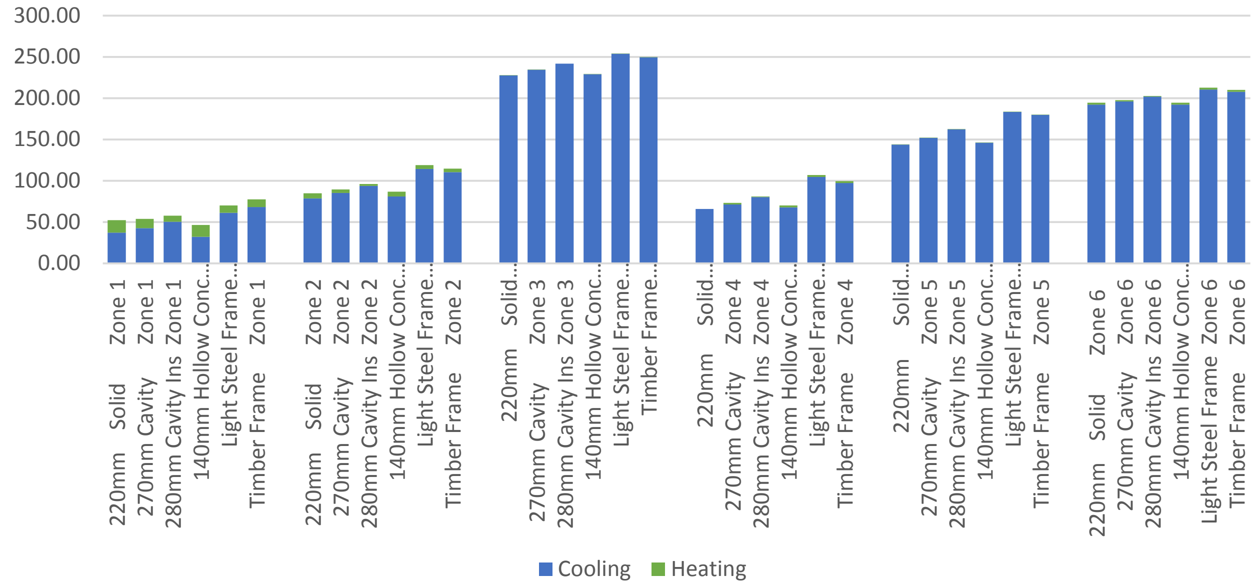

Figure 4 Comparative annual heating and cooling energy usage in kWh per square metre of walling for a 2000m² office or institutional building for six walling systems over six climate zones of the RSA

4.2 Analysis of the results

The results show the variation of heating and cooling energy modelled for the three building typologies, with six walling construction methods compared in each of the six climate zones of South Africa as set out in SANS 10400 Part XA. The results can be summarised as follows:

4.2.1 For the two residential typologies and across all climatic zones, the lowest energy usage per square metre of walling is the thermally insulated 280 mm clay brick cavity walling solution.

4.2.2 For the non-residential building and in all climate zones except climate zone 1 (but only marginally so), the lowest energy usage per square metre of walling is the 220 mm solid clay brick wall.

4.2.3 In all cases the highest energy usage per square metre of walling for residential buildings is the hollow concrete block wall.

4.2.4 The highest energy usage per square metre of walling of the non-residential typology for all climate zones is either mostly the light steel frame walling method or alternatively in one case the timber frame wall.

4.2.5 For the residential walling the trend within the masonry walling is evident and indicates those masonry walls with increasing thermal resistance have increasingly lower energy usage.

4.3 Discussion of the results

Although the three clay brick masonry walling solutions offer the lowest energy usage for all building typologies, clearly the patterns of energy usage are very different for the two 24 hour occupancy residential typologies (Figure 2 & 3) as opposed to the 12 hour daytime occupancy of the office/institutional typology (Figure 4).

For the non-residential typology the 220 mm solid clay brick masonry wall system shows the lowest energy usage in five climate zones and hence can be considered to be the most suitable for this typology, provided the occupancy type remains the same throughout the building's life cycle (Figure 4). The energy generated through the occupants

The dominance of cooling requirements in South African non-residential buildings is evident in Figure 4 and is interesting, because the modelling assumptions do not account for the lighting and other occupancy loads in these buildings. There should be consensus over the proposal that South African non-residential buildings should employ opportunities to dissipate daytime gained heat and to effect night-time cooling of the structure (including the walls) for the greatest energy efficiency. The pre-eminence of the 220 mm solid clay brick masonry wall for lowest energy usage in this building typology is evidence for such a proposal.

For the two residential typologies (Figures 2 & 3) the walling systems with lowest energy usage and hence greatest thermal comfort are consistently the 280 mm insulated clay brick cavity wall. In the residential category the trend of lower energy usage favours the masonry solutions with greatest thermal resistance. This is in line with increasing CR-value as per the SANS 204 methodology, which is simply the product of thermal capacity and thermal resistance.

The evidence of the value of thermal insulation in the cavity of a 280 mm clay brick masonry wall for residential buildings begs the question as to whether this type of wall should be the deemed-to-satisfy solution, and that non-masonry solutions should have a higher effective thermal resistance, an attribute which might be required in subsequent revisions of SANS 10400 Part XA, SANS 517 and SANS 10082.

5. Conclusions

The important conclusions to be reached in this paper relate primarily to the environmental impacts which will result from the energy usage of the various walling construction methods used in the South African building stock in the foreseeable future.

The modelling of the six building typologies informs the actual energy usage required to maintain thermal comfort in such buildings and by extension the environmental performance during the operating phase of the life of these buildings as might be extrapolated into the future.

Based in the evidence presented in this study, architects, private and public sector walling specification developers can make informed decisions as to what future walling specifications should be used, with indications of the positive impact on the environmental performance of buildings.

The evidence presented points to a wisdom in continuing to build day-time occupancy buildings with clay brick masonry and other high mass solutions in view of the predominantly cooling requirement.

The evidence also points to necessary changes in the South African regulatory built environment requirements which would necessitate the use of higher levels of thermal resistance in residential construction, including both masonry and non-masonry solutions.

The results across all South African climatic zones consistently demonstrate the following comparative thermal performance:

5.1 That the most efficient South African walling system for residential buildings is a 270 mm insulated cavity clay brick masonry wall.

5.2 That the most efficient South African walling system for a commercial or institutional building is a 220 mm solid clay brick masonry wall (or for Climate Zone 4: a 270 mm clay brick cavity wall, as is the norm for the Southern Cape condensation problem areas)

5.3 That for residential typologies clay brick masonry wall constructions increase in performance as their thermal resistance increases with insulation added into a cavity wall. It may point to the interim proposal, and as a low cost intervention, that for residential construction in all climate zones of South Africa, all masonry walling should be built with a cavity construction. This has the additional advantage of improved moisture resistance.

5.4 That light steel frame wall construction and timber frame walls (as presently specified in SANS 517) are not as thermally efficient and, as demonstrated, do use more heating and cooling energy compared to clay brick masonry cavity walls in all climate regions, and will need to relook the thermal resistance requirements and heat bridging requirements of SANS 517 and SANS 10082 if they are to contribute to reducing energy usage in the built environment in South Africa.

5.5 That the 140mm hollow concrete block wall is significantly the worst thermal performing or energy using wall, and will need to be re-evaluated in the regulatory environment. This raises the question that the 140 mm hollow concrete block wall requires to be investigated for the social impacts of providing a low quality walling system for subsidised low income housing, and further promoting energy poverty by permanently burdening the poor with excessive heating costs and discomfort during the hot season.

5.6 That there is a significant energy cost premium associated with the use of light-weight partitioning systems in all three building typologies modelled.

6. Acknowledgement

We would like to thank Mr Howard Harris and Prof Dieter Holm for their valuable contributions, expertise and knowledge about thermal performance in buildings.

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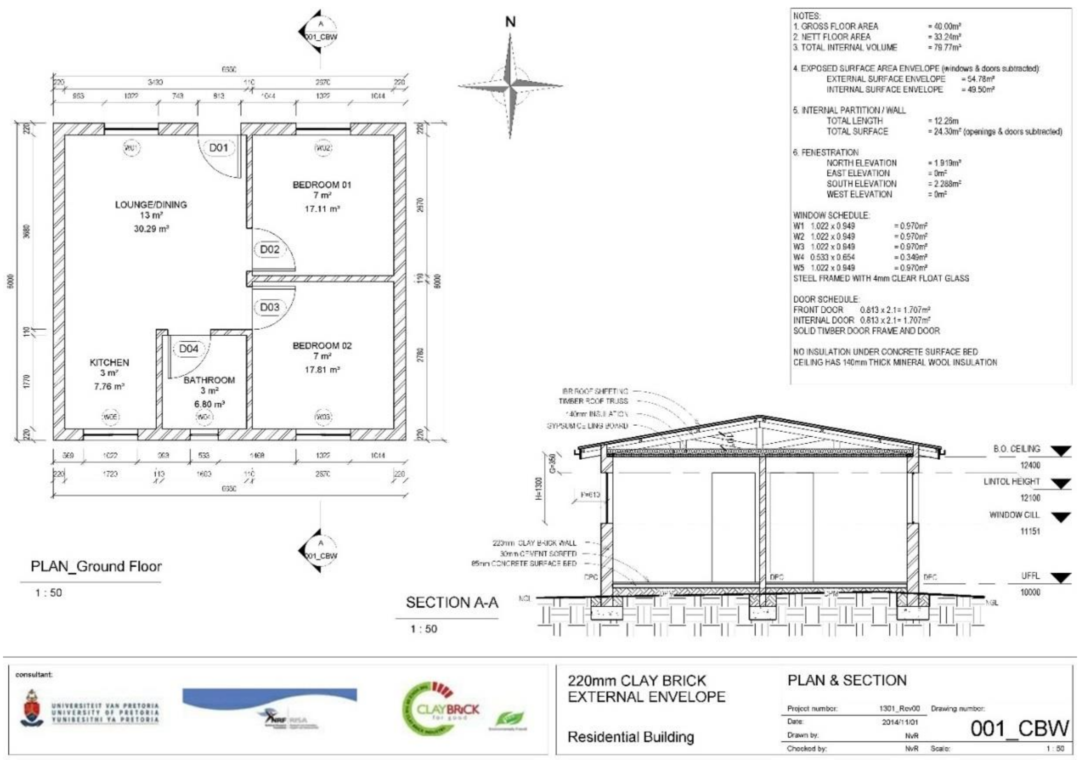
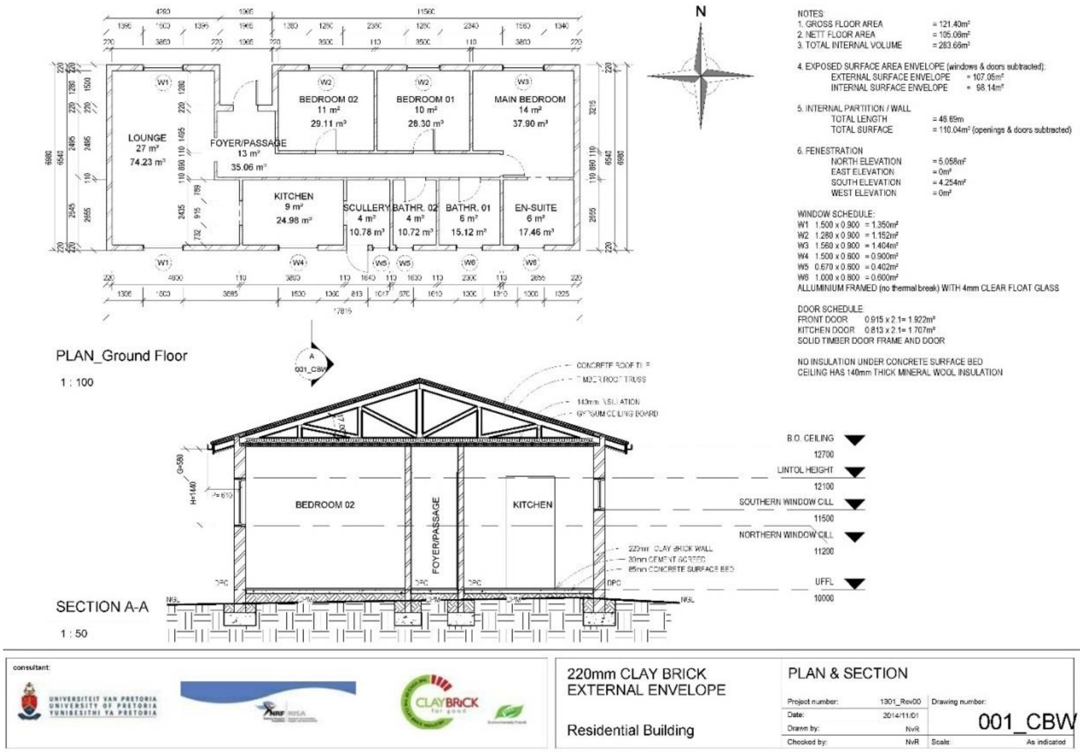
Appendix A

A standardised 40m² residential building design



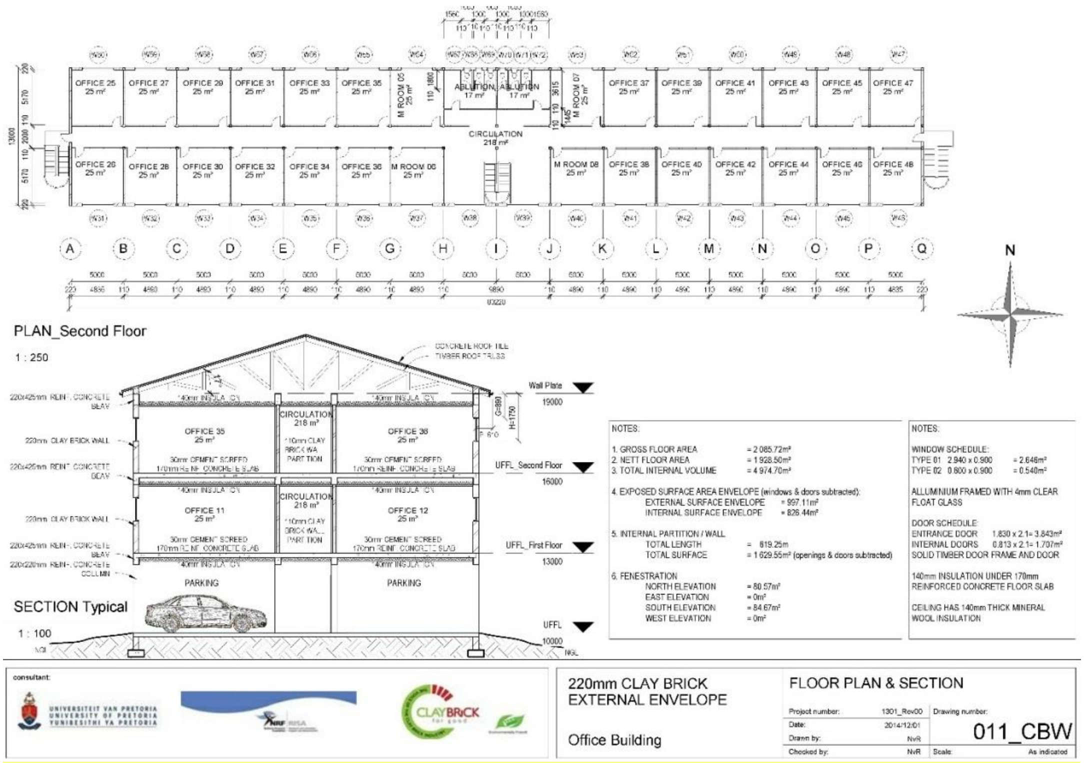
Appendix B

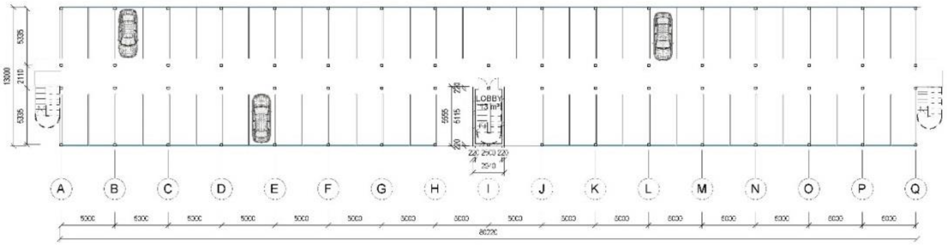
A standardised 130m² residential building design



Appendix C

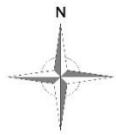
A standardised 2000 m² office or institutional building design

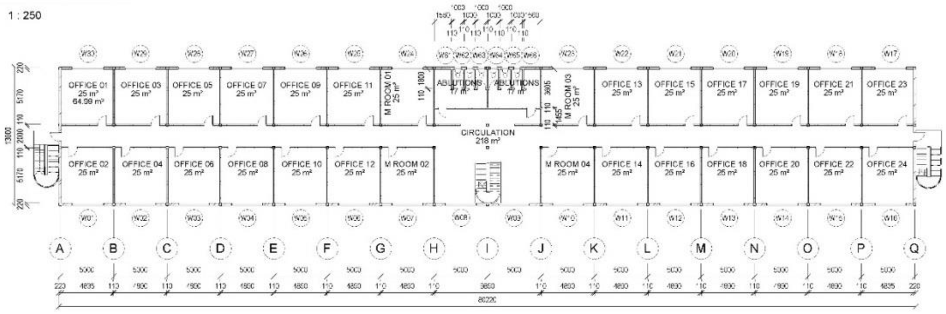




PLAN_Ground Floor

1 : 250





PLAN_First Floor

1 : 250

consultant:

220mm CLAY BRICK
EXTERNAL ENVELOPE

Office Building

FLOOR PLANS

Project number:	1301_Rev00	Drawing number:	
Date:	2014/12/01		010_CBW
Drawn by:	NvR		
Checked by:	NvR	Scale	1 : 250