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

THE CLAY BRICK ASSOCIATION OF SOUTH AFRICA: TECHNICAL REPORT 7B

Prepared by the Department of Architecture, University of Pretoria

for the Clay Brick Association of South Africa

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Disclaimer

The authors and any participant in this study cannot be held liable for any claim of damages of any nature whatsoever, to any person or entity, arising from this study. The data used herein to develop the thermal performance model are based on selected modelling software and certain assumptions made.

The data generated are used to quantify and compare the thermal performance associated with clay brick and other typical walling technologies employed in South Africa. The data used in this study have not been reviewed or audited by a third party.

Abstract

This Thermal Performance Study (TPS) is undertaken to inform and complement the Life Cycle Assessment research project by the University of Pretoria for the Clay Brick Association of South Africa and is aimed at assessing the operational energy usage impacts of structures built with clay brick masonry and other walling systems typically used in South Africa. Since the operational energy usage over a building's lifespan dwarfs its embodied energy, it is important that these impacts are accurately estimated.

A critical evaluation of various available energy modelling software is undertaken, including an investigation into walling heat transfer functions and how these algorithms are built into the software available. The selection of the most appropriate software for the project is made on the basis of this evaluation.

The energy usage of three building typologies is determined, i.e. that of a commercial/institutional building, middle income residential and subsidised low-income housing. The designs modelled are similar to structures used in other prior research. The modelling assumptions are derived primarily from *SANS 10400 Part XA: Energy usage in building* and thereafter *SANS204: Energy efficiency in building*. A blended RSA clay brick masonry wall is proposed as being representative of the average end use and operational energy of the clay brick.

Comparative energy usage (heating and cooling) for six wall construction systems across the selected three building typologies and in all the six climate zones of South Africa is presented. 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.
- 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.

It is recommended that:

- the modelling data in the TPS be used to adjust the present CR-value requirements of Table 3 and solutions of Table 4 of SANS 204.

- this potential for improvement of energy efficiency in South African buildings by prescriptive shading requirements and optimisation of window size and positioning be implemented, as is evidenced in this study.

Ekserp

Hierdie termiese gedragstudie word onderneem ter toeligting en aanvulling van die navorsingprojek oor die lewensiklusassessering van kleibakstene deur die Universiteit van Pretoria vir die Kleibaksteenverenging van Suid Afrika en is gemik op die assessering van die impakte van die operasionele energieverbruik van strukture gebou van kleibakstene en ander muurstelsels tipies gebruik in Suid-Afrika. Aangesien operasionele energieverbruik oor die lewensduur van geboue die ingeslote energie ver oorskry is dit belangrik dat sodanige impakte akkuraat beraam word.

‘n Kritiese evaluering van verskeie beskikbare energie-modellering sagteware word onderneem, insluitend ‘n ondersoek na die muur se hitte-oordragingsfunksies en hoe hierdie algoritmes in die beskikbare sagteware ingebou is. Die keuse van die mees toepaslike sagteware vir gebruik in die studie is gebaseer op hierdie evaluasie.

Die energieverbruik van drie geboutipes word onderoek, tewete ‘n tipiese kommersiële/institusionele gebou, ‘n middel-inkomste residensiële gebou en ‘n lae-inkomste gesubsidieerde residensiële gebou. Die ontwerpe hiervan is soortgelyk aan ander strukture wat in vroeër studies gebruik is. Die modelleringsaannames word hoofsaaklik afgelei van *SANS 10400 Deel XA: Energiegebruik in geboue* asook *SANS 204: Energiedoeltreffendheid in geboue*. 'n Verteenwoordigende baksteemuur is bereken wat die geweegde gemiddelde van alle gebakte kleibaksteenmure [in Suid-Afrika] se lopende- en end-energie vervat. Vergelykende energieverbruik (vir verhitting en verkoeling) vir ses muurkonstruksiemetodes vir drie geboutipologieë in al ses klimaatstreke van Suid-Afrika word aangebied. Die bevindings van die modellering dui aan dat:

- soliede kleibaksteenmure die mees termiese en energiedoeltreffende muurkonstruksiemetodes is vir daggebruik of nie-residensiële geboue.
- kleibaksteenspoumure die mees termiese en energiedoeltreffende muurkonstruksiemetodes is wat oorweeg is vir heeldaggebruik of residensiële geboue.
- ‘n kleibaksteenspoumuur ‘n gepaste keuse is vir algemene toepassing van die Suid-Afrikaanse regulatoriese bou-omgewing (SANS 10400 Deel XA) as ‘n eerste stap na meer doeltreffende muurkonstruksiemetodes in Suid-Afrika, veral as ‘n plaasvervanger vir die 140 mm holbetonblok wat bevind is as die algemeen swakste presteerder van die muurkonstruksiemetodes wat ondersoek is.
- die lae massa ligte staalraam- en houtraammuurkonstruksiemetodes nie so termies- of energiedoeltreffend is as kleibaksteenmuurkonstruksies nie en dat die SANS 517 en 10082 standaarde aangepas behoort te word om die vereiste verhoging in effektiewe termiese insulasie as gevolg van verminderde hittebrûe en/of dikker termiese insulasie te reflekteer.

Dit word aanbeveel:

- dat die modelleringsdata van die studie gebruik word om die huidige CR waardevereistes van Tabel 3 en oplossings van Tabel 4 van SANS 204 aan te pas.
- dat die moontlikheid, soos uit die studie blyk, om die energiedoeltreffendheid van Suid-Afrikaanse geboue te verbeter deur voorskriftelike skaduvereistes en optimalisering van venstergroottes en –posisies implementeer word.

Critical review: Final Statement

This study has been reviewed by Quantis International. Quantis found that the report completely fulfils the conditions to serve as an input report for the clay brick LCA study (Technical Report 7A).

> *"…the authors succeeded in elaborating a few key conclusion that are valid across different building types and climatic regions.*
>
> *… In general, I found no critical issues in this report. I can fully recommend it for publication…"*

- Quantis International

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Definition of terms and abbreviations

Annual Energy Intensity (E.I.)	As per SANS10400 Part XA: Energy usage over a full year divided by Net Floor Area
ASHRAE	American Society of Heating Refrigeration and Air-conditioning Engineers
Average Annual Demand Intensity (D.I.)	as for E.I. above
(Building) Energy Modelling Software	software which calculates the multifarious energy flows in a building often on the basis of hourly calculations throughout a year.
CBA	Clay Brick Association of South Africa
Coefficient of Performance (CoP)	The efficiency by which electrical energy is converted to cooling or heating energy
LCA	Life Cycle Assessment as per ISO 14040
Net Floor Area (NFA)	Floor area excluding vertical elements.
SANS 10400 Part XA: 2011	Energy Usage in Building
SANS 204:2011	Energy Efficiency in Buildings
SANS 517:2011	Light Steel Frame Buildings
SANS 10082:2007	Timber frame Buildings (Edition 4)
(T_n)	Thermal Neutrality

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CHAPTER 1 - SCOPE AND PROBLEM STATEMENT

1.1 INTRODUCTION

A Life Cycle Assessment (LCA) of clay bricks in South Africa was conducted by the University of Pretoria for the Clay Brick Association of South Africa. That study reviewed all environmental impacts associated with the production and use of clay bricks and brick structures from mining of the clay thorough all life cycle stages to the recycling and/or disposal of brick masonry in land-fill.

The need for this 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. 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 Clay Brick Association of South Africa (CBA) has therefore requested the Department of Architecture at the University of Pretoria to develop an exemplary model 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; hence the title of this report: *A thermal performance comparison between six wall construction methods frequently used in South Africa* or the short title: *Thermal Performance Study (TPS).*

1.2 AIM OF THIS STUDY

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

CHAPTER 2 - METHODOLOGY FOR THE THERMAL PERFORMANCE STUDY (TPS)

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 files. 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 environmental impact of energy usage during the operational phase of a residential building has been shown to be between three and a half to five times more significant than that from the embodied energy of the construction phase for all walling systems, if the walling system will last the estimated 40 years operational life of the buildings.

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.

2.3 MEASURING ENERGY EFFICIENCY OF WALLING

The efficacy of the walling systems can be assessed through one of two methods:

2.3.1 This assessment can be made measuring comfort as per *the Percentage Persons Comfortable* or those showing discomfort, and by observing the extent of deviations of this percentage with deviations from optimal comfort conditions. This concept was pioneered by Prof. Olaf Fanger of Chicago University who canvassed students in their response to numerous comfort related variables and expressed these responses as a comfort/discomfort function. This work forms the basis of human thermal comfort standards ISO 7730 and ASHRAE 55.

2.3.2 Alternatively 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 quantification of this energy usage can be translated into a comparative environmental impact.

The energy usage for heating and cooling for various standard buildings constructed with relevant walling systems in use is compared using suitable and internationally accepted thermal modelling software programmes.

2.4 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 in an important referenced study used in this report. 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 study by Dr A Johannsen is set out in Appendix A. 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.

2.5 GENERATING A TYPICAL ENERGY USAGE FOR RSA WALLING

Three different building typologies are analysed; two residential; a standard 40m^2 house which is typical of subsidised housing in South Africa, a 130m^2 design house based on an earlier unpublished CSIR study and as publicised in the Green Buildings Handbook Volume 1, as published periodically by Alive-to-Green, as well as a two storey office design of approximately 2000m^2, 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 RSA 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 B.

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

The walling systems to be compared in this analysis are:

- Double clay brick solid wall (nominally 220 thick)
- Double clay brick cavity wall - un-insulated (nominally 280mm thick)
- Insulated double clay brick wall (nominally 280mm thick)

- 140mm hollow core concrete block (150mm thick with a single external layer of plaster)
- Light steel frame cladded with fibre board to SANS 517 (nominally 145mm thick)
- Timber frame cladded with fibre board (nominally 145mm thick)

Each of these construction methods is be analysed in each of the three building typologies, across the six different climatic zones in South Africa, as per SANS 10400 Part XA: *Energy Usage in buildings,* see Figure 1

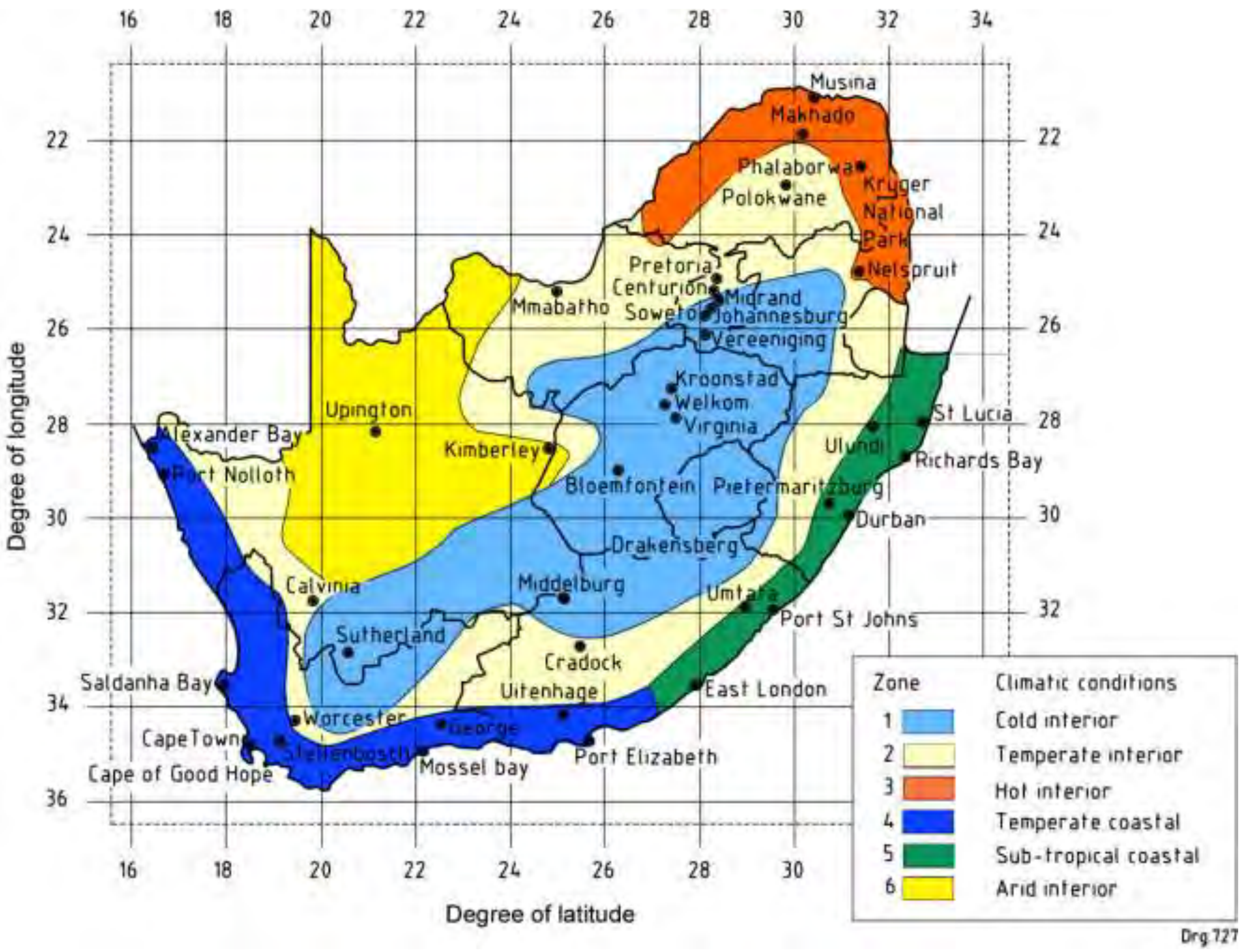

Figure 1: Climate zones of South Africa as per SANS 10400 Part XA

2.6 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 will not detract from the walling performance, and as per the norms for good design and construction of such systems. 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 per consensus decisions made in the CBA LCA Stakeholder Workshop held at the University of Pretoria in January 2014 - in principle the assumptions and stipulations of the modelling should be such as to produce an energy usage – heating and cooling which is realistic and reasonably comparable or reconcilable with typical energy usages in such building typologies.

As the focus of this research is on the performance of clay brick structures, 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.

CHAPTER 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 buildings and residences 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 by Dr. A. Johannsen in a separate report for the CBA which is attached hereto as Appendix A. The recommendations of this report are summarised below and the most suitable calculation methods are explained.

The following conclusions can be drawn:

- In view of its advantages over other calculating methods, the Conduction Transfer Function (CTF) method can be considered the most suitable methods for computer based calculations of unsteady-state heat conduction through multi-layer wall constructions in annual energy simulation of buildings.
- For calculating design cooling and heating loads, the Periodic Response Factors (PRF) method, which is a special case of the CTF method, is preferred.
- For calculating CTF coefficients, the State Space method is preferred by programmers (including Dr. Johannsen) over a finite element type approach in view of its simplicity and computational advantages.

3.2 BUILDING ENERGY MODELLING SOFTWARE SELECTION

The software packages considered for selection for this TPS are confined to programmes which implement the above 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 CTF method as well as the use the State Space method, are the Design Builder Version 3.1 and BSIMAC Version 9.

A third software suite has been considered in the evaluation in view of its use by some adherents in the South African building research and thermal modelling fraternity. Ecotect, which is said (according to Dr. Johannsen) to be based on the Admittance Method, is considered not suitable for the TPS project, in part due to the inadequacy of the treatment of thermal capacity (this in accordance with CSIR researchers reported in the Green Building Handbook referred to earlier) It should however be emphasized that this conclusion had not been corroborated at the time of writing, as information on the internal working of Ecotect software could not be obtained via a scan of public domain sources. Professor Juintow Lin (in the *Introduction to Ecotect™ V5.6*) does however confirm the use of the Admittance Method.

The Parametric Study (Johannsen 2012) compared the performance of three software programmes with a comparative modelling of a 130m^2 residential building and found that the results of the Ecotect software were significantly (35%) higher than the energy usage calculated using the Design Builder and BSIMAC software, and that Ecotect failed to respond adequately to the addition of thermal capacity in walling modelling; Ecotect was therefore considered unsuitable for the TPS.

3.3 INPUT STANDARDISATION

3.3.1 Climate data files

The climate data files selected are those in use in the RSA 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 as per SANS 10400 Part XA are individually analysed. As the climate data files are in general use, the modelling results should 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 sub-continent and the variability of the weather in the region.

3.3.2 Modelling stipulations

3.3.2.1 Measurement

The total floor area 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.

Treating the building as a single zone has the effect of trading off excesses of temperature between rooms, but the overall heating and cooling energy comparison remains valid.

By holding the Gross Floor Area constant, the effect of wall thickness variations causes the Net Floor Area to vary slightly, however, the heat losses and gains then take place over constant and hence comparable external walling areas. The influence on Net Floor Area 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 Net Floor Area held constant versus Gross Floor Area 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 15m^2 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. 5W/m^2 for residential buildings and 17W/m^2 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 5W/m^2 for residential occupancies and 15W/m^2 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 corresponding to meal times or hot water usage but is assumed to be an around the clock usage.

The following space heating technologies are assumed for the various building typologies:

- 40m² residence: coal, paraffin, etc., i.e. multiple fuel sources
- 130m² residence: electrical resistance heating
- 2000m² office: electrical resistance heating

Sufficient heating capacity to heat the whole building has been provided in the model.

Earlier unpublished research work done by WSP Green by Design for the CBA has approached the analysis from a Percentage Persons comfortable/uncomfortable view and effectively captures the human comfort impact of energy efficient walling.

As the main purpose of this TPS is to inform regarding the extent of the environmental impacts of the external walling, the benefits of thermally comfortable buildings have not been highlighted in this report. The project outcomes are simply stated as an energy impact and therefore the carbon-dioxide or green-house gas emissions can be deduced by the reader.

For cost and affordability reasons mechanical cooling is not generally used in residential buildings in South Africa. The cooling, and on occasions the heating energy usage, which is foregone in poorer households which are not able to afford these costs is difficult to quantify and is termed the unfulfilled demand. In this study, in common with other studies which estimate emission reductions via the provision of solar water heating and roof insulation, both the cooling and heating requirements are quantified and are included as an environmental impact. This may result in the reporting of an over-estimation of actual heating and cooling energy used in practice. It should also be borne in mind that the modelling assumes a constant comfort temperature range for 24 hours per day. (See 3.3.2.8 below)

Commercial buildings are assumed to be air-conditioned. The efficiency of cooling is to be as per Table 14 of SANS 10400 Part XA and a coefficient of performance (CoP) of 2.64 is assumed for the cooling cycle. Reverse cycle heating is not included as this is not a requirement of SANS 10400 Part XA. The efficiency with which heating is modelled is therefore at a CoP of unity (1.0).

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.

A more exhaustive treatment would be to compare monthly variable Thermal Neutrality (T_n) or comfort temperatures in terms of the variations of seasonal monthly mean temperatures as per the application of Adaptive Theory principles with the calculated room temperatures on the hour. In this instance the accuracy of modelling has to be considered and weighed up against the accuracy of the Thermal Neutrality or Comfort Zone concepts.

Furthermore, if the Operative Temperature were to be calculated (⅔ Mean Radiant Temperature as per the room internal surface temperatures and ⅓ Air Temperature), and this were compared against the set points, the efficacy of the walling systems would be more accurately tested. The typical output of the software modelling does not easily yield the mean radiant temperature and hence the air temperature is accepted as the surrogate for these temperatures.

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 T_nET (Effective Temperature) rather than T_nDBT (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.

Taking full cognisance of Adaptive Theory would have the effect of broadening the comfort range across all climate zones of South Africa and a range of 19.8 to 26.7 °C was considered by applying the adaptive formula for Dry Bulb Temperature for naturally ventilated buildings across the mean temperatures of each of the climate zones of South Africa and spanning the mean temperature minima extremes of Bloemfontein (7.0°C) and maxima of Musina (29.4°C), namely:

$T_n = 17.6 + 0.31 \times T_{oav}$ +/-3.0K which is valid in the range of $17.8 < T_n < 29.5$°C.

In attempting to take cognisance of humidity effects, the comfort range would be reduced for some climate zones. Holm & Engelbrecht (2004) found that the net differences between T_nET and T_nDBT is 0.5K higher in summer and 0.6K higher in winter.

Regional comfort variations as per the adaptive theory are not applied in this analysis in the interests of simplifying and standardising the set points across climate zones and in part allowing for humidity effects.

3.3.2.9 Lifespan of building

European experience shows that buildings will in practice be in use for more than 100 years, if of good quality materials. US housing lifespan is taken at 32 years as per the National Home Owners Association and this lower figure may be influenced by the use of timber frame and light weight construction systems in the USA housing market.

Masonry buildings' lifespans are in practice extended by regular face-lifting and renovation and therefore on average will exceed 40 years. For the purposes of this study the duration of the operational phase of buildings will therefore be assumed to be 40 years. The justification for this assumption is that for a lifespan exceeding 40 years the effects of the low discount rate used in discounting the net present value causes the initial embodied energy impacts to loose significance over time.

3.3.2.10 Thermal resistances calculation conventions

The conventions applied to the selection of appropriate thermal conductivities of the building envelopes are that 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**.**

3.3.2.11 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 120m^2 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 are 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. This area of north facing wall fenestration is well short of optimal levels as has been indicated by a sensitivity study of this aspect below:

Table 1 Percentage reduction in energy usage for walling systems with optimisation of window size

Walling system Percentage improvement by optimisation of window design	Climatic Zone 1
220mm Solid wall	10
280mm Cavity wall	5
280mm Cavity Insulated	-18
140mm Hollow Concrete	48
Light Steel Frame	-51
Timber Frame	-48

Note: Negative figures indicate over-heating with increased window size

The optimisation of the north elevation fenestration area as applied to Climate Zone 1, i.e. the Highveld Region, demonstrates that the performance of un-insulated masonry solutions can be enhanced (energy usage reduced) by the optimisation of window area and the positioning of sill height in relation to the shading provided. This makes buildings with standard RSA masonry walling less likely to overheat with increased window size.

The same cannot be said for light-weight walling systems which demonstrate a significant over-heating if window areas are increased.

The 140mm hollow concrete block wall benefits most from the increased window size for this Climate Zone with a 48% reduction in energy usage. This improvement could be very useful for Rational Designs and low cost housing regulatory compliance.

The buildings modelled for final reporting in this study in have all cases an eave of 715mm provided. A sill height of 1.2m is provided for north facing windows and 1.5m for south facing windows. The decision to model an arbitrary standardised window area corresponding to a 10% of Net Floor Area and commensurate window dimensions are applied for all of the reported walling systems, rather than an optimised window size and positioning in the wall, is significantly favouring the light-weight systems as the over-heating energy impact and the additional cooling requirement have not been included in the non-masonry walling modelling results.

3.3.2.13 Effective versus nominal thermal transmittance

The influence of thermal bridging on some walling systems is significant; for example the bridging in a light steel frame construction *without* provision for thermal breaks (*without* would be the norm in terms of SANS 517 construction) results in an effective U-values of 0.67 W/m^{2}K and 0.77 W/m^{2}K, for climate zones 2,3,4,&5 and then for climate zones 1&6 respectively. This is in contrast with the nominal requirement as per SANS 10400 Part XA which would be that R-values of 2.2 and 1.9 m^{2}K/W (i.e. U-values 0.45 and 0.53 m^{2}K /W) are achieved in Climate Zones 1 & 6, and in Climate Zones 2, 3, 4 & 5 respectively. The percentage reduction in thermal performance is 20% at the lower level of thermal resistance but 32% at the higher level and is calculated using the ASHRAE Zone Method.

Timber frame wall constructions are similarly treated with 38 x 76 or 38 x 102mm studs at 400mm centres factored into the ASHRAE Zone method calculation to arrive at the appropriate effective thermal transmission. Due to the lower conductivity of the timber studs the loss of thermal performance vis-à-vis the nominal level of insulation is not as severe as the Lightweight Steel construction.

Thermal bridging around cavity wall insulation is also likely at the wall plate, floor junctions, wall ties and around openings, and a similar allowance is built into the effective U-value.

Where rotatable hot box tests results in accordance with ASTM 1363 are available and credible, these have been used. The R-values and U-values used in the modelling are shown in Table 2 below.

Table 2 Thermal Transmittance (U-values) of walling systems input to models

Walling system thermal transmittance (W/m²K)	Climatic Zones 1 & 6	Climate Zones 2,3,4 & 5
220mm Solid clay brick masonry	2.22	2.22
280mm Cavity clay brick masonry	1.66	1.66
280mm Cavity clay brick masonry insulated with R=1.0	0.80	0.80
140mm Hollow Concrete block	3.17	3.17
Light Steel Frame to SANS 204	0.67	0.77
Timber Frame to SANS 204	0.75	0.80

3.3.3 Excluded issues

3.3.3.1 Maintenance

The consensus decisions of the January 2014 CBA LCA Workshop held with all stakeholders were, inter alia, that maintenance issues could be excluded from the TPS as the following environmental impacts are to be brought into the LCA via the SimaPro modelling process:

- All buildings/walls need to be painted
- Only face brick can be maintenance free [these are a subset of the whole]

- Paints environmental impacts are obtained from the EcoInvent database and the VOC effects are brought to account by the SimaPro LCA software.

3.3.3.2 Replacement

The expected lifespan of the selected building walling systems has not been evaluated as this is outside of the scope of the TPS. The influence of having to replace or extensively renovate the walling system of buildings within a shorter period for one walling system versus others is also not evaluated.
The relative durability of the clay brick walling systems is well documented, and the use and reuse of masonry buildings is well beyond the 40 year building life selected for this study.

Building walling systems with shorter expected lifespans will need to factor rebuilding into a similar analysis. The onus would fall on such lightweight systems to demonstrate a capability of exceeding the 40 year lifespan if replacement is not to be assumed.

3.4 BUILDING TYPOLOGIES CONTRIBUTING TO THE AVERAGE SOUTH AFRICAN WALL

3.4.1 Blending of walling in different typologies

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

- ±40m² low income residential: 7%
- ±130m² middle income residential: 43%
- ±2000m² 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

Materials 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 30mm concrete tiles with a 38mm air space created by the battens, a 0.2mm poly-olefin tile underlay, a ceiling airspace of between 0 and 608 mm and with 140mm fibreglass insulation on a 6.4mm gypsum ceiling board.

3.4.2.2 All floors

A 10mm screed on a 75mm concrete surface bed on compacted soil fill.

3.4.2.3 All windows

Windows are constructed from 4mm 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 106mm skins plastered both sides with 15mm of mortar

3.4.2.5 External wall Type 2

Nominal 280mm clay brick cavity masonry wall as above but with 50mm air-cavity in mid-wall.

3.4.2.6 External wall Type 3

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

3.4.2.7 External wall Type 4

Nominal 140mm 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 75mm fibreglass insulation, externally cladded with 9mm fibre cement, a 0.2mm polymer vapour membrane, a 20mm Orientated Strand Board, with 0.8mm steel studs intruding through the insulation, and cladded internally with 15mm gypsum board, in climate zones 2,3,4 and 5. With attendant heat bridging allowances.
As above, with 100mm glass wool insulation batts in combination 0.8mm 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 110mm clay brick single skin wall covered both sides with 15mm plaster for wall types 1 to 3 and bagged for the 110mm hollow concrete block in the case of wall type 4.

3.4.2.11 Internal wall Type 2

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

CHAPTER 4 - MODELLING RESULTS

4.1 GRAPHICAL AND TABULAR 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 tabular and graphical format below. The analysis of these results follows thereafter.

Table 3 Table of gross annual heating and cooling energy for the 40 m² house in each climate zone expressed in kWh

40m² House Annual Energy Usage kWh		Climatic Zone																	
		Climatic Zone 01 Bloemfontein			Climatic Zone 02 Pretoria			Climatic Zone 03 Musina			Climatic Zone 04 Cape Town			Climatic Zone 05 Durban			Climatic Zone 06 Upington		
	Wall Type	**Heating**	**Cooling**	**Total**	**Heating**	**Cooling**	**Total**	**Heating**	**Cooling**	**Total**	**Heating**	**Cooling**	**Total**	**Heating**	**Cooling**	**Total**	**Heating**	**Cooling**	**Total**
1	220mm Solid Clay Brick	1425	39	1464	820	235	1055	16	1266	1282	624	110	734	115	475	590	424	2004	2428
2	270mm Cavity (50mm) Clay Brick with NO Insulation	987	22	1009	553	172	725	7	880	887	409	70	479	62	392	454	294	1610	1904
3	280mm Cavity (50mm) Clay Brick with Insulation	480	16	496	265	114	379	1.7	0	2	166	52	218	19	277	296	134	1110	1244
4	140mm Hollow Concrete Block	2118	46	2164	1235	270	1505	27	1596	1623	938	141	1079	201	548	749	574	2513	3087
5	Light Steel Frame to SABS 517	652	293	945	524	558	1082	109	1026	1135	423	445	868	111	716	827	378	1676	2054
6	Timber Frame with Fibre Board	781	231	1012	558	508	1066	115	738	853	450	412	862	119	667	786	453	1500	1953

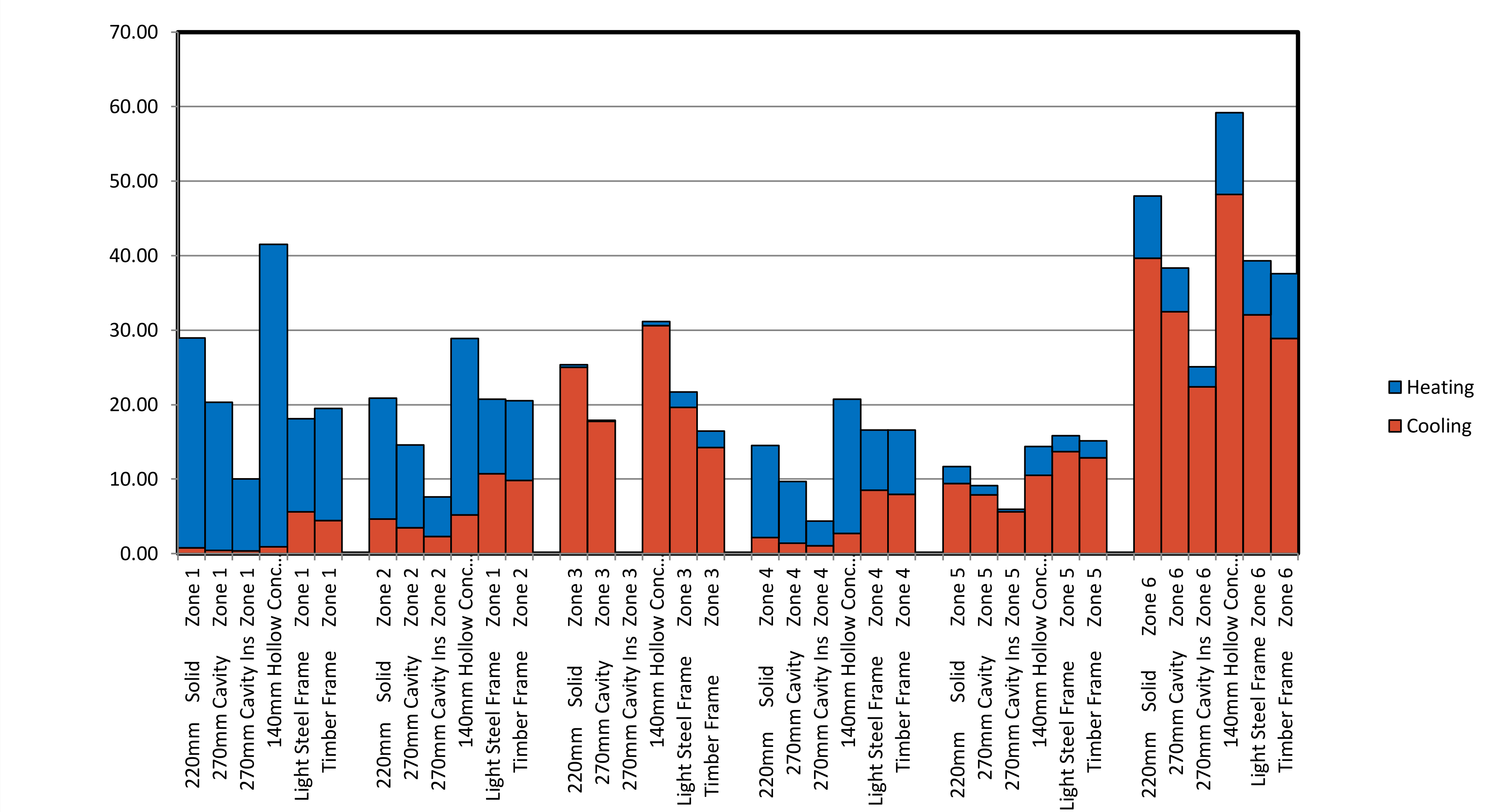

Figure 2 **Comparative annual heating and cooling energy usage in kWh per square metre of walling for a 40 m² house for six walling systems over six climate zones of the RSA**

Table 4 Table of gross annual heating and cooling energy for the 130 m² house in each climate zone expressed in kWh

130m² House Annual Energy Usage kWh		Climatic Zone																	
		Climatic Zone 01 Bloemfontein			Climatic Zone 02 Pretoria			Climatic Zone 03 Musina			Climatic Zone 04 Cape Town			Climatic Zone 05 Durban			Climatic Zone 06 Upington		
	Wall Type	**Heating**	**Cooling**	**Total**	**Heating**	**Cooling**	**Total**	**Heating**	**Cooling**	**Total**	**Heating**	**Cooling**	**Total**	**Heating**	**Cooling**	**Total**	**Heating**	**Cooling**	Total
1	220mm Solid Clay Brick	4389	16	4405	2632	166	2797	116	671	787	2186	56	2242	478	431	909	1504	3258	4762
2	270mm Cavity (50mm) Clay Brick with NO Insulation	3246	5	3251	1926	97	2023	78	0	78	1591	27	1618	314	305	619	1147	2534	3682
3	280mm Cavity (50mm) Clay Brick with Insulation	1852	3	1855	1118	47	1164	45	0	45	861	12	872	167	154	322	681	1547	2228
4	140mm Hollow Concrete Block	6253	32	6285	3756	230	3986	162	2577	2739	3067	99	3166	741	596	1337	1932	4382	6314
5	Light Steel Frame to SABS 517	2434	216	2650	1862	629	2492	478	721	1199	1652	452	2104	509	849	1358	1509	2399	3908
6	Timber Frame with Fibre Board	2684	218	2902	1954	583	2537	496	607	1102	1729	423	2152	536	796	1332	1639	2445	4085

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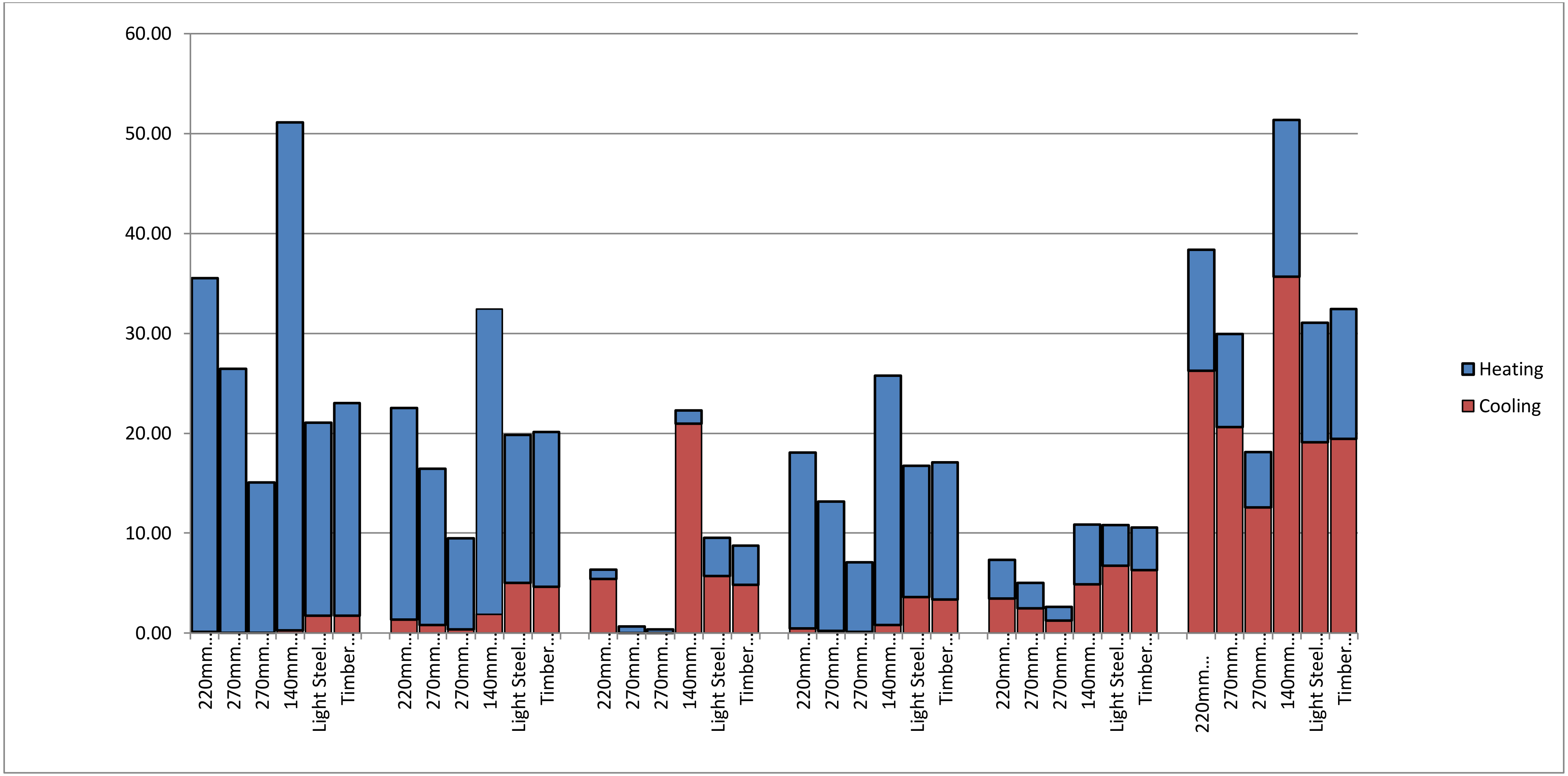

Figure 3 **Comparative annual heating and cooling energy usage in kWh per square metre of walling for a 130 m² house for six walling systems over six climate zones of the RSA**

Table 5 Table of gross annual heating and cooling energy for the 2000m² office in each climate zone expressed in kWh

2000m² Office Building Annual Energy Usage kWh		Climatic Zone																	
		Climatic Zone 01 Bloemfontein			Climatic Zone 02 Pretoria			Climatic Zone 03 Musina			Climatic Zone 04 Cape Town			Climatic Zone 05 Durban			Climatic Zone 06 Upington		
	Wall Type	Heating	Cooling	Total	Heating	Cooling	Total	Heat	Cooling	Total	Heating	Cooling	Total	Heat	Cooling	Total	Heat	Cooling	Total
1	220mm Solid Clay Brick	14818	36271	51088	6032	76860	82892	1	222936	222937	2462	64569	67032	98	140657	140756	2412	188136	190548
2	270mm Cavity (50mm) Clay Brick with NO Insulation	11280	41350	52630	4295	82973	87268	0	228857	228858	1636	69582	71218	48	148143	148191	1642	191292	192934
3	280mm Cavity (50mm) Clay Brick with Insulation	7255	48923	56178	2498	91274	93772	0	236063	236063	762	78055	78817	15	158557	158572	736	197070	197806
4	140mm Hollow Concrete Block	14123	31608	45731	5768	79549	85317	1	225653	225654	2385	66742	69127	97	143886	143983	2454	189327	191781
5	Light Steel Frame to SABS 517	8663	60258	68921	4289	112794	117083	10	250248	250258	2387	103002	105389	172	180808	180980	2171	207598	209769
6	Timber Frame with Fibre Board	9054	67153	76207	4330	108675	113005	9	245861	245870	2018	95828	97846	162	176933	177095	2250	204385	206635

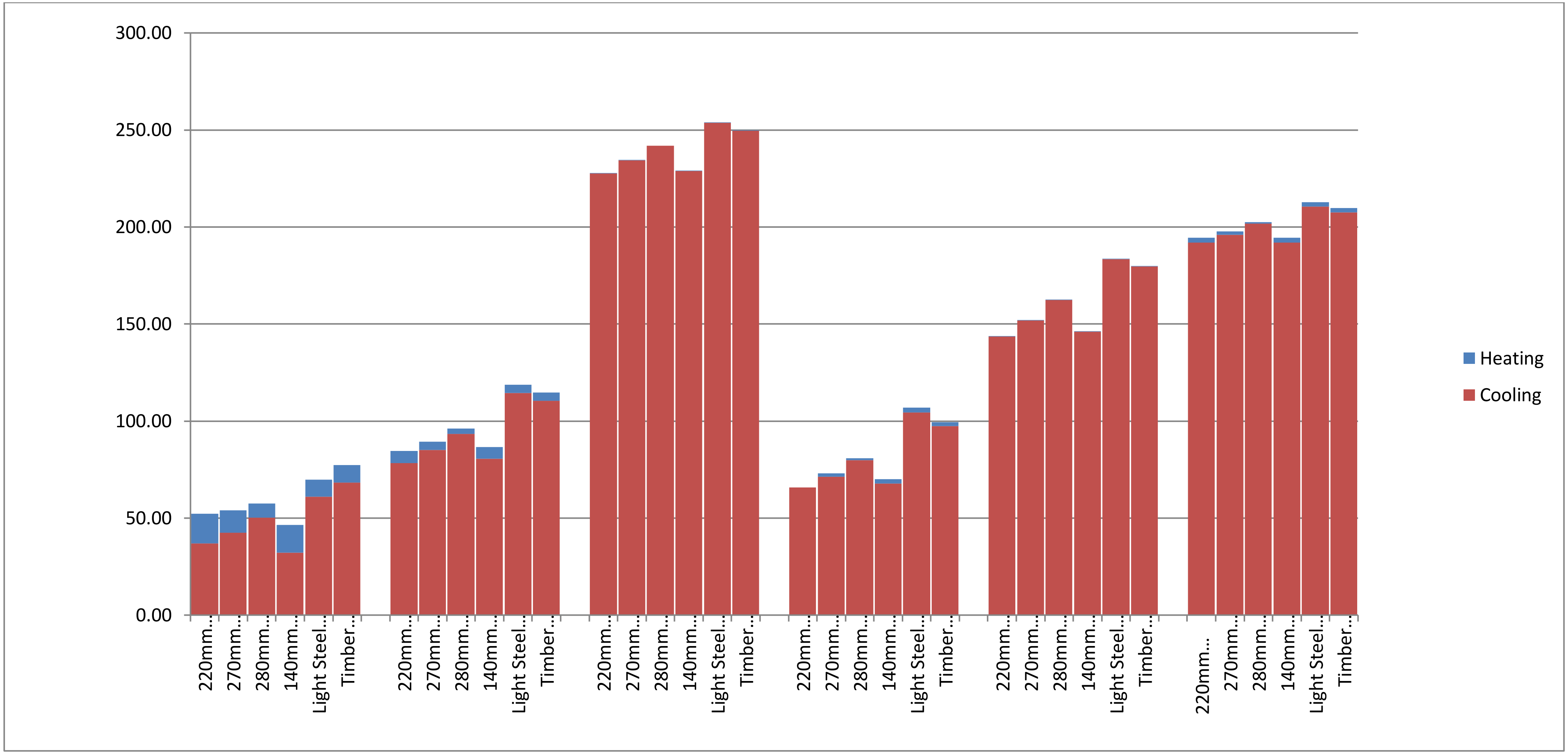

Figure 4 **Comparative annual heating and cooling energy usage in kWh per square metre of walling for a 2000m2 office or institutional building for six walling systems over six climate zones of the RSA**

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 280mm 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 220mm 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 220mm solid clay brick masonry wall system shows the lowest energy usage in all 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 dominance of cooling requirements in South African non-residential buildings is evident in Figure 4 and is interesting, given that 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 220mm 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 280mm 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 280mm 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 still higher effective thermal resistance, an attribute which might be required in subsequent revisions of SANS 10400 Part XA, SANS 517 and SANS 10082.

CHAPTER 5 - CALCULATION OF THE BLENDED RSA WALLING ENERGY IMPACT PER ANNUM

5.1 METHODOLOGY EMPLOYED

The annual energy usage of a blended walling system, combining both heating and cooling, across all walling types is calculated by weighting the annual energy usage per unit area of walling of the three main building typologies modelled herein in proportion to their usage as per the ratios developed by Milford.

The purpose of calculating a blended representative South African wall is to assess whether this can be used to simplify the number of walling permutations in the calculation of an operational energy attributable to walling types.

5.2 CALCULATED BLENDED RSA ANNUAL WALLING AREA ENERGY USAGE

Table 6: Blended RSA annual walling energy usage

Annual heating & cooling energy - All wall types in kWh/m^2 of walling							
Climate zone	**Wall type**	**220mm Solid clay brick**	**270mm Cavity clay brick**	**280mm Insulated Cavity clay brick**	**140mm Hollow Concrete block**	**Light Steel Frame**	**Timber Frame**
Zone 1	Cooling	18.62	21.22	25.09	16.21	31.68	35.14
	Heating	24.75	18.53	10.87	31.88	13.59	14.81
	Total	**43.36**	**39.75**	**35.96**	**48.09**	**45.27**	**49.96**
Zone 2	Cooling	40.12	43.08	47.07	41.52	60.08	55.87
	Heating	13.33	9.72	5.56	17.73	9.24	3.00
	Total	**53.45**	**52.79**	**52.63**	**59.24**	**69.33**	**58.87**
Zone 3	Cooling	117.83	118.44	120.89	125.62	130.71	127.87
	Heating	0.42	0.33	0.16	0.60	1.79	1.85
	Total	**118.25**	**118.77**	**121.05**	**126.22**	**132.50**	**129.72**
Zone 4	Cooling	33.29	35.83	40.09	34.39	54.36	50.64
	Heating	24.75	6.98	3.63	13.20	7.42	7.54
	Total	**43.36**	**42.81**	**43.72**	**47.59**	**61.79**	**58.18**
Zone 5	Cooling	73.92	77.49	82.13	75.81	95.53	93.43
	Heating	1.87	1.21	0.62	2.91	1.97	2.07
	Total	**75.79**	**78.70**	**82.75**	**78.72**	**97.50**	**95.50**
Zone 6	Cooling	110.06	109.10	107.90	114.74	115.70	114.12
	Heating	7.03	5.27	2.95	8.77	6.76	7.35
	Total	**117.09**	**114.37**	**110.85**	**123.52**	**122.46**	**121.47**

The blended RSA walls combine the gross heating and cooling and total energy usage of three building typologies expressed in kWh/m²/annum for each climate zone and are shown in the graphs below:

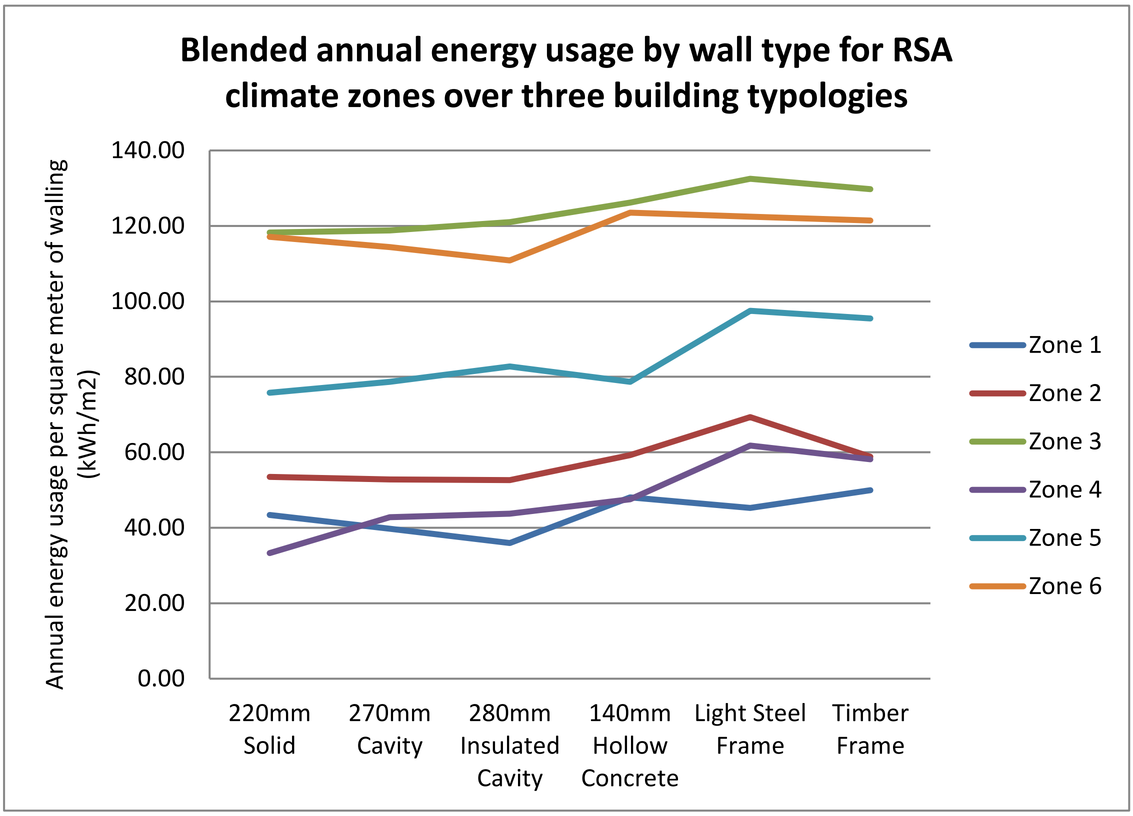

Figure 5: Graph of the annual combined heating and cooling energy usage per annum for six walling systems in six climate zones for a blended RSA wall

5.3 COMMENT ON THE RESULTS OF THE CALCULATION OF BLENDED RSA ANNUAL WALLING AREA ENERGY

The blended RSA wall in Figure 5 shows a trend towards higher energy usage in the lower mass walling systems with lowest annual energy usage belonging in all cases to one or another of the masonry solutions.

If the approach to walling specifications in RSA National Standards is towards single solutions the following points can be made:

1. There is a case for retaining the deemed-to-satisfy role of the masonry walling solutions in general as these are on a weighted area basis the most efficient.

2. There is no case for low mass walling systems to be considered more energy efficient than masonry solutions at present Regulatory levels of thermal resistance.

3. The operational energy usage in buildings in the more extreme and hot parts of the country are higher than in the cooler and milder climate zones across the country, and that the LCA will have to reflect this significant difference.

CHAPTER 6 – CONCLUSIONS

The important conclusions to be reached in this report 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 absolute results on the environmental impacts created by energy usage in the researched walling construction methods will be incorporated in the Life Cycle Assessment of the clay brick produced in South Africa as per a separate but complementary study by the Department of Architecture at the University of Pretoria; refer in this instance to Technical Report 7A prepared for the Clay Brick Association of South Africa titled *A Life Cycle Assessment of clay brick walling in South Africa*, authored by Vosloo, Harris, Holm, van Rooyen & Rice (2014).

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 writers 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:

6.1 That the most efficient South African walling system for residential buildings is a 280mm insulated cavity clay brick masonry wall.

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

6.3. 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.

6.4. 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.

6.5 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 140mm 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.

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

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Appendix A: A review of computer-based calculation methods for simulating unsteady-state heat transfer through walling system

A REVIEW OF COMPUTER-BASED CALCULATION METHODS FOR SIMULATING UNSTEADY-STATE HEAT TRANSFER THROUGH WALLING SYSTEMS

Prepared by Dr Alec Johannsen, 2013

SUMMARY

This review was carried out in support of the Clay Brick Association's (CBA) Technical Project #5, "A Parametric Energy Modelling of Middle Income 130m^2 Residences for South African Conditions, in Six Climatic Regions of South Africa, with Four Walling Systems". One of the objectives of this project is to investigate the thermal performance of different walling systems and their effect on the annual energy requirements of the residences.

One of the key requirements for energy modelling of buildings is to accurately simulate the unsteady-state heat transfer through the walling systems under varying external conditions.

The review 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, and the most suitable calculation method was selected.

Based on the current review, the following conclusions can be drawn.

1. In view of its advantages over other calculating methods, the CTF method, can be considered the most suitable methods for computer based calculations of unsteady-state heat conduction through multi-layer wall constructions in annual energy simulation of buildings.

2. For calculating design cooling and heating loads, the PRF method, which is a special case of the CTF method (see Section 4), is preferred.

3. For calculating CTF coefficients, the State Space method is preferred in view of its simplicity and certain computational advantages.

4. Both software packages that have been certified by Agrément South Africa in terms of SANS 10400-XA, namely DesignBuilder Version 3.1 and BSIMAC Version 9, fully implement the CTF method and can therefore be considered suitable for the CBA project.

5. It appears that Ecotect, which is said to be based on the Admittance method, is not suitable for the CBA project. It should however be emphasized that this conclusion may not be correct, as information on the internal working of Ecotect software could not be obtained.

1. INTRODUCTION

This review is carried out in support of the Clay Brick Association's (CBA) Technical Project #5, "A Parametric Energy Modelling of Middle Income 130m^2 Residences for South African Conditions, in Six Climatic Regions of South Africa, with Four Walling Systems". One of the objectives of this project is to investigate the thermal performance of different walling systems and their effect on the annual energy requirements of the residences.

The walling systems to be investigated in the CBA project consist of a number of layers of different building and insulating materials with different thermal properties and thicknesses. Both 'light' and 'heavy' walls will be included in the project.

One of the key requirements for energy modelling of buildings is to accurately simulate the unsteady-state heat transfer through the walling systems under varying external conditions.

This review starts with the fundamental equations governing heat conduction through walls under a number of simplifying assumptions, and considers different methods of solving these equations for multi-layer walling systems. This is followed with a review of the suitability of these methods for simulating annual energy performance of buildings, and a selection of the most suitable calculation method.

The review then considers the software packages certified by Agrément South Africa in terms of SANS 10400-XA for simulation of the annual energy requirements of buildings. The methods employed by these software packages for calculating the unsteady-state heat transfer through the walling systems are examined in some detail in order to evaluate the suitability of these software packages for the CBA project.

The calculation methods used in the Ecotect software are also considered from the point of view of their suitability for the CBA project.

2. HEAT CONDUCTION THROUGH WALLS

The problem of heat conduction through walls is usually considered with the following simplifying assumptions:

(i) The heat conduction is one-dimensional, in the direction perpendicular to the wall plane. This is a reasonable assumption as the width and height of the wall are typically much greater than the wall thickness. However, this assumption ignores edge effects such as corners and wall-slab joints. It also ignores thermal bridges which require separate treatment, e.g. using a “parallel path” technique.

(ii) Both surfaces of the wall are isothermal.

(iii) The material layers are homogeneous and of uniform thickness.

(iv) The thermal properties of the materials are constant. This assumption ignores temperature related variations in thermal properties of building materials. However, these variations are negligible in the expected range of temperatures.

Based on these assumptions, the general equation for one-dimensional heat conduction in building elements is:

$$\partial^2 T / \partial x^2 = (1 / \alpha)\,(\partial T / \partial t) \tag{1}$$

with

$\alpha = k / (\rho\, c_p)$

where

T – temperature (a function of position and time),
x – position,
t – time,
α – thermal diffusivity of the layer material,
k – thermal conductivity
ρ – density
c_p – specific heat

The heat flux, q at any position and time is related to temperature by Fourier’s law of conduction:

$$q_{x,t} = - k (\partial T_{x,t} / \partial x) \quad (2)$$

Equations 1 and 2 can readily be solved analytically for a single material layer, but the solution becomes extremely difficult for multi-layer constructions as it requires special mathematic functions and complex algebra (Iu and Fisher, 2004).

However, various numerical methods have been developed for modelling heat conduction in multi-layer building elements. Some of the methods for modelling this process are:

(i) Finite difference – used mainly for 3-dimensional problems, or when internal node temperatures are of interest, e.g. when phase change materials are embedded in the wall. Accurate but slower than time series methods.

(ii) Finite element – used mainly for odd shapes, e.g. for corners or thermal bridges. Accurate but slower than other methods

(iii) Z-Transform methods – used mainly for research purposes.

(iv) Frequency response – a simplified procedure for determining a cyclical response to a periodic pattern of external variations, e.g. the Admittance Method advocated by the UK Chartered Institute of Building Services Engineers.

(v) Conduction transfer functions (CTFs) – this method determines the heat flux at either surface of the wall from the current and some of the previous surface temperatures and from some of the previous heat flux values at the surface in question. Uses a linear equation with CTF coefficients that need to be determined only once for a given wall construction. Suitable for any pattern of external and internal variations, including hourly and daily changes in weather parameters. A fast and accurate method.

(vi) Periodic response factors (PRFs) – a special case of CTFs, where the daily pattern of external and internal variations repeats itself for a number of 24-hour cycles preceding the current day. The heat flux at the internal wall surface is a linear function, with PRF coefficients, of the current and past temperatures only. A fast and accurate method.

3. TIME SERIES SOLUTIONS: CTFs AND PRFs

The time series solutions, CTFs and PRFs, have been widely applied in major building energy software packages.

A general time series solution relates the heat flux at one surface of an element to an infinite series of temperature histories at both sides as shown by the response factor equation (Pedersen 2001):

$$q_{e,t} = \sum_{j=0}^{\infty} X_j T_{e,t-j\delta} - \sum_{j=0}^{\infty} Y_j T_{i,t-j\delta} \qquad (3)$$

where

q – heat flux
T – temperature
t – time
δ – time interval
X, Y – response factors
e – external surface
i – internal surface

The higher order temperature terms can be replaced by heat flux history terms to obtain the following basic form of a CTF solution (Pedersen 2001):

For the outside surface:

$$q_{e,t} = H_e + X_0\,T_{e,t} - Y_0\,T_{i,t} \tag{4}$$

with

$$H_e = \sum_{j=1}^{nx} X_j\,T_{e,t-j\delta} - \sum_{j=1}^{ny} Y_j\,T_{i,t-j\delta} + \sum_{j=1}^{nq} \Phi_j\,q_{e,t-j\delta} \tag{5}$$

For the inside surface:

$$q_{i,t} = H_i + Y_0\,T_{e,t} - Z_0\,T_{i,t} \tag{6}$$

with

$$H_i = \sum_{j=1}^{ny} Y_j\,T_{e,t-j\delta} - \sum_{j=1}^{nz} Z_j\,T_{i,t-j\delta} + \sum_{j=1}^{nq} \Phi_j\,q_{i,t-j\delta} \tag{7}$$

where

q – heat flux
T – temperature
t – time
δ – time interval
Xj – Outside CTF coefficient, j = 0, 1,
nx Yj – Cross CTF coefficient, j = 0, 1,
ny Zj – Inside CTF coefficient, j = 0, 1,
nz Φj – Flux CTF coefficient, j = 1, 2, ..., nq
e – external surface
i – internal surface

It can be seen from equations 4 and 6 that the heat fluxes at the current hour are linearly related to the current surface temperatures, with CTF coefficients X, Y, Z, and the history terms H_e and H_i as constants for the current hour. Equations 5 and 7 show that the history terms contain previous temperatures on both surfaces as well as the previous heat fluxes on the surface being considered.

As the previous heat fluxes are initially unknown, equations 4 and 5 or 6 and 7 have to be solved iteratively. However, as the calculations proceed to the next hour on an hour-by-hour basis, as is the case with an annual energy simulation, the previous heat fluxes have already been calculated and no further iterations are required.

The following quotations from ASHRAE Loads Toolkit (Pedersen 2001) summarize some of the advantages of the CTF method:

> "The final CTF solution form reveals why it is so elegant and powerful. With a single, relatively simple, linear equation with constant coefficients, the conduction heat transfer through an element can be calculated. The coefficients (CTFs) in the equation are constants that only need to be determined once for each construction type. The only storage of data required are the CTFs themselves and a limited number of temperature and
> flux terms. The formulation is valid for any surface type and does not require the calculation or storage of element interior temperatures."

> "The largest advantage of the time series approach is its speed. Whereas a finite difference solution will have many nodes to calculate at small time steps, the times series approach only has to calculate the temperature or flux at the points of interest, the inside and outside faces of the surface. In addition, these calculations only have to be done at very reasonable time steps such as an hour. This significantly reduces the time required
> to simulate the conduction components of the heat balance with little loss of generality."

Conclusion: In view of the abovementioned advantages, the CTF method, and the related to it PRF method (see Section 4), can be considered the most suitable methods for computer based calculations of unsteady-state heat conduction through multi-layer wall constructions.

4. CTFs or PRFs?

As mentioned earlier, the PRF method is a special case of the CTF method, and for a given construction, the PRFs can be computed directly from the CTF coefficients according to an algorithm described by Iu and Fisher (2004) or using the PRF Generator software developed by

Iu (2001).

The CTF method is suitable for calculating heat conduction through walls with any pattern, however irregular, of external and internal variations, including hourly and daily changes in weather parameters.

The PRF method is only suitable for a daily pattern of external and internal variations which repeats itself for a number of 24-hour cycles preceding the current day. There is however no restriction with this method regarding the shape or form of the daily pattern, as the method can handle any daily pattern, however irregular.

During an annual energy simulation, the outdoor thermal environment changes continuously on an hourly and daily basis due to the following effects:

(i) Hourly changes of ambient temperature;
(ii) Hourly, often irregular, changes of diffuse solar radiation due to variations in cloud cover;
(iii) Hourly, often irregular, changes of direct solar radiation reaching the wall due to changes in sun's position, variations in cloud cover and effects of external shading;
(iv) Hourly changes of wind speed;
(v) Daily changes in all abovementioned parameters.

In addition, there may also be day-to-day variations in the indoor environment due to variations in usage patterns or in internal heat gains.

Due to these day-to-day variations, it is the CTF method that should be used for an annual energy simulation.

On the other hand, a heating or cooling load computation is done on a "design day" which is assumed to be the same for a number of 24-hour cycles preceding the design day. The PRF method is therefore perfectly suitable for these cases.

The PRFs, when presented in a dimensionless form, called Conduction Time Series (CTS), provide a useful, easy to understand representation of the time related thermal performance of the wall. Each of these hourly factors indicate the heat flux at the inside wall surface as a percentage of the initial heat flux pulse of one hour duration at the outside surface. The sum of all 24 factors must add up to 100%.

CTS factors can be obtained from PRFs from:

$$F_{CTS} = F_{PRF} / U \quad (8)$$

where

F_{CTS} – CTS factor
F_{PRF} – PRF (Periodic response factor)
U – Transmittance of the wall

Examples of CTS factors for three different wall constructions are shown in Table 1 and in Figure 1. These factors were calculated using an internal routine of Bsimac 9 software (Johannsen, 2011), and were confirmed using the PRF Generator (Iu 2001).

Table 1: Conduction time series factors for three wall constructions

Hour	110mm face brick, 50mm gap, 110mm common brick	110mm face brick, 30mm Isoboard, 110mm common brick	15mm wood siding, 50 mm fibreglass board 12 mm gypsum board
1	0.57%	1.15%	26.23%
2	1.08%	1.25%	60.32%
3	3.91%	2.61%	11.91%
4	7.23%	4.69%	1.36%
5	9.10%	6.29%	0.15%
6	9.64%	7.20%	0.02%
7	9.37%	7.56%	0.00%
8	8.68%	7.54%	0.00%
9	7.79%	7.26%	0.00%
10	6.86%	6.84%	0.00%
11	5.96%	6.34%	0.00%
12	5.13%	5.79%	0.00%
13	4.39%	5.24%	0.00%
14	3.74%	4.71%	0.00%
15	3.17%	4.21%	0.00%
16	2.68%	3.74%	0.00%
17	2.26%	3.31%	0.00%
18	1.91%	2.92%	0.00%
19	1.61%	2.57%	0.00%
20	1.35%	2.25%	0.00%
21	1.14%	1.97%	0.00%
22	0.96%	1.73%	0.00%
23	0.80%	1.51%	0.00%
24	0.67%	1.31%	0.00%
Total	100.00%	100.00%	100.00%

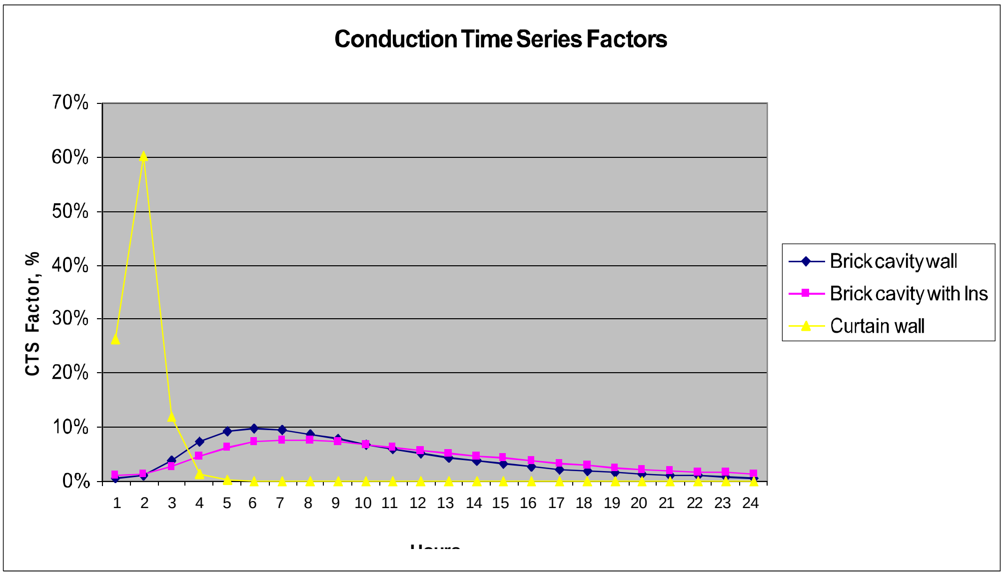

Figure 1: Conduction time series factors for three wall constructions

It can be seen from Table 1 and Figure 1 that the curtain wall responds very rapidly to an initial heat flux pulse of one hour duration at hour 1 on the outside of the wall. A peak heat flux on the inside of the wall occurs at hour 2 and amounts to 60.3% of the initial heat input. Within the first two hours, some 87% of the heat input has been transferred to the inside, and within the first three hours almost all (98.5%) has been transferred.

The brick walls' response is very much slower and it is spread over the entire 24-hour cycle. The peak for the uninsulated cavity wall is 9.6% and occurs at hour 6. For the insulated cavity wall the peak is only 7.56% and occurs at hour 7. At hour 24, the residual heat flux values are 0.67% and 1.31% for the uninsulated and insulated walls respectively.

It is interesting to note that the heat flux at hour 1 is 1.15% for the insulated wall and only 0.57% for the uninsulated one. This, somewhat surprising result, can be explained by the fact that the effects of the initial heat pulse still continue to be felt beyond hour 24 for the two brick walls, but more so for the insulated wall. As this is a 24-hour cycle, the values for the hours following hour 24 are automatically 'wrapped around' (in accordance with the definition of PRFs) and added to the initial hours, i.e. the value at hour 25 is added to hour 1, the value at hour 26 is added to hour 2, and so on. The values for the hours after hour 24 are not shown here, but are higher for the uninsulated wall, which explains why the values for the initial hours are also higher for this wall.

5. CALCULATION OF CTF COEFFICIENTS

The ASHRAE Loads Toolkit (Pedersen et al. 2001) presents two methods for calculating CTF coefficients, the State Space method (Ceylan and Myers 1980; Seem 1987; Ouyang and Haghighat 1991) and the Laplace method (Hittle 1979, 1983). These methods offer similar accuracy, but the State Space methods offers the ability to use time steps shorter than one hour and the ability to model 2- and 3-dimensional heat conduction problems. Fortran 90 source code for these methods is included in the ASHRAE Loads Toolkit.

The two calculation methods have been extensively tested against each other, against the finite difference method, and against analytical solutions for single-layer constructions. These tests have shown that the accuracy of the solution is adequate for the purpose of modelling energy usage in buildings.

6. SOFTWARE PACKAGES CERTIFIED BY AGRÉMENT SOUTH AFRICA

The two software packages that have been certified by Agrément South Africa in terms of SANS 10400-XA are:

(i) DesignBuilder Version 3.1

(ii) BSIMAC Version 9

6.1 DesignBuilder Version 3.1

The DesignBuilder is essentially a user interface for the US Department of Energy EnergyPlus software. The DesignBuilder uses the EnergyPlus engine for all its calculations (US Department of Energy 2012).

The EnergyPlus software includes a comprehensive Engineering Reference – The Reference to EnergyPlus Calculations, which provides detailed descriptions of the entire package with the individual modules, and describes the theoretical background and modeling techniques employed in the various modules.

EnergyPlus offers a free 'Open source license' which allows one to obtain EnergyPlus source code, modify it, combine it with other software that is licensed under different terms, distribute it, and re-license it. Based on this license it was possible to obtain and examine the Fortran 90 source code for the 'ConductionTransferFunctionCalc' module used in EnergyPlus Version 7.2 for calculating the CTF coefficients.

The module is essentially the same as the CTF module included in the ASHRAE Loads Toolkit. It uses the State Space method to calculate the CTF coefficients in accordance with a procedure proposed by Seem (1987), with additional options to consider 2-D geometries, and to use time steps other than 1-hour.

The CTF coefficients are determined in EnergyPlus for the wall construction itself, without the surface film resistances. These resistances are considered separately as part of the outside and inside surfaces heat balance.

Thermal bridges are considered in EnergyPlus as separate wall constructions if they can be modelled as a 1-D system. For more complex geometries, their U-values are calculated using a manual procedure or a stand-alone software, and these U-values are used as input to EnergyPlus.

Conclusion: Based on the above, it can be concluded that DesignBuilder Version 3.1 implements fully the CTF method for calculating unsteady-state heat conduction through multi-layer wall constructions and can therefore be considered suitable for the CBA project.

6.2 BSIMAC Version 9

BSIMAC 9 is a South African building energy analysis software for simulating the annual energy consumption and for determining design cooling and heating loads. The writer has access to the source code of BSIMAC.

The heat conduction through walls for annual energy simulation is calculated in BSIMAC using the CTF method, with the CTF coefficients determined with the State Space method according to Seem (1987).

The CTF module in BSIMAC for calculating the CTF coefficients is a Visual Basic version of the Fortran 90 'ConductionTransferFunctionCalc' module used in EnergyPlus Version 7.2. The only difference in the code is a modification to the discretization formula for determining the number of nodes in a material layer, as shown below.

$$\Delta x = \sqrt{C \alpha \delta t}$$

where

Δx – distance between nodes
C – discretization constant, in EnergyPlus: C = 2, in BSIMAC: C = 0.4
α– thermal diffusivity
δt – time step

With a lower constant C, the distance between nodes becomes smaller, and the number of nodes is increased for greater accuracy. This only affects thick material layers with high thermal mass, such as brick or heavy concrete layers thicker than about 200 mm. The minimum and maximum number of nodes per layer in BSIMAC are still the same as in EnergyPlus, namely 6 and 19, respectively.

The CTF coefficients are determined in BSIMAC for the wall construction including the surface film resistances. The boundary conditions used during the simulation are the sol-air temperature on the outside and the room temperature on the inside.

The outside film resistance is based on a correlation taken from Figure 1, Page 24.1, ASHRAE Handbook of Fundamentals (ASHRAE 1997). The wind speed used in the correlation is the design value for the locality of the building, and the roughness of the surface is a user-selected value dependent on the surface finish.

The inside film resistance is based on a correlation taken from Table 1, Page 24.2, ASHRAE Handbook of Fundamentals (ASHRAE 1997), which allows for variable emittance of the surface.

The heat conduction through walls for cooling and heating loads is calculated in BSIMAC using the PRF method, with the PRF coefficients for a given wall determined from the CTF coefficients using an internal BSIMAC routine. The working of this routine has been checked using the PRF Generator software (Iu 2001).

A comparison of CTS factors calculated by BSIMAC and by the PRF Generator for a cavity brick wall is shown in Table 2. The CTS factors are shown instead of the PRFs (see Equation 8) as they provide a more intuitive view of the performance of the wall.

Table 2: Conduction time series factors calculated by BSIMAC and PRF Generator for a brick cavity wall: 110mm face brick, 50mm air gap, 110mm common brick

Hour	Calculated by BSIMAC	Calculated by PRF Generator	Ratio: BSIMAC / PRF Generator
1	0.57%	0.57%	1.00332
2	1.08%	1.09%	0.99064
3	3.91%	3.94%	0.99199
4	7.23%	7.26%	0.99523
5	9.10%	9.12%	0.99756
6	9.64%	9.65%	0.99932
7	9.37%	9.38%	0.99938
8	8.68%	8.68%	0.99969
9	7.79%	7.79%	1.00047
10	6.86%	6.86%	1.00050
11	5.96%	5.96%	1.00064
12	5.13%	5.13%	1.00074
13	4.39%	4.38%	1.00226
14	3.74%	3.73%	1.00153
15	3.17%	3.16%	1.00249
16	2.68%	2.67%	1.00352
17	2.26%	2.25%	1.00529
18	1.91%	1.90%	1.00356
19	1.61%	1.60%	1.00356
20	1.35%	1.35%	1.00081
21	1.14%	1.13%	1.00548
22	0.96%	0.95%	1.00532
23	0.80%	0.80%	1.00316
24	0.67%	0.67%	1.00627
Total	100.00%	100.00%	

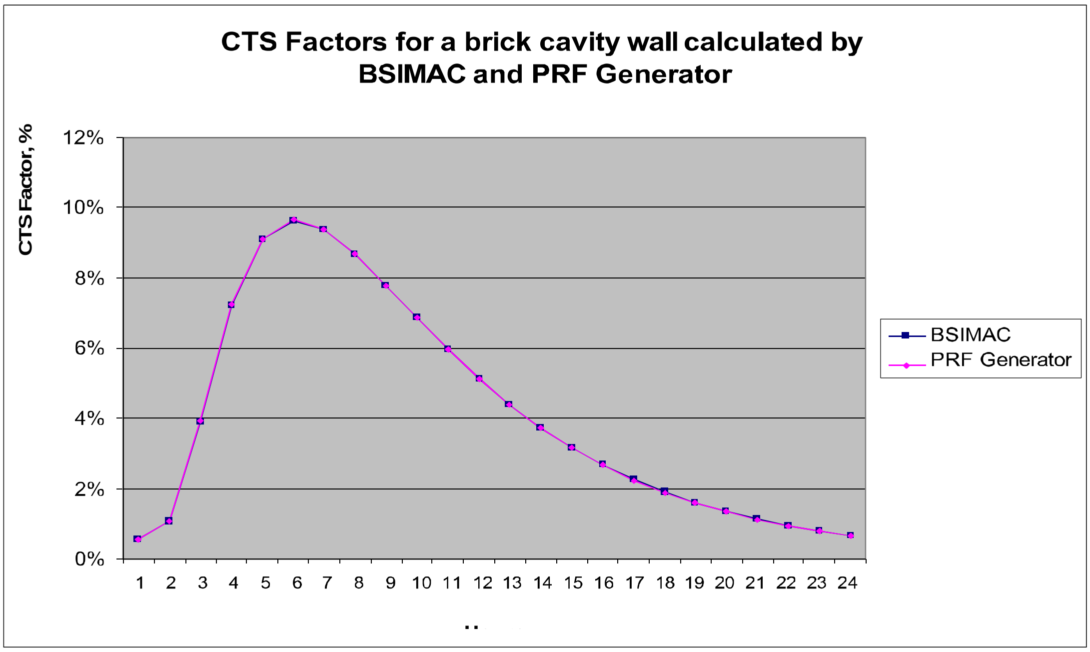

Figure 2: A comparison of CTS factors calculated by BSIMAC and PRF Generator

It can be seen from Figure 2 that the two curves are virtually identical which confirms that there is a close agreement between the CTS factors calculated by BSIMAC and those calculated by the PRF Generator.

Thermal bridges are considered in BSIMAC in the same way as in EnergyPlus, i.e. they are treated as separate wall constructions if they can be modelled as a 1-D system. For more complex geometries, their U-values are calculated using a manual procedure or a stand-alone software, and these U-values are then used as input to BSIMAC.

Conclusion: Based on the abovementioned information, it can be concluded that BSIMAC Version 9 implements fully the CTF method for calculating unsteady-state heat conduction through multi-layer wall constructions and can therefore be considered suitable for the CBA project.

7. ECOTECT SOFTWARE

The only information that we could find on the calculation methods used in Ecotect software were two items on Ecotect website (shown below) indicating that Ecotect uses the Admittance method for calculating cooling and heating loads:

Results for Admittance method

Admittancemethod

Results from Autodesk.com / Support / Ecotect Analysis load calculations

Ecotect Analysis load calculations ID: TS14587669 Issue You want to know how Ecotect Analysis calculates loads. Solution Ecotect Analysis calculates loads based on the widely used CIBSE Admittance method (ISO13792-2005).
http://usa.autodesk.com/adsk/servlet/ps/dl/item?id=14587669&linkID=13734494&siteID=1231 12

Published: 2010-Feb-18 Category: Knowledge Base

Validation of Ecotect Analysis results

) Tests for Software Verification and Accreditation'. Solar access and rights-to-light calculations conform to the 'BRE Site Planning Handbook'.

Ecotect Analysis's specific use of the admittance method is based on 'ISO 13791:2004 Thermal performance
http://usa.autodesk.com/adsk/servlet/ps/dl/item?id=14576143&linkID=13734494&siteID=1231 12

Published: 2010-Feb-17 Category: Knowledge Base

A brief description of the Admittance method is given below (CIBSE 1986, Rees *et al*. 2000).

The Admittance method is a frequency response method for calculating a cyclical response to a periodic pattern of external variations.

The outside boundary conditions are assumed to fluctuate sinusoidally in a 24-hour cycle.

The reference point for the indoor condition is the Environmental Temperature, which is used to calculate the combined radiant and convective heat exchange with the room surfaces. The environmental temperature lies between the room air and mean surface temperatures and is approximately 1/3*Ta* + 2/3*Tm*, where *Ta* is the air temperature and *Tm* is the mean surface temperature.

The cooling loads calculation procedure is split into the mean component and fluctuating component as shown diagrammatically in Figure 3 below (Rees *et al*. 2000).

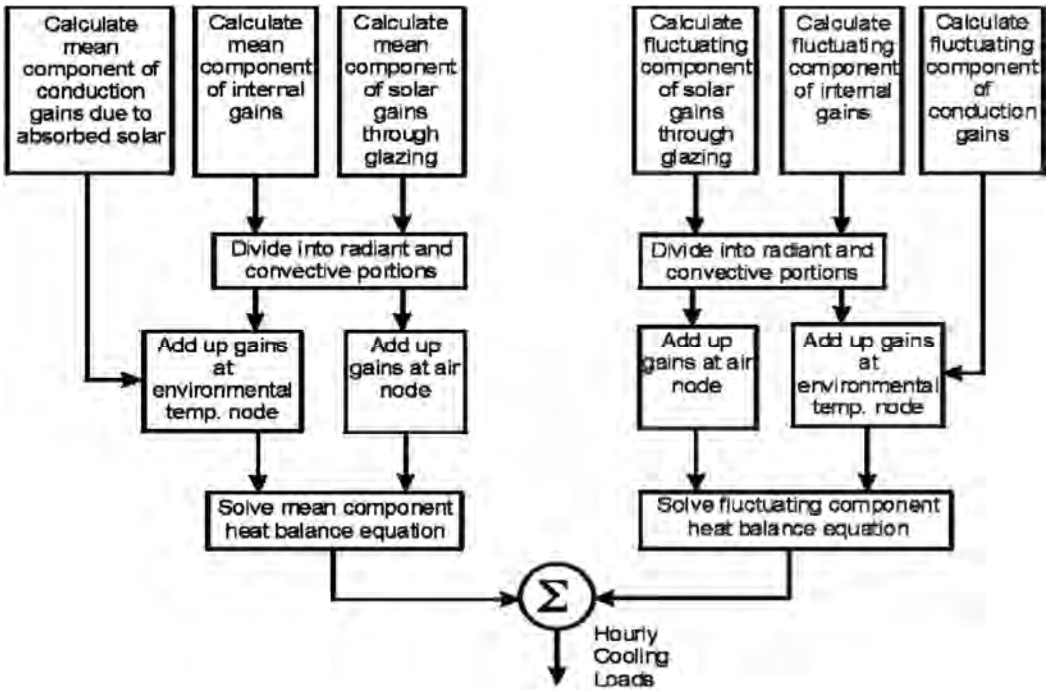

Figure 3: A diagram of the CIBSE Admittance cooling load calculation method

The mean and fluctuating components of the cooling load, shown in the left and right hand side of the diagram, respectively, are calculated separately for each hour and then added up to obtain the hourly cooling loads.
The fluctuating component of the conduction heat gain through the wall is determined by the decrement factor *f*, the admittance *A*, and the surface factor *F* (Rees *et al*. 2000). Each of these has a time lead/lag associated with it. The values of these quantities are derived from the thermophysical properties of the wall layers using a frequency domain solution to the unsteady conduction heat transfer equation, assuming that the fluctuating temperatures and heat fluxes can be defined by sinusoidal functions with a 24-hour period. The derivation of these quantities is given in Milbank and Harrington-Lynn (1974).

Solar heat gains are treated by one of two methods, both of which rely on tabulated data, and have been historically developed for manual calculations. As concluded by Rees *et al*. (2000), “these methods are very simplified by current standards and cannot be expected to give accurate results except in a limited range of circumstances.”

In the context of this review, a key assumption of the Admittance method, related to the heat conduction through walls, is that variations in the outdoor thermal environment have a sinusoidal, 24-hour cyclic pattern, and that this pattern repeats itself for a number of days preceding the current day.

As stated in Section 4 (items (i) to (v)), during an annual energy simulation, the outdoor thermal environment changes continuously on an hourly and daily basis. These variations can be highly irregular, far removed from the sinusoidal pattern assumed in the Admittance method.

Conclusion: Based on the general principles of the Admittance method, it can be seen that a key assumption of this method, related to the heat conduction through walls, is generally not valid during an annual energy simulation. It therefore appears that Ecotect software, which is said to be based on the Admittance method, is not suitable for the CBA project. It should however be emphasized that this conclusion may not be correct, as information on the internal working of Ecotect software could not be obtained.

8. CONCLUSIONS

Based on the current review, the following conclusions can be drawn.

8.1. In view of its advantages over other calculating methods, the CTF method, can be considered the most suitable methods for computer based calculations of unsteady-state heat conduction through multi-layer wall constructions in annual energy simulation of buildings.

8.2. For calculating design cooling and heating loads, the PRF method, which is a special case of the CTF method (see Section 4), is preferred.

8.3. For calculating CTF coefficients, the State Space method is preferred in view of its simplicity and certain computational advantages.

8.4. Both software packages that have been certified by Agrément South Africa in terms of SANS 10400-XA, namely DesignBuilder Version 3.1 and BSIMAC Version 9, fully implement the CTF method and can therefore be considered suitable for the CBA project.

8.5. It appears that Ecotect, which is said to be based on the Admittance method, is not suitable for the CBA project. It should however be emphasized that this conclusion may not be correct, as information on the internal working of Ecotect software could not be obtained.

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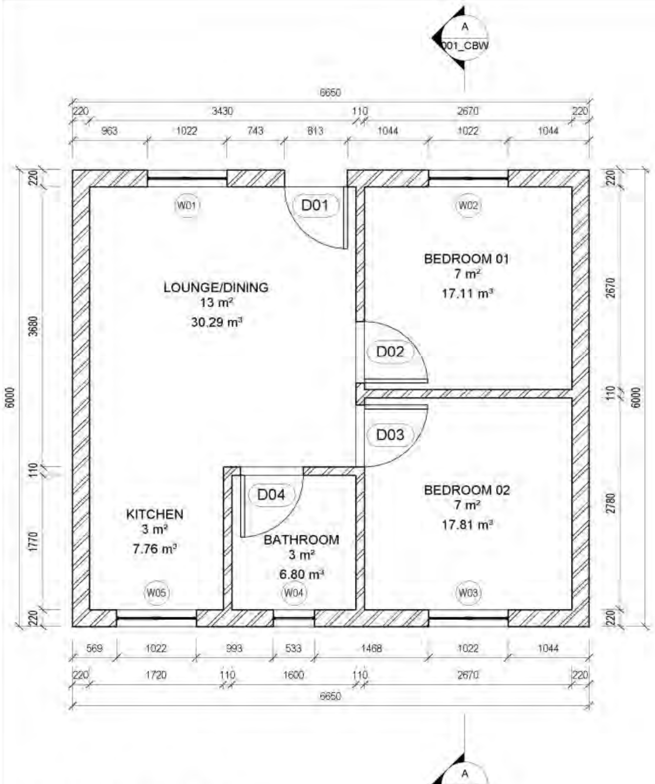
Appendix B: A standardised 40m^2 residential building design

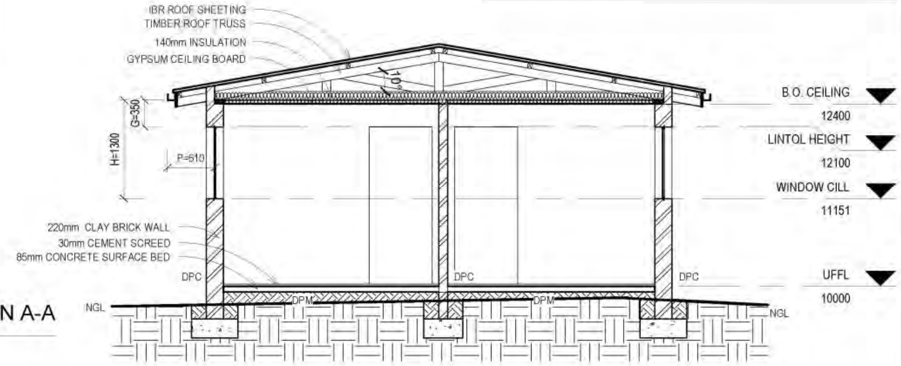
A standardised energy usage modelling of a 40m^2 residential building design

The standardised design of the 40m^2 residential building has been developed from a design which has been derived from earlier 53m^2 NE51/6 an NE51/9 series of house design which had been used in other research in the past done by the CSIR and for the Department of Housing/Human Settlements as input to the development of the SANS 204; Energy Efficiency in building standards development process.



PLAN_Ground Floor

1 : 50



SECTION A-A

1 : 50

NOTES:
1. GROSS FLOOR AREA = 40.00m²
2. NETT FLOOR AREA = 33.24m²
3. TOTAL INTERNAL VOLUME = 79.77m³

4. EXPOSED SURFACE AREA ENVELOPE (windows & doors subtracted):
EXTERNAL SURFACE ENVELOPE = 54.78m²
INTERNAL SURFACE ENVELOPE = 49.50m²

5. INTERNAL PARTITION / WALL
TOTAL LENGTH = 12.26m
TOTAL SURFACE = 24.30m² (openings & doors subtracted)

6. FENESTRATION
NORTH ELEVATION = 1.919m²
EAST ELEVATION = 0m²
SOUTH ELEVATION = 2.288m²
WEST ELEVATION = 0m²

WINDOW SCHEDULE:
W1 1.022 x 0.949 = 0.970m²
W2 1.022 x 0.949 = 0.970m²
W3 1.022 x 0.949 = 0.970m²
W4 0.533 x 0.654 = 0.349m²
W5 1.022 x 0.949 = 0.970m²
STEEL FRAMED WITH 4mm CLEAR FLOAT GLASS

DOOR SCHEDULE:
FRONT DOOR 0.813 x 2.1= 1.707m²
INTERNAL DOOR 0.813 x 2.1= 1.707m²
SOLID TIMBER DOOR FRAME AND DOOR

NO INSULATION UNDER CONCRETE SURFACE BED
CEILING HAS 140mm THICK MINERAL WOOL INSULATION

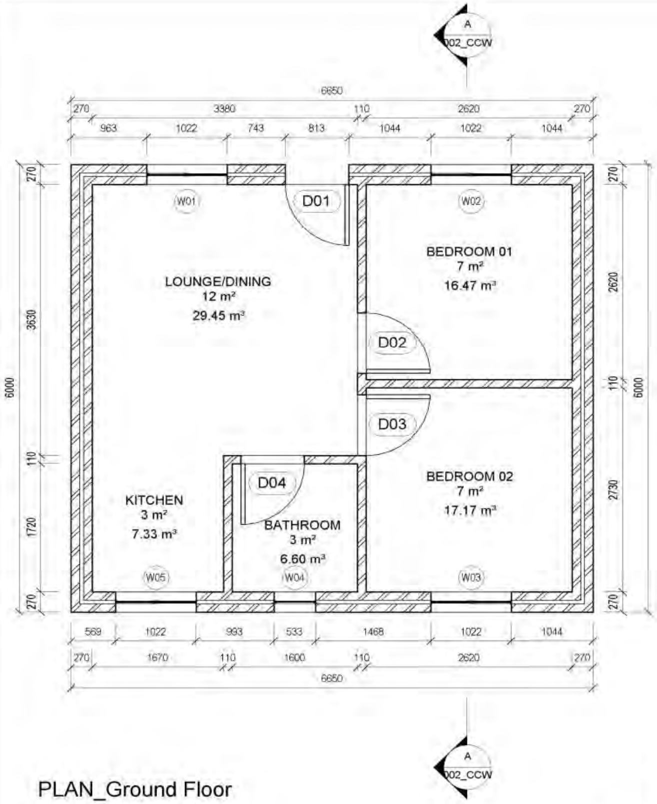
consultant:

220mm CLAY BRICK EXTERNAL ENVELOPE

Residential Building

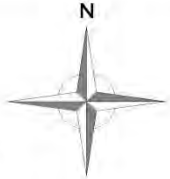
PLAN & SECTION

Project number:	1301_Rev00	Drawing number:	
Date:	2014/11/01	001_CBW	
Drawn by:	NvR		
Checked by:	NvR	Scale:	1 : 50



PLAN_Ground Floor

1 : 50



NOTES:

1. GROSS FLOOR AREA = 40.00m²
2. NETT FLOOR AREA = 32.09m²
3. TOTAL INTERNAL VOLUME = 77.03m³

4. EXPOSED SURFACE AREA ENVELOPE (windows & doors subtracted):
   - EXTERNAL SURFACE ENVELOPE = 54.78m²
   - INTERNAL SURFACE ENVELOPE = 48.54m²

5. INTERNAL PARTITION / WALL
   - TOTAL LENGTH = 12.19m
   - TOTAL SURFACE = 24.13m² (openings & doors subtracted)

6. FENESTRATION
   - NORTH ELEVATION = 1.919m²
   - EAST ELEVATION = 0m²
   - SOUTH ELEVATION = 2.288m²
   - WEST ELEVATION = 0m²

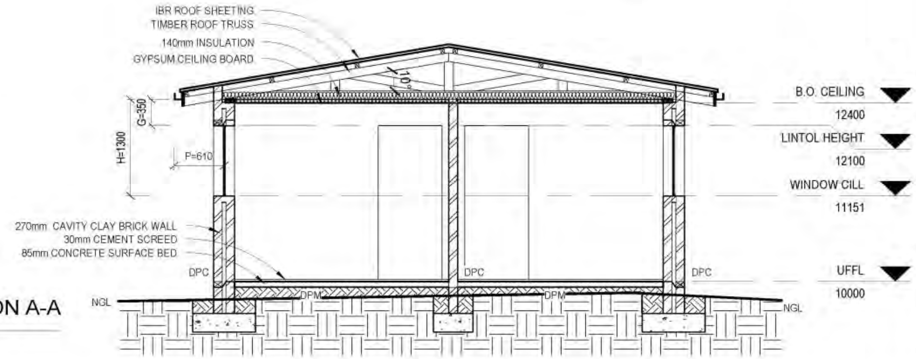
WINDOW SCHEDULE:

W1 1.022 x 0.949 = 0.970m²
W2 1.022 x 0.949 = 0.970m²
W3 1.022 x 0.949 = 0.970m²
W4 0.533 x 0.654 = 0.349m²
W5 1.022 x 0.949 = 0.970m²
STEEL FRAMED WITH 4mm CLEAR FLOAT GLASS

DOOR SCHEDULE:

FRONT DOOR 0.813 x 2.1= 1.707m²
INTERNAL DOOR 0.813 x 2.1= 1.707m²
SOLID TIMBER DOOR FRAME AND DOOR

NO INSULATION UNDER CONCRETE SURFACE BED
CEILING HAS 140mm THICK MINERAL WOOL INSULATION



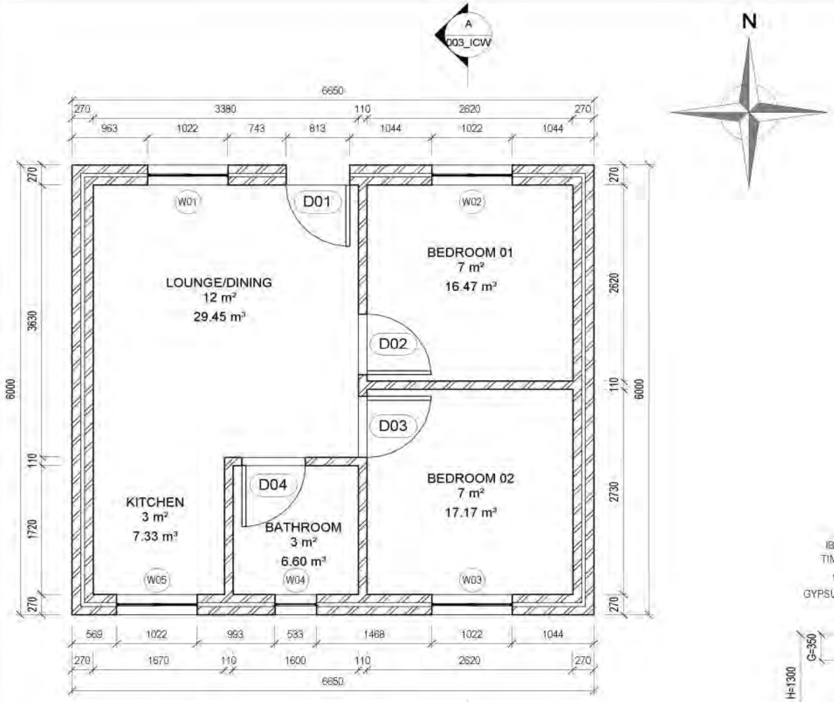
SECTION A-A

1 : 50

consultant:

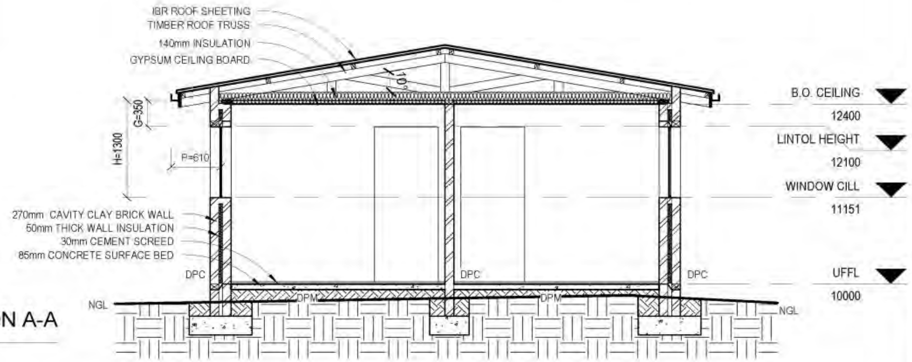
UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

270mm CAVITY CLAY BRICK EXTERNAL ENVELOPE Residential Building	PLAN & SECTION			
	Project number:	1301_Rev00	Drawing number:	
	Date:	2014/11/01		002_CCW
	Drawn by:	NvR		
	Checked by:	NvR	Scale:	1 : 50



PLAN_Ground Floor

1 : 50



SECTION A-A

1 : 50

NOTES:
1. GROSS FLOOR AREA = 40.00m²
2. NETT FLOOR AREA = 32.09m²
3. TOTAL INTERNAL VOLUME = 77.03m³

4. EXPOSED SURFACE AREA ENVELOPE (windows & doors subtracted):
EXTERNAL SURFACE ENVELOPE = 54.78m²
INTERNAL SURFACE ENVELOPE = 48.54m²

5. INTERNAL PARTITION / WALL
TOTAL LENGTH = 12.19m
TOTAL SURFACE = 24.13m² (openings & doors subtracted)

6. FENESTRATION
NORTH ELEVATION = 1.919m²
EAST ELEVATION = 0m²
SOUTH ELEVATION = 2.577m²
WEST ELEVATION = 0m²

WINDOW SCHEDULE:
W1 1.022 x 0.949 = 0.970m²
W2 1.022 x 0.949 = 0.970m²
W3 1.022 x 0.949 = 0.970m²
W4 0.533 x 0.654 = 0.349m²
W5 1.022 x 0.949 = 0.970m²
STEEL FRAMED WITH 4mm CLEAR FLOAT GLASS

DOOR SCHEDULE:
FRONT DOOR 0.813 x 2.1= 1.707m²
INTERNAL DOOR 0.813 x 2.1= 1.707m²
SOLID TIMBER DOOR FRAME AND DOOR

NO INSULATION UNDER CONCRETE SURFACE BED
CEILING HAS 140mm THICK MINERAL WOOL INSULATION

consultant:

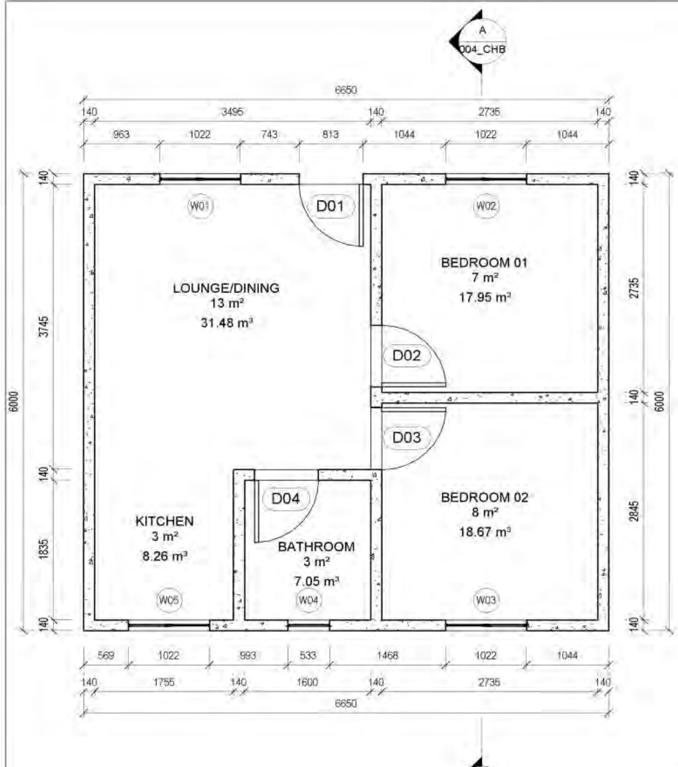
UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

280mm INSULATED CAVITY CLAY BRICK EXTERNAL ENVELOPE

Residential Building

PLAN & SECTION

Project number:	1301_Rev00	Drawing number:	
Date:	2014/11/01	003_ICW	
Drawn by:	NvR		
Checked by:	NvR	Scale:	1 : 50



PLAN_Ground Floor

1 : 50

NOTES:
1. GROSS FLOOR AREA = 40.00m²
2. NETT FLOOR AREA = 34.75m²
3. TOTAL INTERNAL VOLUME = 83.41m³

4. EXPOSED SURFACE AREA ENVELOPE (windows & doors subtracted):
EXTERNAL SURFACE ENVELOPE = 54.78m²
INTERNAL SURFACE ENVELOPE = 50.75m²

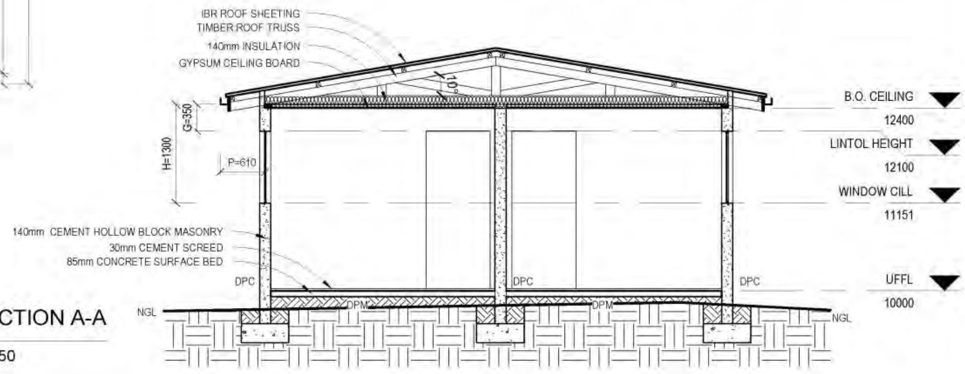
5. INTERNAL PARTITION / WALL
TOTAL LENGTH = 12.19m
TOTAL SURFACE = 24.13m² (openings & doors subtracted)

6. FENESTRATION
NORTH ELEVATION = 1.919m²
EAST ELEVATION = 0m²
SOUTH ELEVATION = 2.577m²
WEST ELEVATION = 0m²

WINDOW SCHEDULE:
W1 1.022 x 0.949 = 0.970m²
W2 1.022 x 0.949 = 0.970m²
W3 1.022 x 0.949 = 0.970m²
W4 0.533 x 0.654 = 0.349m²
W5 1.022 x 0.949 = 0.970m²
STEEL FRAMED WITH 4mm CLEAR FLOAT GLASS

DOOR SCHEDULE:
FRONT DOOR 0.813 x 2.1= 1.707m²
INTERNAL DOOR 0.813 x 2.1= 1.707m²
SOLID TIMBER DOOR FRAME AND DOOR

NO INSULATION UNDER CONCRETE SURFACE BED
CEILING HAS 140mm THICK MINERAL WOOL INSULATION



SECTION A-A

1 : 50

consultant:

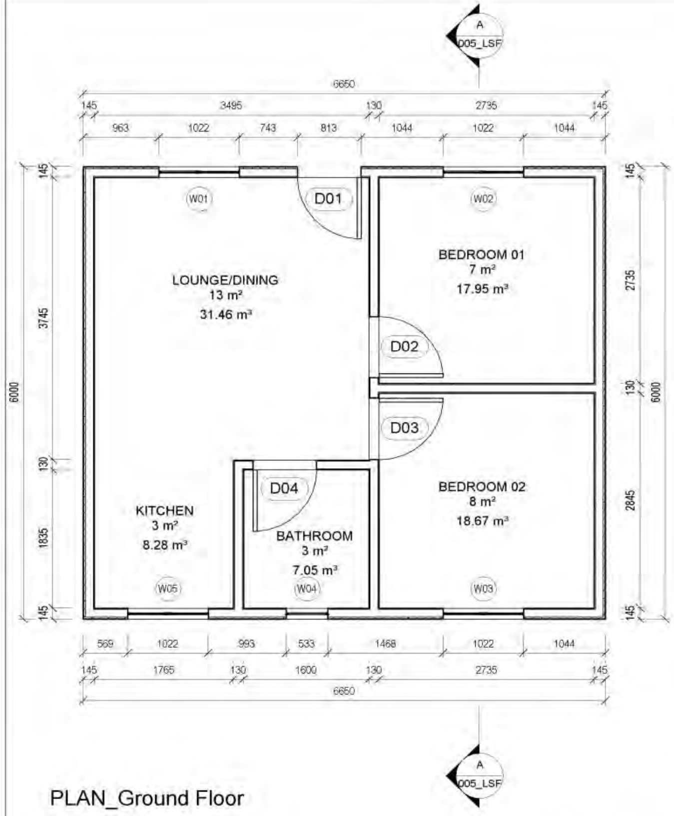
UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

140mm CONCRETE HOLLOW BLOCK EXTERNAL ENVELOPE

Residential Building

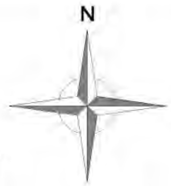
PLAN & SECTION

Project number:	1301_Rev00	Drawing number:	
Date:	2014/11/01		004_CHB
Drawn by:	NvR		
Checked by:	NvR	Scale:	1 : 50



PLAN_Ground Floor

1 : 50



NOTES:
1. GROSS FLOOR AREA = 40.00m²
2. NETT FLOOR AREA = 34.75m²
3. TOTAL INTERNAL VOLUME = 83.41m³

4. EXPOSED SURFACE AREA ENVELOPE (windows & doors subtracted):
EXTERNAL SURFACE ENVELOPE = 54.78m²
INTERNAL SURFACE ENVELOPE = 50.75m²

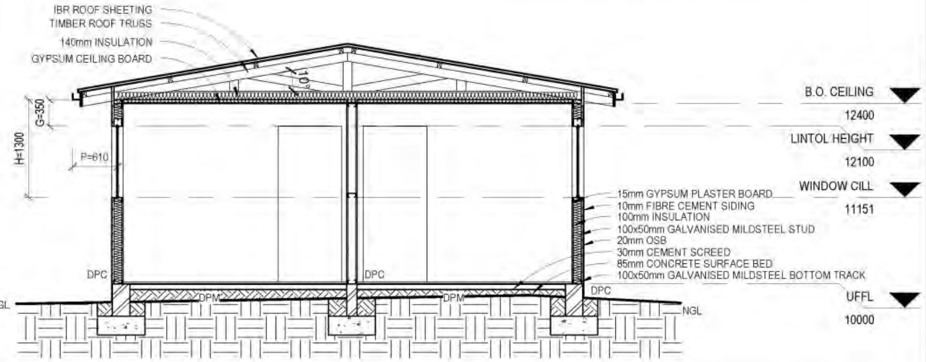
5. INTERNAL PARTITION / WALL
TOTAL LENGTH = 12.43m
TOTAL SURFACE = 24.71m² (openings & doors subtracted)

6. FENESTRATION
NORTH ELEVATION = 1.919m²
EAST ELEVATION = 0m²
SOUTH ELEVATION = 2.288m²
WEST ELEVATION = 0m²

WINDOW SCHEDULE:
W1 1.022 x 0.949 = 0.970m²
W2 1.022 x 0.949 = 0.970m²
W3 1.022 x 0.949 = 0.970m²
W4 0.533 x 0.654 = 0.349m²
W5 1.022 x 0.949 = 0.970m²
STEEL FRAMED WITH 4mm CLEAR FLOAT GLASS

DOOR SCHEDULE:
FRONT DOOR 0.813 x 2.1= 1.707m²
INTERNAL DOOR 0.813 x 2.1= 1.707m²
SOLID TIMBER DOOR FRAME AND DOOR

NO INSULATION UNDER CONCRETE SURFACE BED
CEILING HAS 140mm THICK MINERAL WOOL INSULATION



SECTION A-A

1 : 50

consultant:

UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

CLAYBRICK

145mm LIGHT STEEL FRAME
EXTERNAL ENVELOPE

Residential Building

PLAN & SECTION

Project number:	1301_Rev00	Drawing number:	
Date:	2014/11/01		005_LSF
Drawn by:	NvR		
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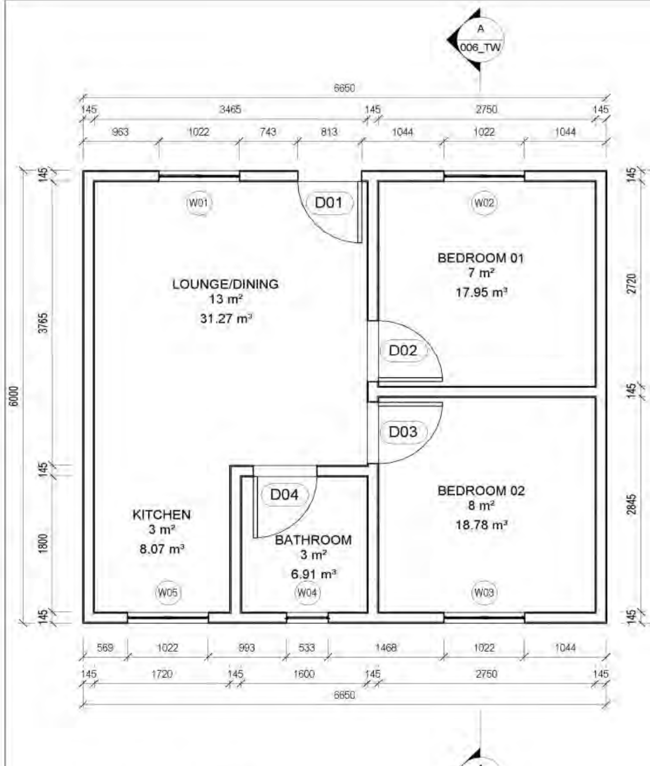


PLAN_Ground Floor

1 : 50

NOTES:
1. GROSS FLOOR AREA = 40.00m²
2. NETT FLOOR AREA = 34.57m²
3. TOTAL INTERNAL VOLUME = 82.98m³

4. EXPOSED SURFACE AREA ENVELOPE (windows & doors subtracted):
EXTERNAL SURFACE ENVELOPE = 54.78m²
INTERNAL SURFACE ENVELOPE = 50.61m²

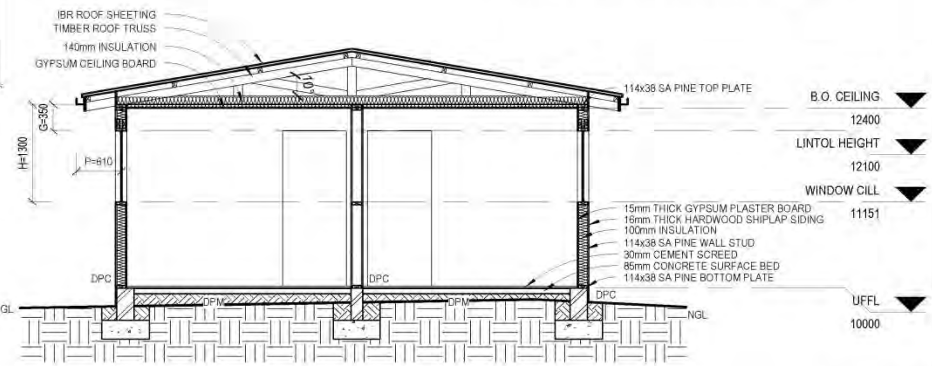
5. INTERNAL PARTITION / WALL
TOTAL LENGTH = 12.44m
TOTAL SURFACE = 24.73m² (openings & doors subtracted)

6. FENESTRATION
NORTH ELEVATION = 1.919m²
EAST ELEVATION = 0m²
SOUTH ELEVATION = 2.288m²
WEST ELEVATION = 0m²

WINDOW SCHEDULE:
W1 1.022 x 0.949 = 0.970m²
W2 1.022 x 0.949 = 0.970m²
W3 1.022 x 0.949 = 0.970m²
W4 0.533 x 0.654 = 0.349m²
W5 1.022 x 0.949 = 0.970m²
STEEL FRAMED WITH 4mm CLEAR FLOAT GLASS

DOOR SCHEDULE:
FRONT DOOR 0.813 x 2.1= 1.707m²
INTERNAL DOOR 0.813 x 2.1= 1.707m²
SOLID TIMBER DOOR FRAME AND DOOR

NO INSULATION UNDER CONCRETE SURFACE BED
CEILING HAS 140mm THICK MINERAL WOOL INSULATION



SECTION A-A

1 : 50

consultant:

UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

CLAYBRICK

145mm TIMBER FRAME
EXTERNAL ENVELOPE

Residential Building

PLAN & SECTION

Project number:	1301_Rev00	Drawing number:	006_TW
Date:	2014/11/01		
Drawn by:	NvR		
Checked by:	NvR	Scale:	1 : 50

Appendix C: A standardised 130m^2 residential building design

A standardised energy usage modelling of a $130m^2$ residential building design

The standardised design of the $130m^2$ residential building has been developed from a design which has been derived from earlier $130m^2$ CSIR designs (the so-called Garsfontein house) which has been used in other research in the past done by the CSIR and for the Department of Minerals & Energy as input to the development of the SANS 204:Energy Efficiency in building standards development process.

The building plan used is reproduced herewith below, with key measurements extracted for input to energy models to be performed with selected software.

NOTES:
1. GROSS FLOOR AREA = $121.40m^2$
2. NETT FLOOR AREA = $105.06m^2$
3. TOTAL INTERNAL VOLUME = $283.66m^3$

4. EXPOSED SURFACE AREA ENVELOPE (windows & doors subtracted):
EXTERNAL SURFACE ENVELOPE = $107.05m^2$
INTERNAL SURFACE ENVELOPE = $98.14m^2$

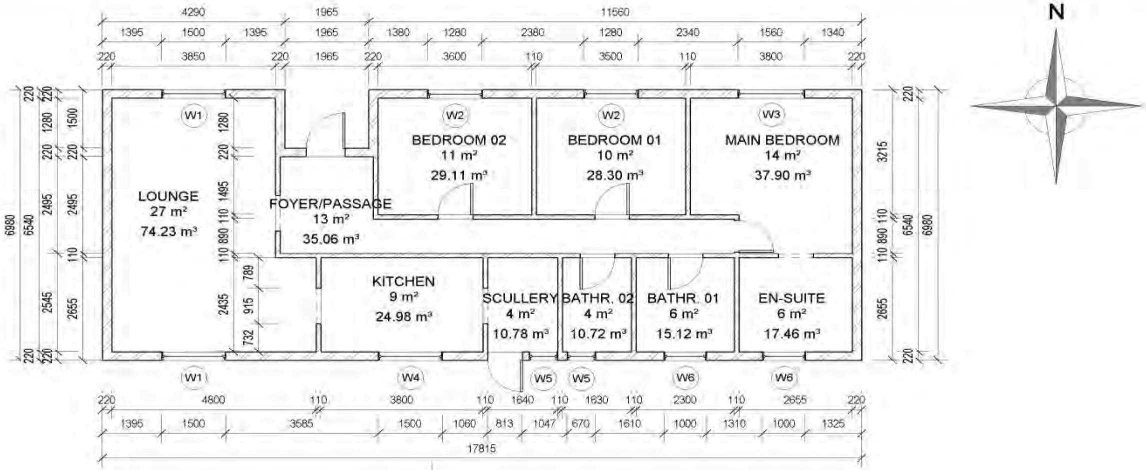
5. INTERNAL PARTITION / WALL
TOTAL LENGTH = 46.69m
TOTAL SURFACE = $110.04m^2$ (openings & doors subtracted)

6. FENESTRATION
NORTH ELEVATION = $5.058m^2$
EAST ELEVATION = $0m^2$
SOUTH ELEVATION = $4.254m^2$
WEST ELEVATION = $0m^2$

WINDOW SCHEDULE:
W1 1.500 x 0.900 = $1.350m^2$
W2 1.280 x 0.900 = $1.152m^2$
W3 1.560 x 0.900 = $1.404m^2$
W4 1.500 x 0.600 = $0.900m^2$
W5 0.670 x 0.600 = $0.402m^2$
W6 1.000 x 0.600 = $0.600m^2$
ALLUMINIUM FRAMED (no thermal break) WITH 4mm CLEAR FLOAT GLASS

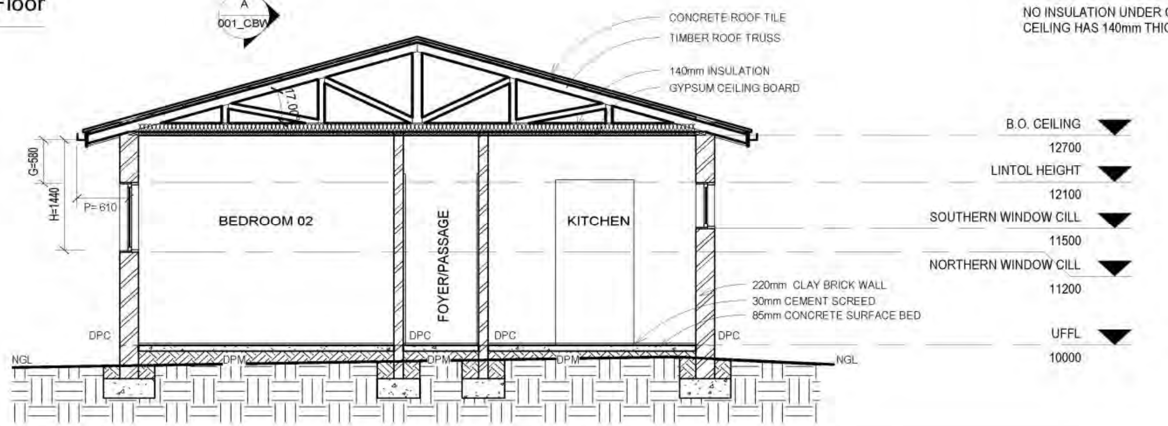
DOOR SCHEDULE:
FRONT DOOR 0.915 x 2.1= $1.922m^2$
KITCHEN DOOR 0.813 x 2.1= $1.707m^2$
SOLID TIMBER DOOR FRAME AND DOOR

NO INSULATION UNDER CONCRETE SURFACE BED
CEILING HAS 140mm THICK MINERAL WOOL INSULATION



PLAN_Ground Floor

1 : 100



SECTION A-A

1 : 50

consultant:

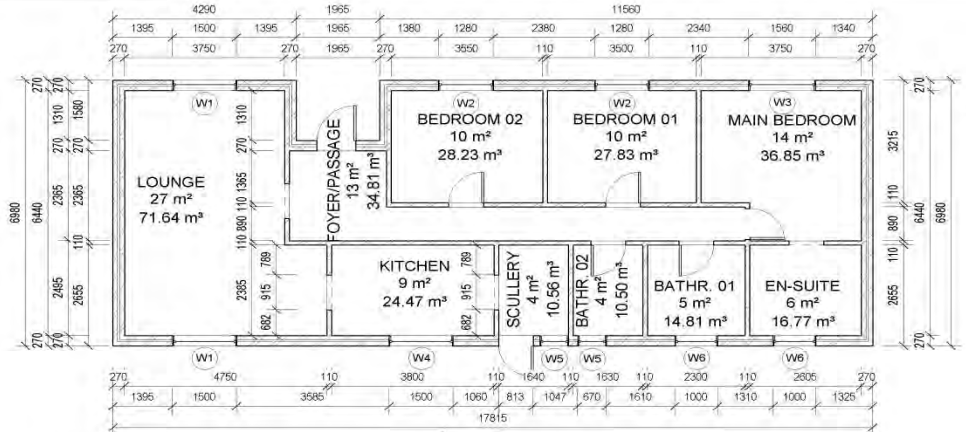
UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

220mm CLAY BRICK
EXTERNAL ENVELOPE

Residential Building

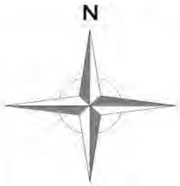
PLAN & SECTION

Project number:	1301_Rev00	Drawing number:	
Date:	2014/11/01		001_CBW
Drawn by:	NvR		
Checked by:	NvR	Scale:	As indicated



PLAN_Ground Floor

1 : 100



NOTES:
1. GROSS FLOOR AREA = 121.40m²
2. NETT FLOOR AREA = 102.40m²
3. TOTAL INTERNAL VOLUME = 276.48m³

4. EXPOSED SURFACE AREA ENVELOPE (windows & doors subtracted):
EXTERNAL SURFACE ENVELOPE = 107.05m²
INTERNAL SURFACE ENVELOPE = 97.22m²

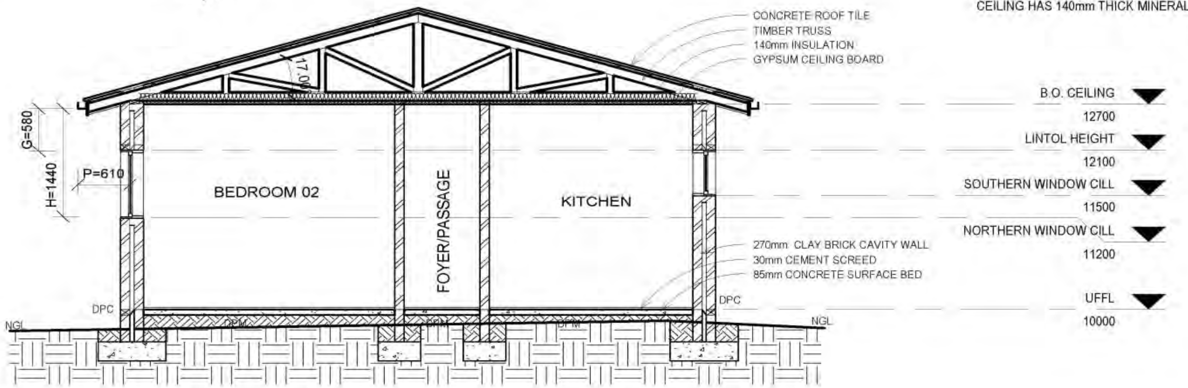
5. INTERNAL PARTITION / WALL
TOTAL LENGTH = 46.28m
TOTAL SURFACE = 108.93m² (openings & doors subtracted)

6. FENESTRATION
NORTH ELEVATION = 5.058m²
EAST ELEVATION = 0m²
SOUTH ELEVATION = 4.254m²
WEST ELEVATION = 0m²

WINDOW SCHEDULE:
W1 1.500 x 0.900 = 1.350m²
W2 1.280 x 0.900 = 1.152m²
W3 1.560 x 0.900 = 1.404m²
W4 1.500 x 0.600 = 0.900m²
W5 0.670 x 0.600 = 0.402m²
W6 1.000 x 0.600 = 0.600m²
ALUMINIUM FRAMED (no thermal break) WITH 4mm CLEAR FLOAT GLASS

DOOR SCHEDULE:
FRONT DOOR 0.915 x 2.1= 1.922m²
KITCHEN DOOR 0.813 x 2.1= 1.707m²
SOLID TIMBER DOOR FRAME AND DOOR

NO INSULATION UNDER CONCRETE SURFACE BED
CEILING HAS 140mm THICK MINERAL WOOL INSULATION



Section A-A

1 : 50

consultant:

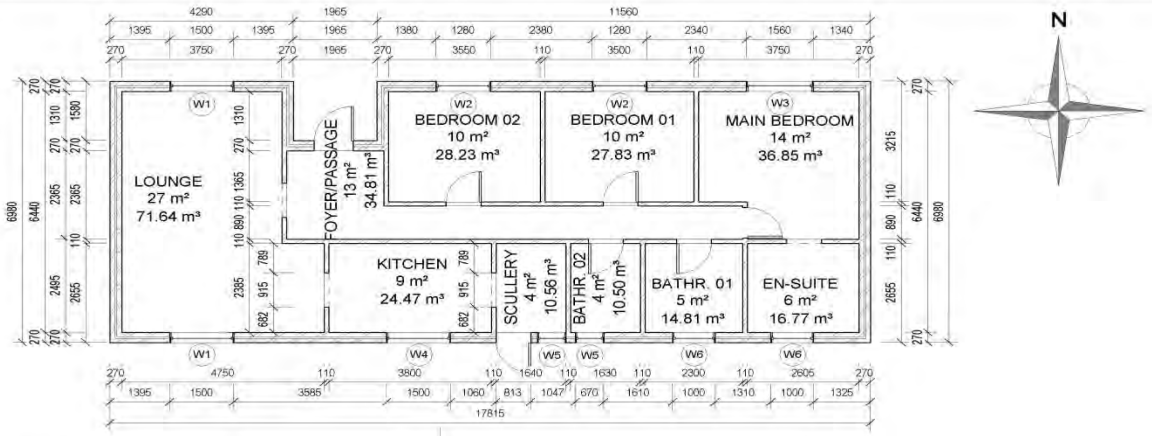
UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

270mm CAVITY CLAY BRICK EXTERNAL ENVELOPE

Residential Building

PLAN & SECTION

Project number:	1301_Rev00	Drawing number:	
Date:	2014/11/01	002_CCW	
Drawn by:	NvR		
Checked by:	NvR	Scale:	As indicated



PLAN_Groud Floor

1 : 100

NOTES:
1. GROSS FLOOR AREA = 121.40m²
2. NETT FLOOR AREA = 102.40m²
3. TOTAL INTERNAL VOLUME = 276.48m³

4. EXPOSED SURFACE AREA ENVELOPE (windows & doors subtracted):
EXTERNAL SURFACE ENVELOPE = 107.05m²
INTERNAL SURFACE ENVELOPE = 97.22m²

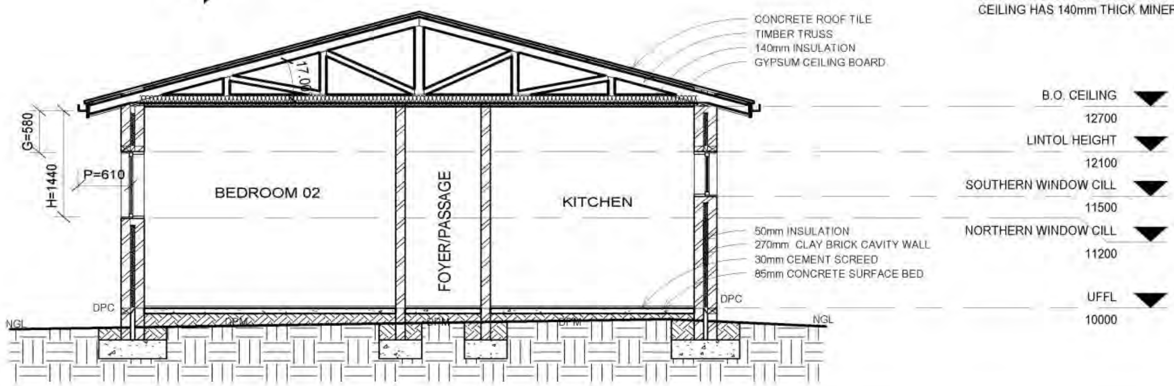
5. INTERNAL PARTITION / WALL
TOTAL LENGTH = 46.28m
TOTAL SURFACE = 108.93m² (openings & doors subtracted)

6. FENESTRATION
NORTH ELEVATION = 5.058m²
EAST ELEVATION = 0m²
SOUTH ELEVATION = 4.254m²
WEST ELEVATION = 0m²

WINDOW SCHEDULE:
W1 1.500 x 0.900 = 1.350m²
W2 1.280 x 0.900 = 1.152m²
W3 1.560 x 0.900 = 1.404m²
W4 1.500 x 0.600 = 0.900m²
W5 0.670 x 0.600 = 0.402m²
W6 1.000 x 0.600 = 0.600m²
ALLUMINIUM FRAMED (no thermal break) WITH 4mm CLEAR FLOAT GLASS

DOOR SCHEDULE:
FRONT DOOR 0.915 x 2.1= 1.922m²
KITCHEN DOOR 0.813 x 2.1= 1.707m²
SOLID TIMBER DOOR FRAME AND DOOR

NO INSULATION UNDER CONCRETE SURFACE BED
CEILING HAS 140mm THICK MINERAL WOOL INSULATION



Section A-A

1 : 50

consultant:

UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

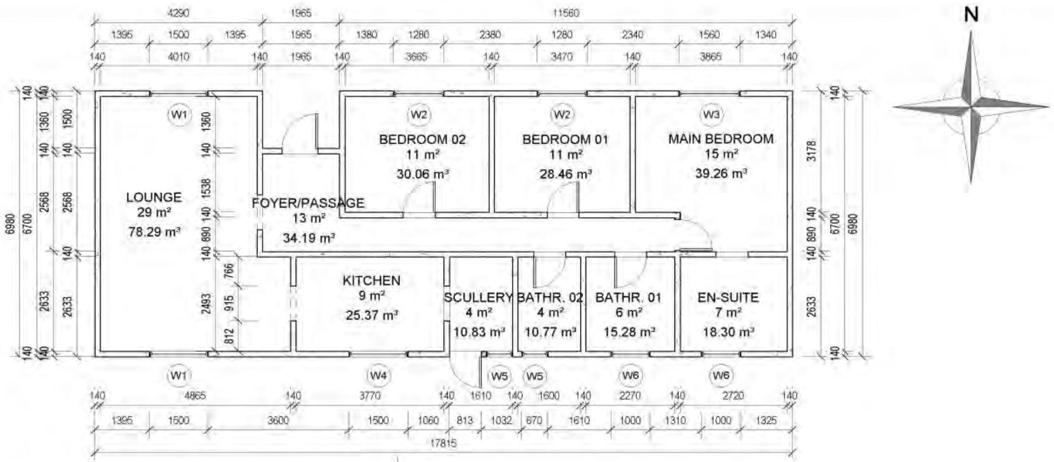
CLAYBRICK

280mm INSULATED CAVITY CLAY BRICK EXTERNAL ENVELOPE

Residential Building

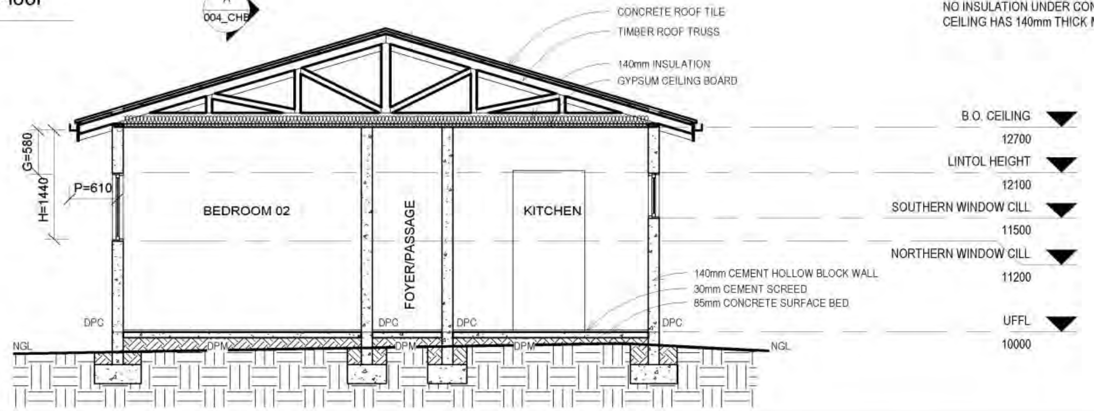
PLAN & SECTION

Project number:	1301_Rev00	Drawing number:	
Date:	2014/11/01	003_ICW	
Drawn by:	NvR		
Checked by:	NvR	Scale:	As indicated



PLAN_Ground Floor

1 : 100



SECTION A-A

1 : 50

NOTES:

1. GROSS FLOOR AREA = 121.40m²
2. NETT FLOOR AREA = 107.05m²
3. TOTAL INTERNAL VOLUME = 290.81m³

4. EXPOSED SURFACE AREA ENVELOPE (windows & doors subtracted):
   EXTERNAL SURFACE ENVELOPE = 107.05m²
   INTERNAL SURFACE ENVELOPE = 100.49m²

5. INTERNAL PARTITION / WALL
   TOTAL LENGTH = 47.01m
   TOTAL SURFACE = 110.93m² (openings & doors subtracted)

6. FENESTRATION
   NORTH ELEVATION = 5.058m²
   EAST ELEVATION = 0m²
   SOUTH ELEVATION = 4.254m²
   WEST ELEVATION = 0m²

WINDOW SCHEDULE:
W1 1.500 x 0.900 = 1.350m²
W2 1.280 x 0.900 = 1.152m²
W3 1.560 x 0.900 = 1.404m²
W4 1.500 x 0.600 = 0.900m²
W5 0.670 x 0.600 = 0.402m²
W6 1.000 x 0.600 = 0.600m²
ALLUMINIUM FRAMED (no thermal break) WITH 4mm CLEAR FLOAT GLASS

DOOR SCHEDULE:
FRONT DOOR 0.915 x 2.1= 1.922m²
KITCHEN DOOR 0.813 x 2.1= 1.707m²
SOLID TIMBER DOOR FRAME AND DOOR

NO INSULATION UNDER CONCRETE SURFACE BED
CEILING HAS 140mm THICK MINERAL WOOL INSULATION

consultant:

UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

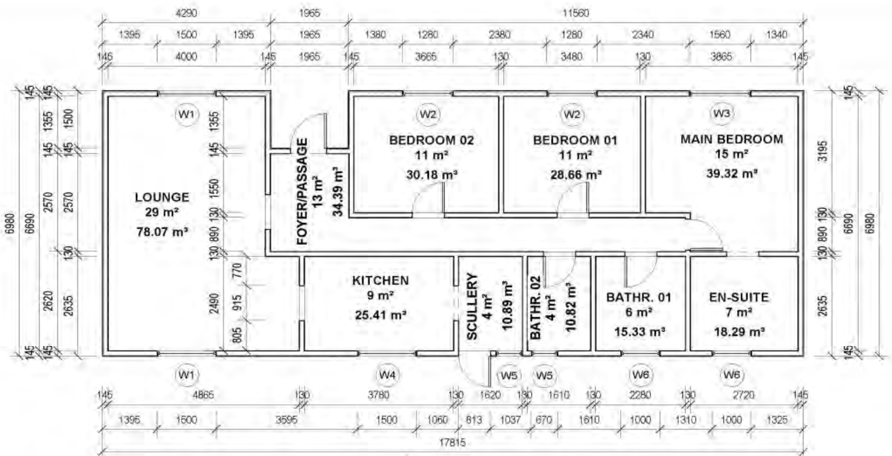
CLAYBRICK

140mm CONCRETE HOLLOW BLOCK EXTERNAL ENVELOPE

Residential Building

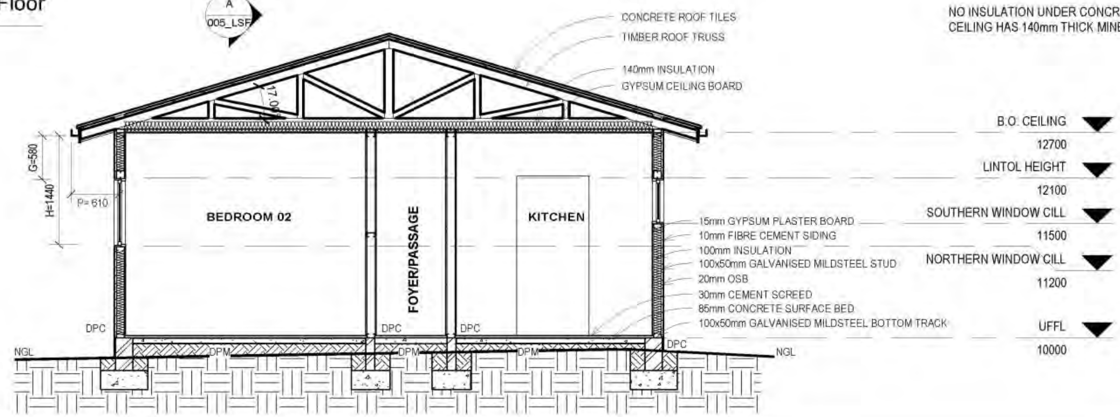
PLAN & SECTION

Project number:	1301_Rev00	Drawing number:	004_CHB
Date:	2014/11/01		
Drawn by:	NvR		
Checked by:	NvR	Scale:	As indicated



PLAN_Ground Floor

1 : 100



SECTION A-A

1 : 50

NOTES:
1. GROSS FLOOR AREA = 121.40m²
2. NETT FLOOR AREA = 107.91m²
3. TOTAL INTERNAL VOLUME = 291.36m³

4. EXPOSED SURFACE AREA ENVELOPE (windows & doors subtracted):
EXTERNAL SURFACE ENVELOPE = 107.05m²
INTERNAL SURFACE ENVELOPE = 100.32m²

5. INTERNAL PARTITION / WALL
TOTAL LENGTH = 47.01m
TOTAL SURFACE = 110.91m² (openings & doors subtracted)

6. FENESTRATION
NORTH ELEVATION = 5.058m²
EAST ELEVATION = 0m²
SOUTH ELEVATION = 4.254m²
WEST ELEVATION = 0m²

WINDOW SCHEDULE:
W1 1.500 x 0.900 = 1.350m²
W2 1.280 x 0.900 = 1.152m²
W3 1.560 x 0.900 = 1.404m²
W4 1.500 x 0.600 = 0.900m²
W5 0.670 x 0.600 = 0.402m²
W6 1.000 x 0.600 = 0.600m²
ALLUMINIUM FRAMED (no thermal break) WITH 4mm CLEAR FLOAT GLASS

DOOR SCHEDULE:
FRONT DOOR 0.915 x 2.1= 1.922m²
KITCHEN DOOR 0.813 x 2.1= 1.707m²
SOLID TIMBER DOOR FRAME AND DOOR

NO INSULATION UNDER CONCRETE SURFACE BED
CEILING HAS 140mm THICK MINERAL WOOL INSULATION

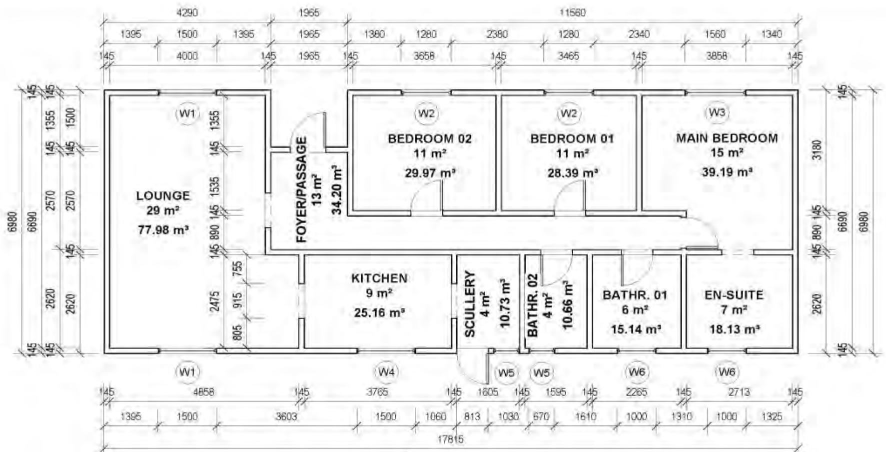
consultant:

145mm LIGHT STEEL FRAME
EXTERNAL ENVELOPE

Residential Building

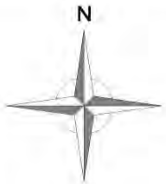
PLAN & SECTION

Project number:	1301_Rev00	Drawing number:	
Date:	2014/11/01		005_LSF
Drawn by:	NvR		
Checked by:	NvR	Scale:	As indicated



PLAN_Ground Floor

1 : 100



NOTES:
1. GROSS FLOOR AREA = 121.40m²
2. NETT FLOOR AREA = 107.24m²
3. TOTAL INTERNAL VOLUME = 289.54m³

4. EXPOSED SURFACE AREA ENVELOPE (windows & doors subtracted):
EXTERNAL SURFACE ENVELOPE = 107.05m²
INTERNAL SURFACE ENVELOPE = 100.01m²

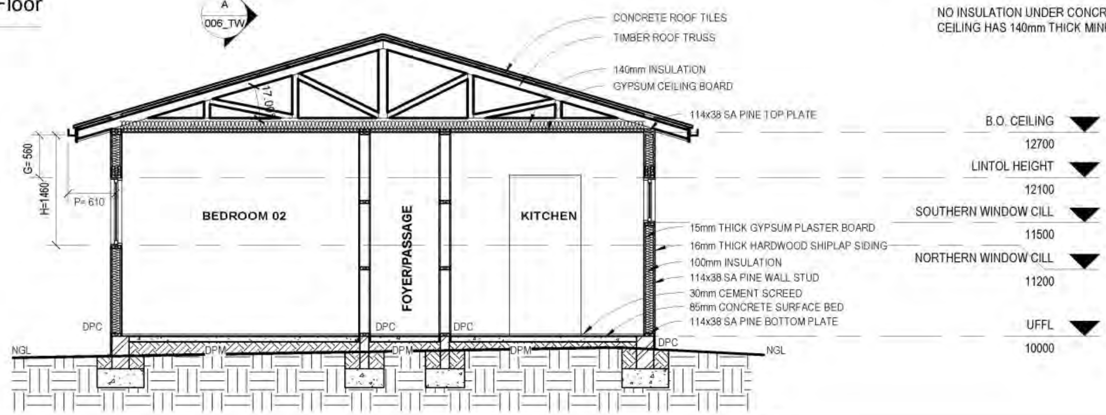
5. INTERNAL PARTITION / WALL
TOTAL LENGTH = 46.97m
TOTAL SURFACE = 110.82m² (openings & doors subtracted)

6. FENESTRATION
NORTH ELEVATION = 5.058m²
EAST ELEVATION = 0m²
SOUTH ELEVATION = 4.254m²
WEST ELEVATION = 0m²

WINDOW SCHEDULE:
W1 1.500 x 0.900 = 1.350m²
W2 1.280 x 0.900 = 1.152m²
W3 1.560 x 0.900 = 1.404m²
W4 1.500 x 0.600 = 0.900m²
W5 0.670 x 0.600 = 0.402m²
W6 1.000 x 0.600 = 0.600m²
ALLUMINIUM FRAMED (no thermal break) WITH 4mm CLEAR FLOAT GLASS

DOOR SCHEDULE:
FRONT DOOR 0.915 x 2.1= 1.922m²
KITCHEN DOOR 0.813 x 2.1= 1.707m²
SOLID TIMBER DOOR FRAME AND DOOR

NO INSULATION UNDER CONCRETE SURFACE BED
CEILING HAS 140mm THICK MINERAL WOOL INSULATION



SECTION A-A

1 : 50

consultant:

UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

CLAYBRICK

145mm TIMBER FRAME
EXTERNAL ENVELOPE

Residential Building

PLAN & SECTION

Project number:	1301_Rev00	Drawing number:	
Date:	2014/11/01	006_TW	
Drawn by:	NvR		
Checked by:	NvR	Scale:	As indicated

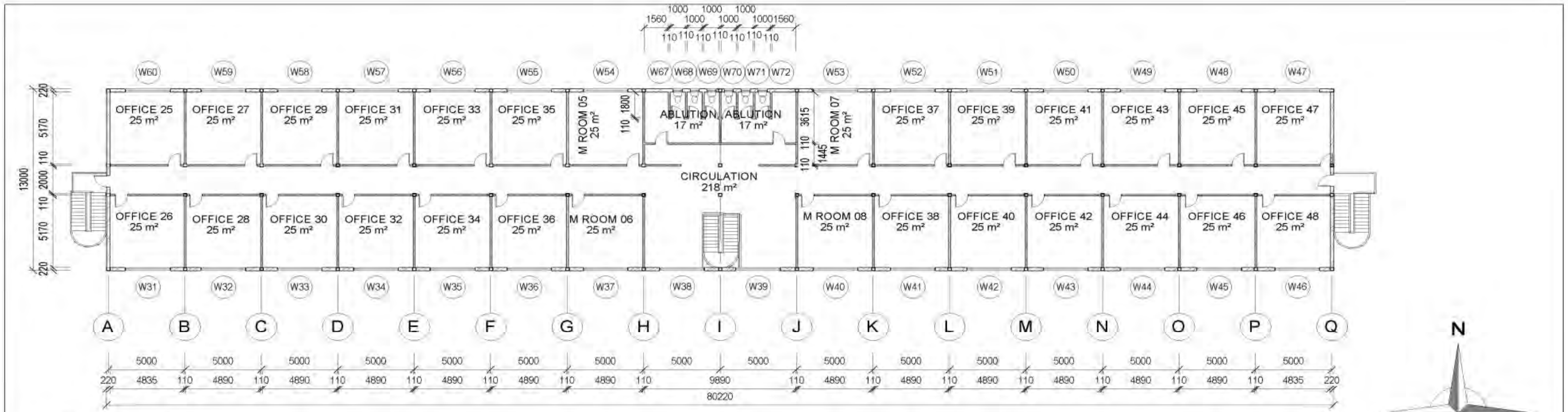
Appendix D: A standardised 2000m^2 office or institutional building design

A standardised energy usage modelling of a 2000m^2 commercial building design

The standardised design of the 2000m^2 commercial residential building is developed from a design which has been derived from earlier research in the past done by the Department of Minerals & Energy as input to the development of the SANS 204; Energy Efficiency in building standards development process.

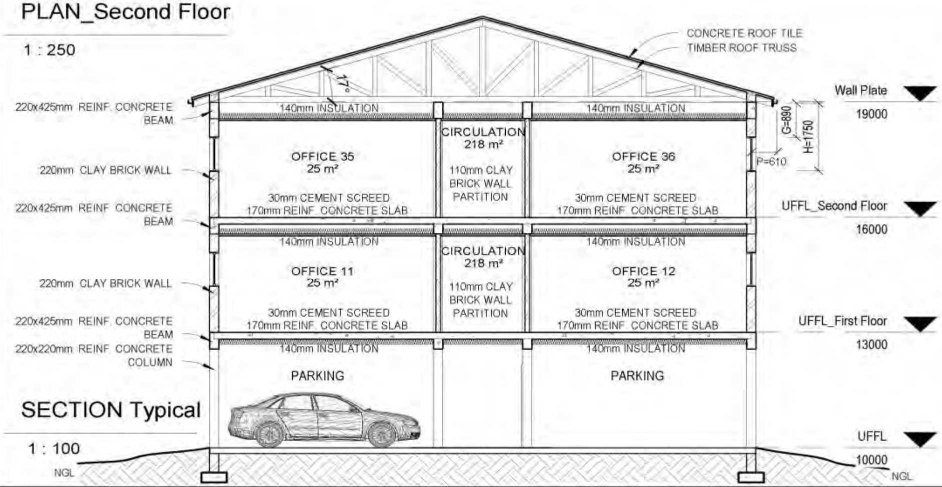
The building plan used is shown below, with key measurements extracted for input to energy models to be performed with selected software.

It is assumed that the structural elements (concrete floor slabs and supporting columns) are the same in all cases although the 140mm hollow concrete block, the timber frame and light steel frame constructions are likely to have a steel frame with the walling as an infill system. The reduced thermal mass of these structural systems is likely to prejudice their energy efficiency, much in the way that the lighter partitioning systems are shown to cause an increase in energy usage.



PLAN_Second Floor

1 : 250



SECTION Typical

1 : 100

NOTES:

1. GROSS FLOOR AREA = 2 085.72m²
2. NETT FLOOR AREA = 1 928.50m²
3. TOTAL INTERNAL VOLUME = 4 974.70m³

4. EXPOSED SURFACE AREA ENVELOPE (windows & doors subtracted):
   - EXTERNAL SURFACE ENVELOPE = 997.11m²
   - INTERNAL SURFACE ENVELOPE = 826.44m²

5. INTERNAL PARTITION / WALL
   - TOTAL LENGTH = 619.25m
   - TOTAL SURFACE = 1 629.55m² (openings & doors subtracted)

6. FENESTRATION
   - NORTH ELEVATION = 80.57m²
   - EAST ELEVATION = 0m²
   - SOUTH ELEVATION = 84.67m²
   - WEST ELEVATION = 0m²

NOTES:

WINDOW SCHEDULE:
TYPE 01 2.940 x 0.900 = 2.646m²
TYPE 02 0.600 x 0.900 = 0.540m²

ALLUMINIUM FRAMED WITH 4mm CLEAR FLOAT GLASS

DOOR SCHEDULE:
ENTRANCE DOOR 1.830 x 2.1= 3.843m²
INTERNAL DOORS 0.813 x 2.1= 1.707m²
SOLID TIMBER DOOR FRAME AND DOOR

140mm INSULATION UNDER 170mm REINFORCED CONCRETE FLOOR SLAB

CEILING HAS 140mm THICK MINERAL WOOL INSULATION

consultant:

UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

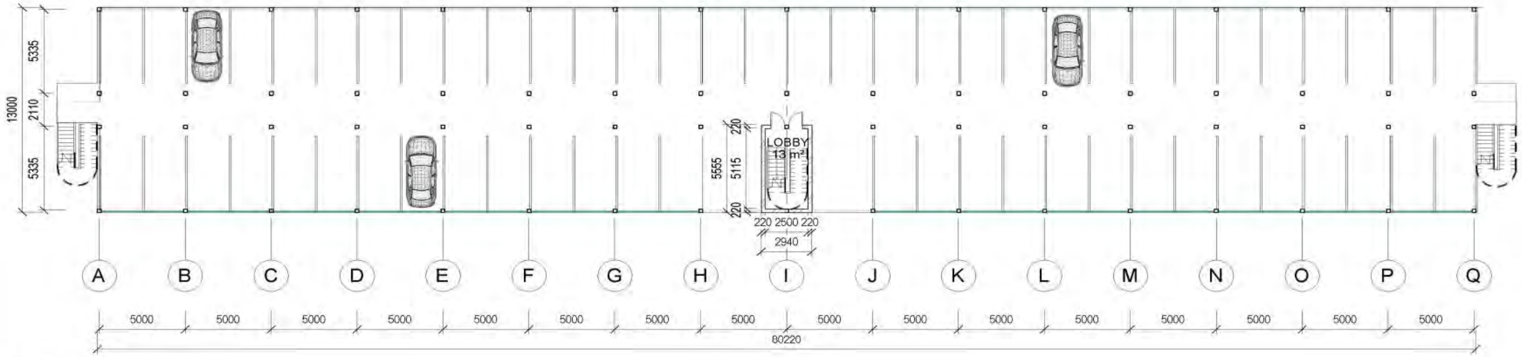
CLAYBRICK

220mm CLAY BRICK EXTERNAL ENVELOPE

Office Building

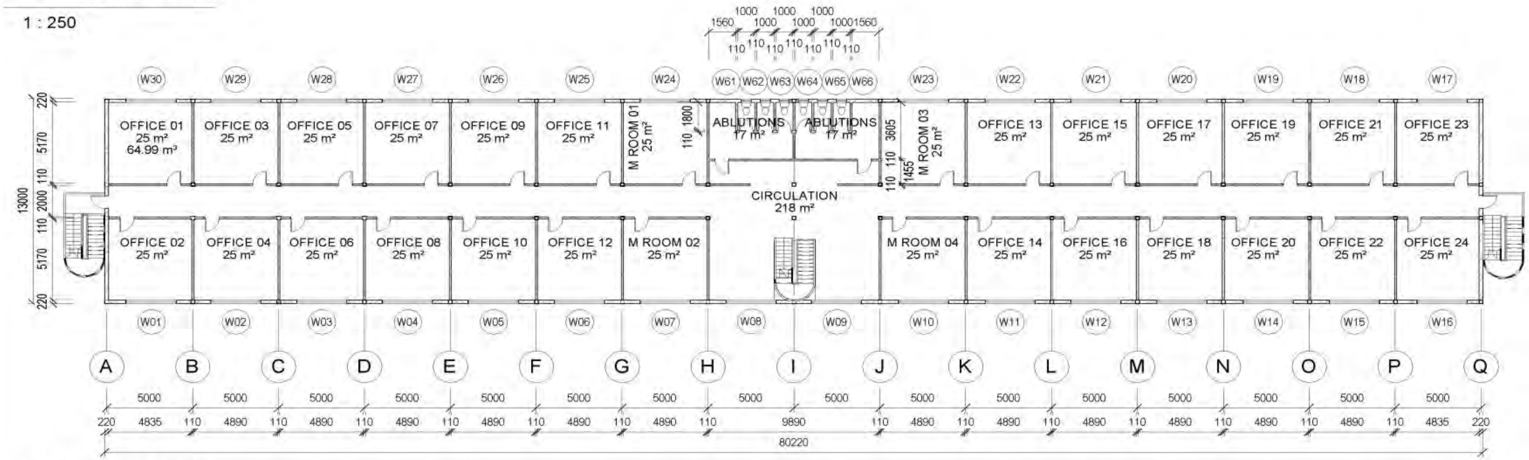
FLOOR PLAN & SECTION

Project number:	1301_Rev00	Drawing number:	
Date:	2014/12/01		011_CBW
Drawn by:	NvR		
Checked by:	NvR	Scale:	As indicated



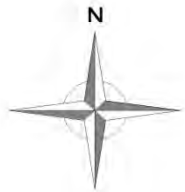
PLAN_Ground Floor

1 : 250



PLAN_First Floor

1 : 250



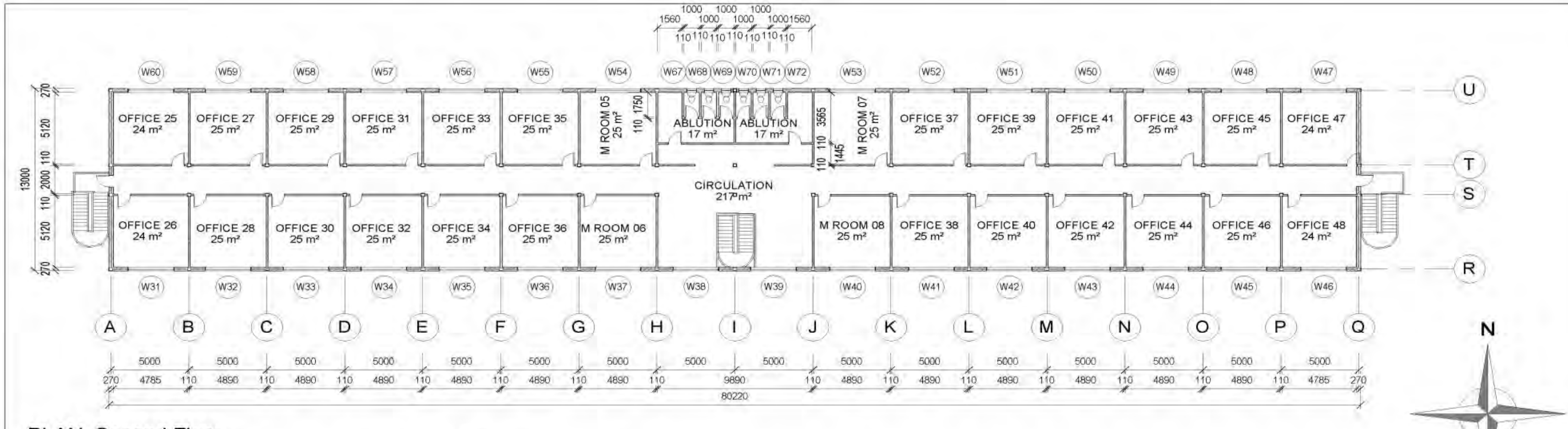
consultant:

220mm CLAY BRICK
EXTERNAL ENVELOPE

Office Building

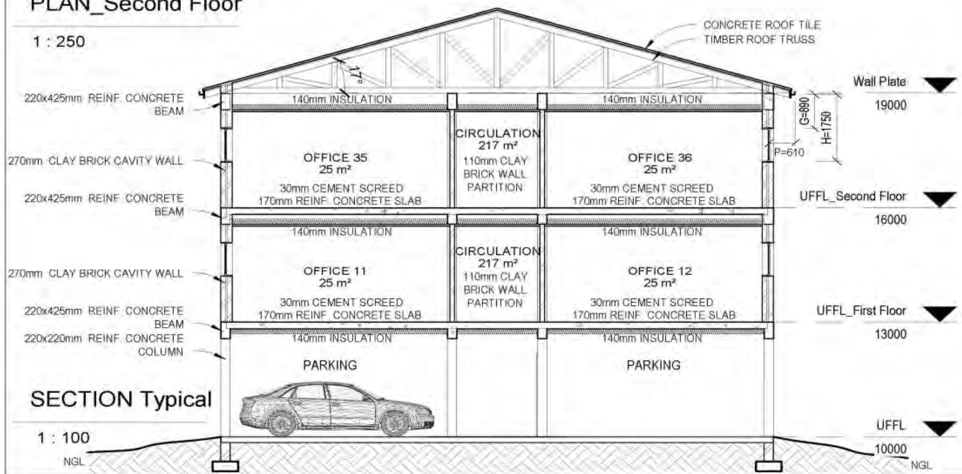
FLOOR PLANS

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



PLAN_Second Floor

1 : 250



SECTION Typical

1 : 100

NOTES:

1. GROSS FLOOR AREA = 2 085.72m²
2. NETT FLOOR AREA = 1 910.79m²
3. TOTAL INTERNAL VOLUME = 4 928.81m³

4. EXPOSED SURFACE AREA ENVELOPE (windows & doors subtracted):
 EXTERNAL SURFACE ENVELOPE = 997.11m²
 INTERNAL SURFACE ENVELOPE = 822.67m²

5. INTERNAL PARTITION / WALL
 TOTAL LENGTH = 615.95m
 TOTAL SURFACE = 1 620.21m² (openings & doors subtracted)

6. FENESTRATION
 NORTH ELEVATION = 80.57m²
 EAST ELEVATION = 0m²
 SOUTH ELEVATION = 84.67m²
 WEST ELEVATION = 0m²

NOTES:

WINDOW SCHEDULE:
TYPE 01 2.940 x 0.900 = 2.646m²
TYPE 02 0.600 x 0.900 = 0.540m²

ALLUMINIUM FRAMED WITH 4mm CLEAR FLOAT GLASS

DOOR SCHEDULE:
ENTRANCE DOOR 1.830 x 2.1= 3.843m²
INTERNAL DOORS 0.813 x 2.1= 1.707m²
SOLID TIMBER DOOR FRAME AND DOOR

140mm INSULATION UNDER 170mm REINFORCED CONCRETE FLOOR SLAB

CEILING HAS 140mm THICK MINERAL WOOL INSULATION

consultant:

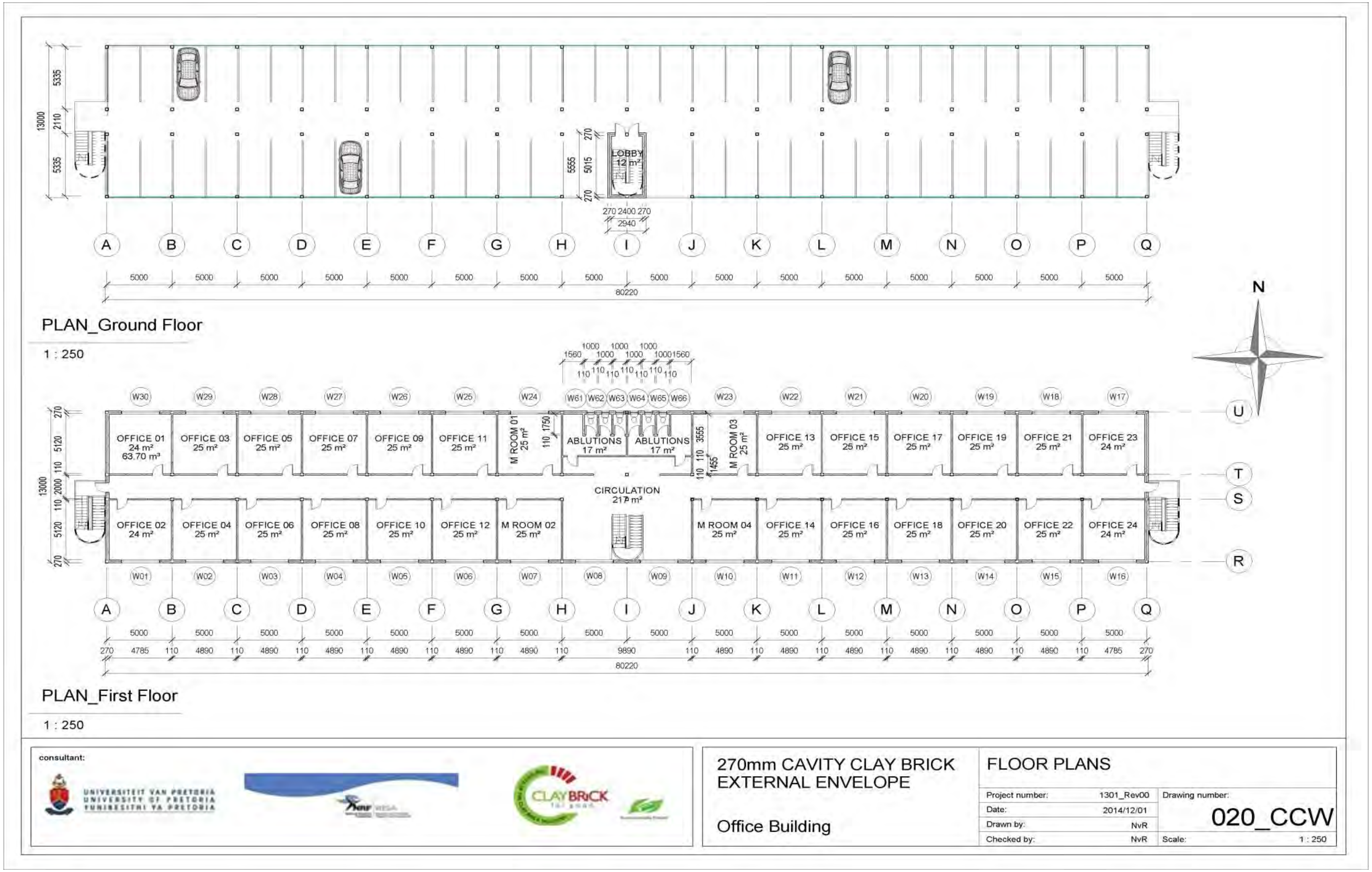
UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

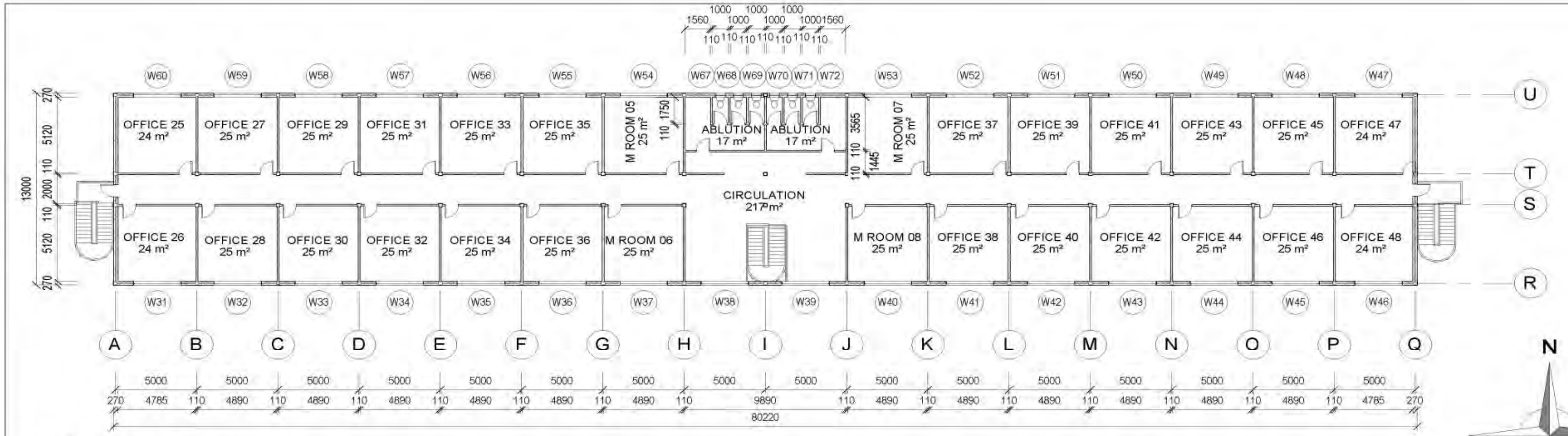
270mm CAVITY CLAY BRICK EXTERNAL ENVELOPE

Office Building

FLOOR PLAN & SECTION

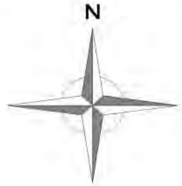
Project number:	1301_Rev00	Drawing number:	021_CCW
Date:	2014/12/01		
Drawn by:	NvR		
Checked by:	NvR	Scale:	As indicated

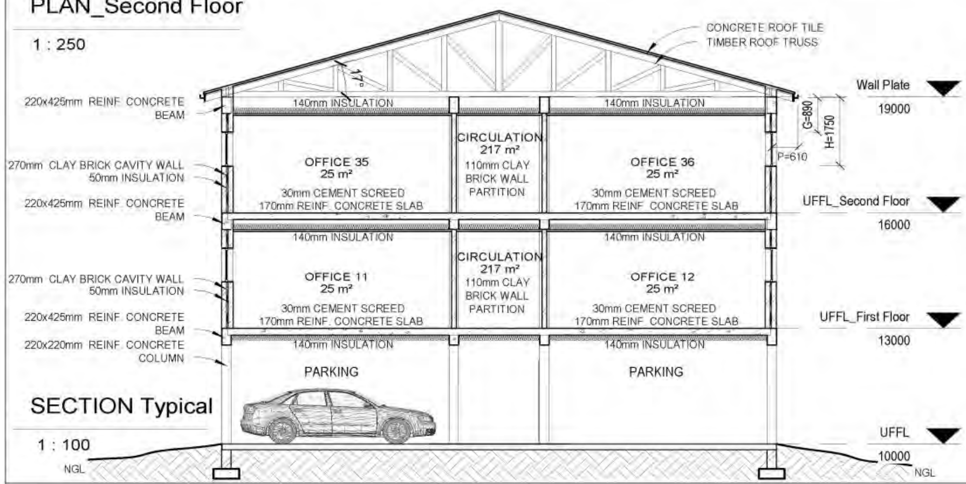

PLAN_Ground Floor
1 : 250
LOBBY
12 m²
A B C D E F G H I J K L M N O P Q
5000
80220
PLAN_First Floor
1 : 250
OFFICE 01
24 m²
63.70 m³
OFFICE 03
25 m²
OFFICE 05
25 m²
OFFICE 07
25 m²
OFFICE 09
25 m²
OFFICE 11
25 m²
M ROOM 01
25 m²
ABLUTIONS
17 m²
ABLUTIONS
17 m²
M ROOM 03
25 m²
OFFICE 13
25 m²
OFFICE 15
25 m²
OFFICE 17
25 m²
OFFICE 19
25 m²
OFFICE 21
25 m²
OFFICE 23
24 m²
CIRCULATION
217 m²
OFFICE 02
24 m²
OFFICE 04
25 m²
OFFICE 06
25 m²
OFFICE 08
25 m²
OFFICE 10
25 m²
OFFICE 12
25 m²
M ROOM 02
25 m²
M ROOM 04
25 m²
OFFICE 14
25 m²
OFFICE 16
25 m²
OFFICE 18
25 m²
OFFICE 20
25 m²
OFFICE 22
25 m²
OFFICE 24
24 m²
U T S R
N
consultant:
UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA
CLAY BRICK
270mm CAVITY CLAY BRICK
EXTERNAL ENVELOPE
Office Building
FLOOR PLANS
Project number: 1301_Rev00
Date: 2014/12/01
Drawn by: NvR
Checked by: NvR
Drawing number:
020_CCW
Scale: 1 : 250



PLAN_Second Floor

1 : 250





SECTION Typical

1 : 100

NOTES:

1. GROSS FLOOR AREA = 2 085.72m²
2. NETT FLOOR AREA = 1 910.79m²
3. TOTAL INTERNAL VOLUME = 4 928.81m³

4. EXPOSED SURFACE AREA ENVELOPE (windows & doors subtracted):
   - EXTERNAL SURFACE ENVELOPE = 997.11m²
   - INTERNAL SURFACE ENVELOPE = 822.67m²

5. INTERNAL PARTITION / WALL
   - TOTAL LENGTH = 615.95m
   - TOTAL SURFACE = 1 620.21m² (openings & doors subtracted)

6. FENESTRATION
   - NORTH ELEVATION = 80.57m²
   - EAST ELEVATION = 0m²
   - SOUTH ELEVATION = 84.67m²
   - WEST ELEVATION = 0m²

NOTES:

WINDOW SCHEDULE:
TYPE 01 2.940 x 0.900 = 2.646m²
TYPE 02 0.600 x 0.900 = 0.540m²

ALLUMINIUM FRAMED WITH 4mm CLEAR FLOAT GLASS

DOOR SCHEDULE:
ENTRANCE DOOR 1.830 x 2.1= 3.843m²
INTERNAL DOORS 0.813 x 2.1= 1.707m²
SOLID TIMBER DOOR FRAME AND DOOR

140mm INSULATION UNDER 170mm REINFORCED CONCRETE FLOOR SLAB

CEILING HAS 140mm THICK MINERAL WOOL INSULATION

consultant:

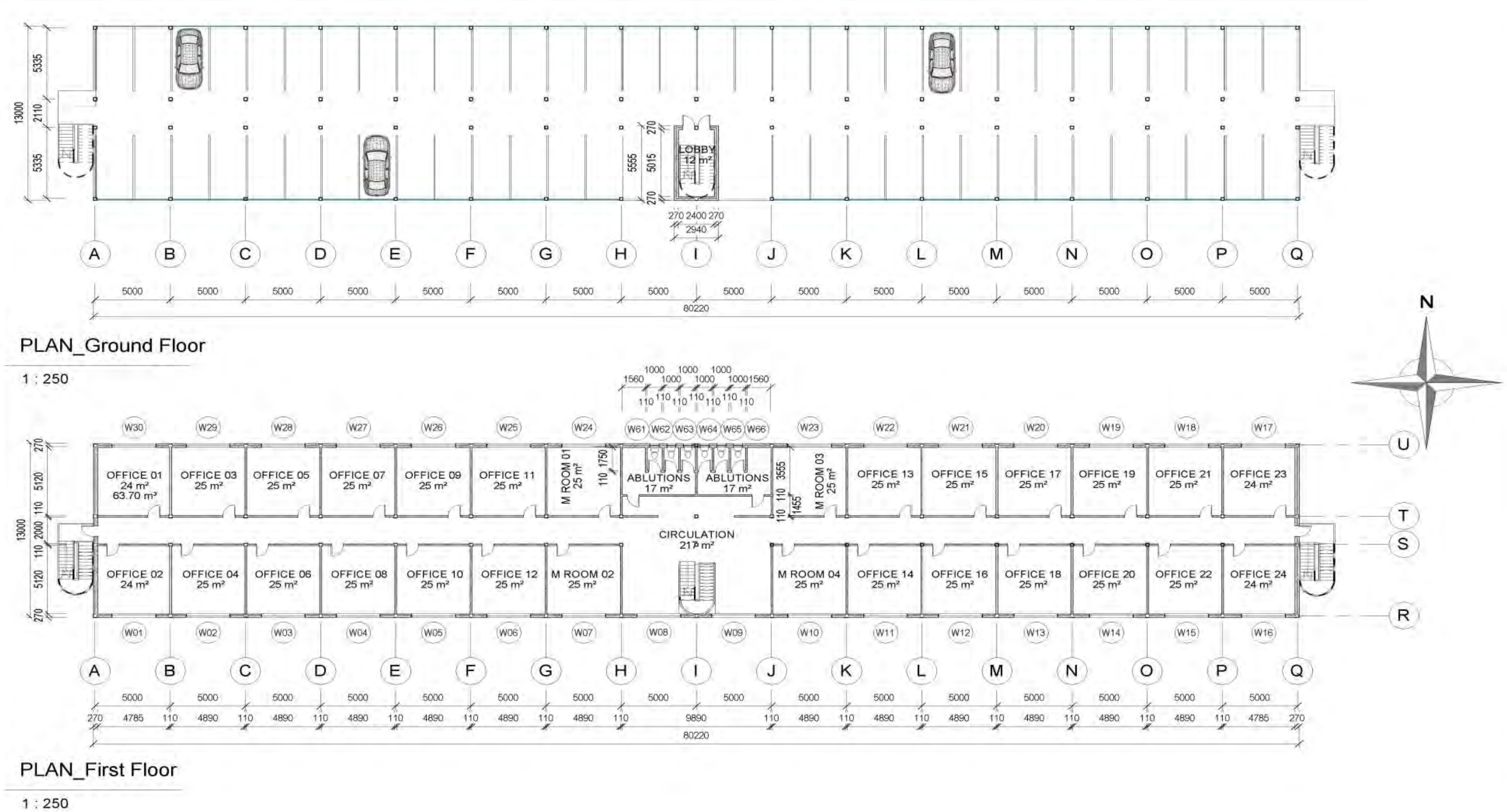
UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

280mm INSULATED CAVITY CLAY BRICK EXTERNAL ENVELOPE

Office Building

FLOOR PLAN & SECTION

Project number:	1301_Rev00	Drawing number:	
Date:	2014/12/01	031_ICW	
Drawn by:	NvR		
Checked by:	NvR	Scale:	As indicated



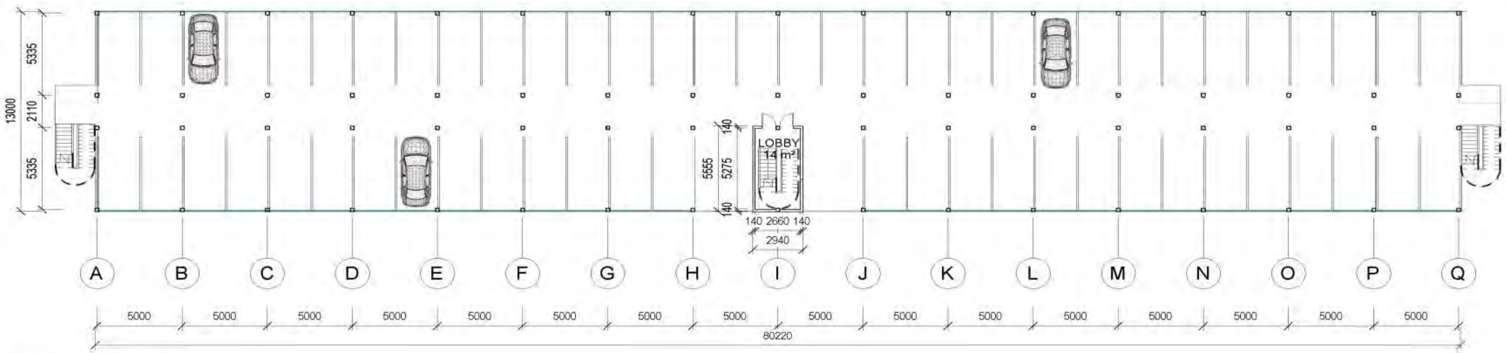
consultant:

280mm INSULATED CAVITY CLAY BRICK EXTERNAL ENVELOPE

Office Building

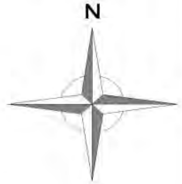
FLOOR PLANS

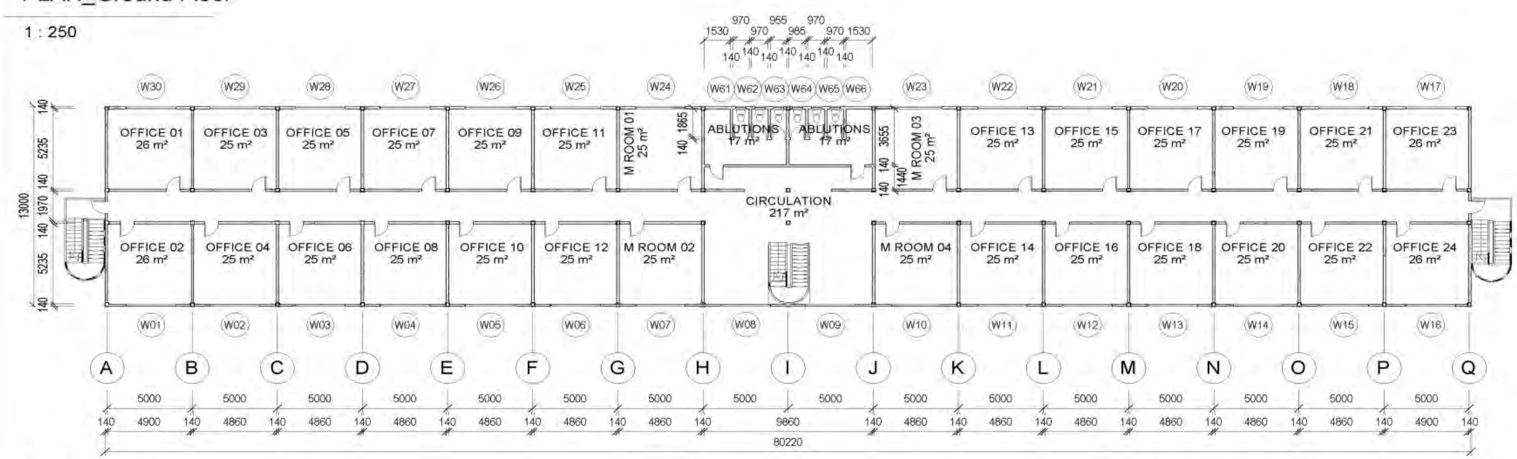
Project number:	1301_Rev00	Drawing number:	030_ICW
Date:	2014/12/01		
Drawn by:	NvR		
Checked by:	NvR	Scale:	1 : 250



PLAN_Ground Floor

1 : 250





PLAN_First Floor

1 : 250

consultant:

UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

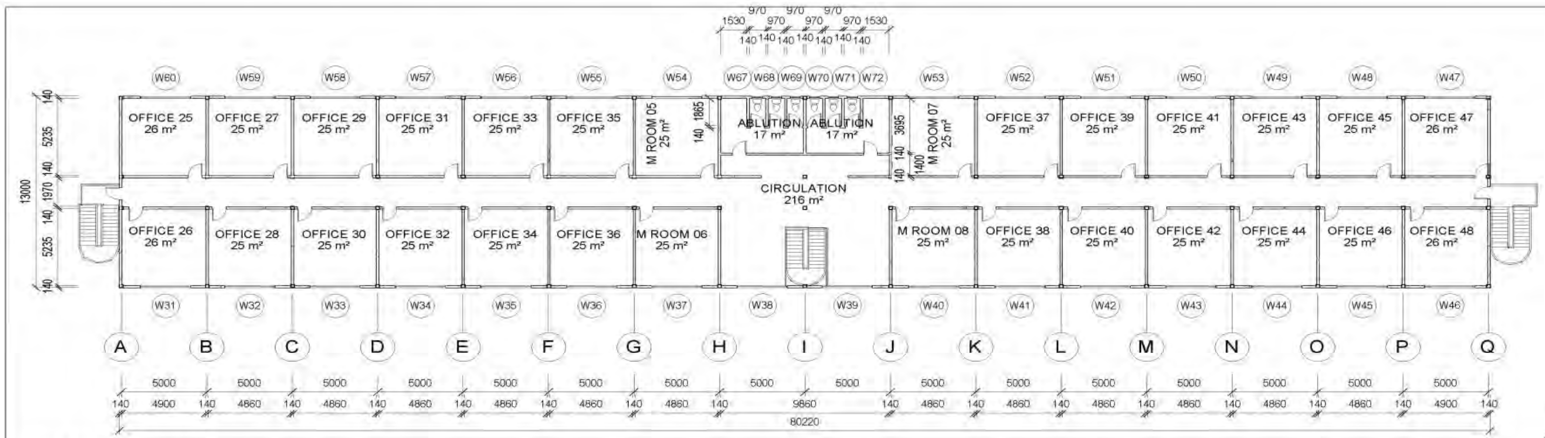
CLAYBRICK

140mm CONCRETE HOLLOW BLOCK EXTERNAL ENVELOPE

Office Building

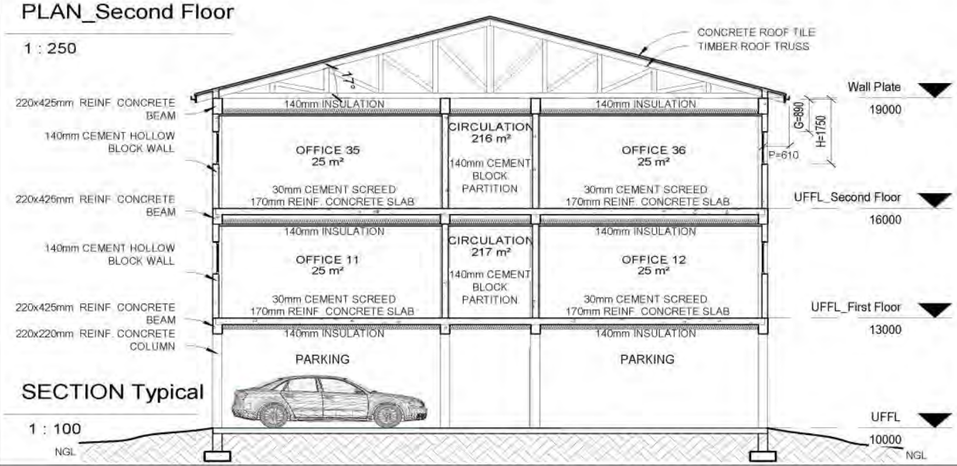
FLOOR PLANS

Project number:	1301_Rev00	Drawing number:	
Date:	2014/12/01	040_CHB	
Drawn by:	NvR		
Checked by:	NvR	Scale:	1 : 250



PLAN_Second Floor

1 : 250



SECTION Typical

1 : 100

NOTES:

1. GROSS FLOOR AREA = 2 085.72m²
2. NETT FLOOR AREA = 1 940.21m²
3. TOTAL INTERNAL VOLUME = 5 006.13m³

4. EXPOSED SURFACE AREA ENVELOPE (windows & doors subtracted):
 EXTERNAL SURFACE ENVELOPE = 997.11m²
 INTERNAL SURFACE ENVELOPE = 827.14m²

5. INTERNAL PARTITION / WALL
 TOTAL LENGTH = 623.65m
 TOTAL SURFACE = 1 642.00m² (openings & doors subtracted)

6. FENESTRATION
 NORTH ELEVATION = 80.57m²
 EAST ELEVATION = 0m²
 SOUTH ELEVATION = 84.67m²
 WEST ELEVATION = 0m²

NOTES:

WINDOW SCHEDULE:
TYPE 01 2.940 x 0.900 = 2.646m²
TYPE 02 0.600 x 0.900 = 0.540m²

ALLUMINIUM FRAMED WITH 4mm CLEAR FLOAT GLASS

DOOR SCHEDULE:
ENTRANCE DOOR 1.830 x 2.1= 3.843m²
INTERNAL DOORS 0.813 x 2.1= 1.707m²
SOLID TIMBER DOOR FRAME AND DOOR

140mm INSULATION UNDER 170mm REINFORCED CONCRETE FLOOR SLAB

CEILING HAS 140mm THICK MINERAL WOOL INSULATION

consultant:

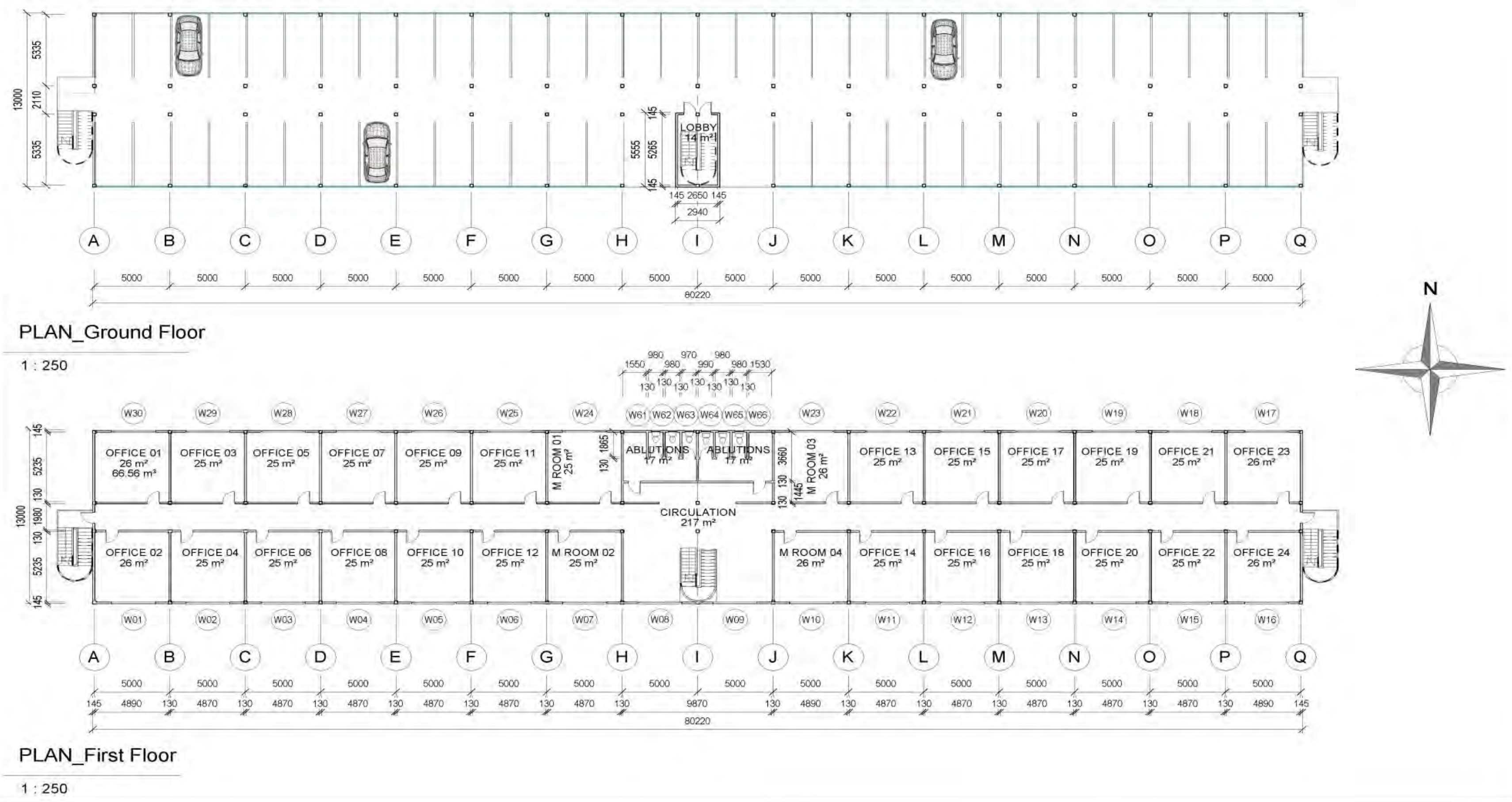
UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

140mm CONCRETE HOLLOW BLOCK EXTERNAL ENVELOPE

Office Building

FLOOR PLAN & SECTION

Project number:	1301_Rev00	Drawing number:	041_CHB
Date:	2014/12/01		
Drawn by:	NvR		
Checked by:	NvR	Scale:	As indicated



consultant:

UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

CLAYBRICK

145mm LIGHT STEEL FRAME
EXTERNAL ENVELOPE

Office Building

FLOOR PLANS

Project number:	1301_Rev00	Drawing number:	
Date:	2014/12/01		050_LSF
Drawn by:	NvR		
Checked by:	NvR	Scale:	1 : 250

Appendix E Critical Review: Final Statement Quantis International

Prof. Piet Vosloo
Pr LArch Pr CPM
BSc(Bouk) BArch ML PhD
Associate Professor
Department of Architecture
Building Science, Room 2-16
University of Pretoria, South Africa

Dr. Rainer Zah
Quantis Switzerland/Germany
Reitergasse 11
8004 Zürich
Schweiz

Zürich, 2nd of March, 2015

Critical Review of „THERMAL PERFORMANCE COMPARISON BETWEEN SIX WALL CONSTRUCTION METHODS FREQUENTLY USED IN SOUTH AFRICA"

Dear Prof. Vosloo,

this is my review of the above mentioned report. This TPS-study basically serves as an input for calculating the LCA of clay bricks in South Africa. Therefor, I focussed this review on evaluating the compliance of this report for that goal.
My general impression of this TPS study is very positive. This report completely fulfils the conditions to serve as an input report for the clay brick LCA study. Please find my more detailed review in the following paragraphs:

Abstract
The abstract is well written, and concisely summarizes the key findings of the report.

Introduction
This chapter clearly states the problem and accurately describes the goal of this study.

Method
Chapter 2 and 3 describe in detail the scope of the study. E.g., which buildings, wall types and regions have been considered. Also clear statements have been made on the calculation methods applied and the Software tools used to do the thermal modelling. Especially chapter 3 succeeds in standardising all the modelling details that are very crucial for the final comparability of the results.
Chapter 2.2: The reference is missing for your statement of 3.5 to 5x higher environmental impact in the use phase then in the construction phase of buildings.

Results
The results are presented very clearly in the form of tables and graphs for the different housing types and as blended results. Also the conclusions drawn from the results are sound and summarize nicely the findings.

Conclusion/Discussion
Although the results are quite multi-dimensional, the authors succeeded in elaborating a few key conclusions that are valid across different building types and climatic regions. Generally, this study completely fulfils the goals as an input to the clay brick LCA study.

Language
The report is well written, error-free and easily understandable.

In general, I found no critical issues in this report. I can fully recommend it for publication.

With best wishes

Rainer Zah
Managing Director Switzerland/Germany
Quantis International

Quantis Switzerland/Germany, Reitergasse 11, 8004 Zürich (Switzerland) TEL +41 (0) 445 52 08 39
info.schweiz@quantis-intl.com- www.quantis-intl.com