AN ASSESSMENT OF THE IMPACT OF SELECTED CONSTRUCTION MATERIALS ON THE LIFE CYCLE ENERGY PERFORMANCE AND THERMAL COMFORT IN BUILDINGS

A Thesis
by
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Declaration

This thesis, except where indicated in the text is the candidate's own work and has not been submitted in part, or in whole at any other University. The data used in the completion of this thesis was taken from both primary and secondary sources. Where secondary sources were used reference has been made to them

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Dedication and Acknowledgements

Glory be to GOD Almighty for the guidance in the successful completion of my study. May thou grace and mercy continue to overflow in my life. My PhD study is dedicated to my mum, the late Mrs. W Haripersad, who always encouraged and supported me, especially in my studies. Mum, may I always receive your blessings and be guided in the right direction.

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Abstract

South Africa is a developing country with various construction projects that are being undertaken both by government and the private sector. The requirements for the construction of energy-efficient buildings as well as the selection methods for providing construction materials have hence become important. Energy efficiency improvements needs to be implemented in the construction of these buildings in order to decrease energy usage and costs and provide more comfortable conditions for its occupants. Previous studies revealed that most of the focus for improving energy efficiency in buildings has been on their operational emissions. It is estimated that about 30% of all energy consumed throughout the lifetime of a building is utilized as embodied energy (this percentage varies based on factors such as age of building, climate and materials). In the past this percentage was much lower, but with increased emphasis placed on reducing operational emissions (such as energy efficiency improvements in heating and cooling systems), the embodied energy contribution has become more significant. Hence, it is important to employ a life-cycle carbon framework in analysing the carbon emissions in buildings.

The study aims to augment energy efficiency initiatives by showcasing energy reduction strategies for buildings. The study assessed the thermal performance of selected construction materials by analysing different buildings using energy modelling program, EnergyPlus and TRNSYS. The parametric study was set in the central plateau region of South Africa and was performed to determine appropriate energy efficiency improvements that can be implemented for maximum savings. A life cycle cost analysis was performed on the selected improvements. The models created are representative of the actual buildings when simulated data is compared to recorded data from these buildings. Results showed a significant variation in energy and construction costs with varying construction materials over the buildings' life cycle. Findings suggest that there is a significant reduction in energy usage when simple efficiency measures are implemented.

The study recommends the use of different energy efficient building materials and the implementation of passive interventions in the constructing of buildings; the thermal performance of a building be optimized to ensure thermal comfort and the developed model be adopted for use in the engineering and construction industry for the reduction of energy consumption.

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Conference Papers

Haripersad, R., Lazarus, I. J. & Singh, R. 2015. Impact of Construction materials on Embodied Energy and building costs in low-income housing in South Africa. Proceeding of the 7th International Conference on Applied Energy – ICAE2015, Abu Dhabi, United Arab Emirates, UAE, March 28-31.

Haripersad, R., Lazarus, I. J. & Singh, R. 2016. A review of energy efficiency and indoor environmental quality. Proceedings of the 3rd International Conference of the *Journal of Green Economy and Development, (JGED 16),* Makaranga Lodge, Kloof, Durban, 8-10 July.

CHAPTER ONE: INTRODUCTION

1.1 Background

According to the Construction Industry Development Board (CIDB), the South African building industry utilises approximately 31% of total electricity supply in its operations (CIDB, 2008), hence this industry is a significant role player in the demand for energy. The energy consumption of the country exceeds the electrical power supply, which in turn raises environmental concerns. The Department of Minerals and Energy reported the South African (SA) government's intention to reduce pressure on the electricity supply, by a general policy to improve energy efficiency by 12% by 2015. The sector-specific target for the residential building sector, which is measured in relation to operational energy, is 10% by 2015 (DME, 2008).

Notwithstanding, energy demand decrease requires an emphasis on embodied energy, rather than operational energy in the low-income category. Government's goal to build around three million sponsored, Reconstruction Development Programme (RDP) houses by 2020 presents an ideal opportunity for the low-income category to meet the sector-explicit objective. The low-income category represents 50% of households presently, however, it contributes just 16% of the electrical energy demand of the residential building sector.

The electrical energy requirement of the low-income category is probably not going to increase significantly soon (CIDB, 2008), regardless of the arranged, mass turn out of new homes because of affordability issues. In contrast, the energy demand for material production will increase as the key structural material for RDP houses is cement and its production is energy intensive. Moreover, the dangers to human wellbeing and security could raise because of the sector's reliance on cheap, yet hazardous fuel sources (Klunne, 2006). There is a demand for housing from citizens of developing countries due to population growth in mainly urban and suburban communities.

Numerous nations, including South Africa, have perceived this need and incorporated housing policies and plans to fulfil this demand for housing into their constitution and other government reports (Republic of South Africa Constitutional Assembly, 1996).

A test for governments of non-industrial nations is to provide housing for their constituents. Government leaders in South Africa, with a rapidly growing population, want to improve the living conditions for the citizens, by providing housing on a large scale by utilising modular and pre-designed houses (South Africa Human Rights Commission, 2004). When providing housing to the lowest-income group, utilising a basic structure can give incredible short-term upgrades in comfort levels and safety for the inhabitants. For instance, in the central plateau region of South Africa, which is a colder climate where the prevailing energy need is for heating, the government has a house structure plan to replace homes made of sheet metal. In light of a valid concern for limiting capital expenses much as possible, the housing plans may not take into account the prescribed procedures for insulation, air infiltration, or general energy efficiency. There are several motives for sustainable building, including environmental, economic, and social benefits. The expectation of an energy-efficient structure design is to focus on the reduction of the prevailing operational energy component. Over the last twenty years, the coordination of both passive measures and dynamic advancements into "green" building configuration has definitely decreased operational energy; on numerous occasions, savings of 50% and more were accomplished. As opposed to this, embodied energy decrease methodologies are less noticeable; and the mainstream material asset techniques, for example, the utilisation of reused content materials, are additionally not evaluated to affirm whether they are yielding the ideal environmental advantages.

The building sector is one of the sectors that consume a significant amount of thermal and electrical energy for indoor thermal comfort and appliances. The sector also consumes vast quantities of materials, and each material must be extracted, processed, and finally transported to the building construction site. Although the energy consumed during the various activities in buildings from construction to their operation is critically important for modern lifestyle and development of humans, it also puts at risk the quality and sustainability of the biosphere due to undesirable results or second-order effects (Hammond, 2000; Yu et al., 2011). Energy-efficient buildings (EEBs) and green buildings constructed taking into account energy efficiency (Turner, Frankel, 2008), water conservation (USGBC, 2009), use of environmentally friendly construction material and their conservation (Ren et al., 2015) and efficient construction processes, are more environmentally friendly and sustainable. Also, in EEB and green building construction, the workplace satisfaction of the occupants (Kim et al., 2015; Thatcher & Milner, 2014) is considered in addition to indoor thermal comfort, and psychological (Allen et al., 2016; Armitage et al., 2011), and behavioural (Kashe et al., 2015) benefits. Ross et al. (2007) also indicated that a significant amount of money can be saved using green building concepts over conventional building design concepts. It is noted that reducing energy consumption in the operational energy is not the only way of improving energy efficiency in buildings, but energy consumption and greenhouse gas emissions can also be minimized using appropriate construction materials. Therefore, in light of the energy crisis and climate change issues, it is imperative that the building sector be given adequate attention in developing buildings with a minimum negative environmental impact.

The building industry in developing countries is familiar with several design practices and material choices that result in a more energy-efficient house; however, when considering potential improvements in energy efficiency for small, low-cost houses, few energy-efficient design components are implemented. Improvement in energy consumption is based on available data that is regularly drawn from applications to larger buildings with different construction types. Although this is useful to a degree, the RDP houses in South Africa are much smaller, compared to those on which simulation and testing were performed. Therefore, the relative effect of one improvement versus another will not be the same. For instance, extra wall insulation may have an alternate relative impact on the total heating energy load of a small structure like a RDP-sized house than it would on a larger structure.

The absence of experimental data on small structures and the use of green building concepts to ensure the sustainability of the building sector is apparent. Enhancing energy efficiency through effective building envelopes, efficient gadgets and the integration of renewable energy solutions should be given priority

By executing programs for the development of sponsored houses that utilises a standard plan, the replacement of inadequate housing with more permanent structures can be implemented with economies of scale. In endeavouring to accomplish the most minimal capital venture for the houses, the development is restricted to an extremely basic plan, which ignores the lifecycle energy use of the structure. The effect of this type of housing will turn out to be more obvious in later years as millions are built and occupied. Energy-efficient plans for these standardised houses are vital to reduce the future financial burden on the national infrastructure, as well as the inhabitants of these homes, who are in the lowest income bracket in the society.

From the literature survey, it was found that limited systematic studies for energy conservation opportunities in buildings through passive/hybrid systems have been conducted in South Africa or globally. Most of the research investigated the energy conservation opportunities in commercial/residential and industrial buildings mainly for operational energy. Hardly, any research has been emphasized to study the energy impact related to the embodied energy of buildings. This study will focus on different regions in South Africa during the heating season when energy efficiency saves money as well as improves the wellbeing and security of the inhabitants. The investigation will conclude with suggestions for enhancements to masonry-based, low-income housing for energy effectiveness, considering energy use and cost.

1.2 Problem Statement

During 1977, South Africa delivered the Building Standards Act and National Building Regulations, which set the groundwork for the building industry in the country. After numerous changes, the South African National Standards (SANS) 10400 document was utilised as a guideline for builders on the application of the National Building Regulations. Until July of 2011, there was no direction on energy utilisation for buildings in SANS10400, and this requirement was recently included in South Africa National Standards, (2011). This consideration shows the mission and long-term vision of the government to control the ever-expanding energy demand of a quickly growing population. However, while the energy efficiency building criteria are presently specified, comparing the RDP houses and the national energy code highlights that the government-subsidised houses neglect to meet the code in most categories, (Haripersad et al., 2015). This impact will become apparent over many years and result in an adverse effect on the mission of the South African Government and the construction industry. However, several related issues impact energy-efficient building projects including inadequate design; poor quality construction, and affordability.

The sub-problems

- Sub-problem 1: Inadequate design in the form of, *inter alia*, incorporating energy-efficiency guidelines of National Building Regulations and SANS into building plans and using appropriate building materials with high thermal capacity.
- Sub-problem 2: The construction quality in low-cost houses is not of a consistently high standard in South Africa thus comprising the building envelope leading to excessive heat loss.
- Sub-problem 3: Mainstreaming of energy-efficiency initiatives are usually expensive.

1.3 Research Questions

What is the impact of selected construction materials when consolidated into the design of low-income, masonry-based houses in optimizing life-cycle energy, considering both construction costs and embodied energy?

What are the comparative results of two energy models created to address the primary inquiry, utilising the energy simulation programs EnergyPlus and TRNSYS?

What is the effects of the passive interventions on the thermal performance and comfort in the buildings?

In order to address this inquiry, the research sub-questions are:

- What are the costs and embodied energy data related to construction materials that is available in the South African market?

- Are there estimates of component and zone-wise overall embodied energies using the design specifications and plans of the surveyed buildings?
- What is the impact on the indoor thermal comfort for selected buildings?

1.4 Aim and Objectives of the study

Aim

This study aims to assess the impact of selected construction materials on operational and embodied energy and indoor thermal comfort on different residential buildings in South Africa with the intent to develop a model to improve embodied energy for thermal comfort.

Objectives of the Study

The three primary objectives of this study have sub-objectives to address the aims of the research. The first objective seeks to identify and deal with the assessment of factors that are critical to energy and construction costs. The second objective is to suggest solutions to the associated problems with the market and field survey while the last objective is to develop a model for Life Cycle Energy Assessment (LCEA).

Objective one - sub-objectives

- To conduct a market and field survey to identify the cost of the construction materials and embodied energy of materials available in the South African market.
- To estimate the component and zone wise overall embodied energies using the design specifications and plans of the surveyed buildings.
- To investigate indoor thermal comfort for selected buildings.

Objective two - sub-objectives

- To design plans for the different buildings, investigate and develop a baseline model energy-efficient building.
- To calculate and analyse techno-economic impact using simulated energy consumption and estimate the system cost for the proposed buildings.
- To explore and establish minimum criteria for energy-efficiency, taking into consideration the National Building Regulations (NBR) and the South African National Standards (SANS 10400XA and 204).

Objective three - sub-objectives

- To perform a life cycle analysis for all considered buildings using different construction materials and design specifications.

1.5 Purpose of the Study

This study will examine the relative improvement capability of different efficiency best practices on small, masonry-based structures, like those normally developed for RDP housing in South Africa. This will have the effect of improving the standard plan of such homes, which might be adopted or adapted for government-built housing and subsequently improve the quality of life in the country.

These upgrades will decrease life-cycle expenses of houses and lessen the energy burdens on the government. By zeroing in on climates where the requirement for heating energy is predominant, the upgrades in house designs are required for comfort as well as to prevent unsafe temperatures during winter conditions. The investigation of different energy enhancements for small houses require a precise strategy for examination and a controlled report where building highlights can be changed, and the impacts examined on a variety of potential feature designs.

The study will find and recommend innovative development solutions to improving the competitiveness and performance of the building sector, as per the South African government's mandate. The present life cycle analysis (LCA) intends to increase energy-efficient industrial activities by displaying energy decreasing techniques for low-income housing. The research examines whether the change from customary material advances as represented by the RDP house, to creative material innovations, as represented by the conventional house (CH), can result in quantifiable improvement with regard to embodied energy use over the whole building's life cycle.

1.6 Significance of the Study

This study is useful for associations intending to plan and develop low-income housing utilising masonry construction. The results of the study will also be extremely beneficial to policymakers, building designers and consultants, architectures, homeowners, occupants, as well as construction material manufacturers. The kinds of upgrades that will be recommended will be scientifically verified to reduce life-cycle costs versus an uninsulated design utilising realistic assumptions of upgrade costs, life-cycle utilisation, climate data, and inhabitant behaviour. The life-cycle cost and energy savings can be duplicated when countless houses will be planned, creating an estimate of the overall savings for the occupants both in money related and energy forms. Many housing improvement plans executed by the government to provide housing to a huge number of its constituents include a cost-sharing model for capital and energy costs. Designing an energy-efficient, low-cost house with standard materials and development practices benefits the inhabitants of the house as well as the infrastructure and the government that serves the people. The capacity of a structure to maintain indoor thermal comfort becomes more significant when the climate gets colder. Many emerging nations are situated in hotter climates where the essential concern is keeping the occupants cool and dry. This investigation will recommend energy-efficient designs that will improve the capacity of the house to remain warm in colder climates with less energy. This will maintain the inhabitants' comfort level and keep them warmer and safe during the coldest conditions, which can dip below freezing at night. By creating building energy models over two different simulation software packages, this study can furnish energy modellers with instruments and tips to utilise in other modelling projects regarding small, masonry-built structures. The current literature does not archive the changing sensitivity of building energy models to various boundaries as the size of the structure decreases. Additionally, it is worth noting that this study researches the LCEA which considers embodied energy and uses a predictive formulated model equation that could be directly used for such estimations.

1.7 Scope/Delimitations of the Study

To permit a more profound investigation of energy use and improvement procedures, only masonry-based structures will be considered in this study. The type of construction materials utilised can fundamentally influence the kinds of enhancements that can be executed, including the relative effectiveness of energy efficiency measures. Many other countries including South Africa have based their building design on a concrete and brick construction for the durability factor and economic advantages. This research will only focus on this construction material type.

Discovering energy-efficient enhancements for concrete and masonry-built houses that are cost-effective and can be effortlessly executed by homebuilders includes utilising simple design modifications. Hence, this study will not test building advances that drastically adjust the concrete, masonry-built construction and additionally require the utilisation of purpose-fit structural components. The selected climate is the central plateau region of South Africa. This location requires far more heating than most of the districts in Africa, despite the fact that the climate is generally mild in contrast to the more uneven and colder areas in numerous other developing countries of the world. The characteristic of the climate significantly affects the suitability of a building, and the energy effectiveness upgrades suggested in this study may not be relevant in more extraordinary climate regions. Notwithstanding, this study aims to give understanding into the behaviour of small buildings during various climatic conditions but still provide direction towards the predicted viability of efficiency enhancements to houses in those more extreme climates.

This study will not compare the RDP houses of masonry construction in South Africa to the traditional earthen huts used in the country. Different studies have indicated that the traditional earthen houses can provide more thermal stability than the uninsulated masonry-built houses presently in existence (Makaka & Meyer, 2006), and the consequences of those investigations can be cross-referenced with the results of this study.

1.8 Outlines of the Thesis

In this thesis, efforts have been made to optimise the model considering building size, orientation and interventions as per the local climatic condition.

The basis of such a study is the primary data regarding energy consumption, possibilities of energy conservation and techno-economic feasibility. This thesis is presented in five chapters. Each of the chapters of the thesis addresses a specific area of the study as follows:

The outline of the thesis is presented as follows. Chapter Two of this study presents the literature for the study. The building life cycle that incorporates embodied energy and operational energy will be discussed in the context of the research problem. The road map to the material selection that plays a significant role in embodied energy and thermal comfort is also highlighted with the researcher showing the correlations between the context of the research problem and the literature. A summary of the housing policies and building codes in energy-efficient construction as well as an overview of the different energy modelling software, EnergyPlus and TRNSYS, used were presented.

The research methodology employed to conduct the study is discussed in Chapter Three. The rationale for the methodology and sample technique used is provided. The research methodology followed in the study used a control group and an experimental group of houses, which were modelled using two different energy simulation software. The chapter provides details regarding the working principles and mechanisms pertaining to the analytical techniques employed in the experimental aspect of the study. The principles of the different techniques of computational modelling are also discussed here.

The Fourth Chapter of the thesis presents and discusses the findings of the study. The data is presented in graphical and tabular formats and analysed under relevant themes as per thematic analysis compliance. A comparative analysis between experimental and computational results are also presented here for validation and complementary purposes. Five different building parameters (geometry, wall, window, ceiling and slab) were compared in terms of energy outputs and their interactions with each other. The simulated data were verified with actual recorded data. The embodied energy was also analysed, and life-cycle analysis performed.

Finally, Chapter Five presents the conclusions and recommendations of the study, that are based on the findings that are presented in Chapter Four. This chapter also summarises the thesis, providing an overall sense of the achievements that were made in line with the aim, objectives and research questions of the study. It also indicates the contribution made to literature and recommendations for future work.

CHAPTER TWO: LITERATURE REVIEW

2.1 Relevant Research

Buildings are responsible for 30% to 40% of global energy consumption (Ghaffarian et al., 2013), 30% raw material and 25% water consumption (Adalberth, 1997), 12% land use and 25% solid waste generation (Zeng et al., 2007). Also, 33% of global greenhouse gas emissions come from the building sector (Levin, 1997). These statistics have attracted the attention of scientists, policymakers, politicians, and other stakeholders to tackle the above issues adopting sustainable solutions for building applications. Green building design strategies and integrating renewable energy technologies have been developed by experts in the field and numerous research has shown that it is being utilised in recent years in many new building developments. As a result, significant progress has been observed in the building and civil engineering industry in the area of green building development in both developing and developed countries. In energy-efficient building using green building concepts, significant attention has been given by relevant stakeholders to sustainable construction materials, energy efficiency, and renewable energy in order to optimize the life cycle energy.

The building life cycle demands both embodied and operational energy (Figure 2.1). Kotaji et al. (2003) assessed that embodied energy (EBE) represents about 10% to 20% of total life cycle energy in conventional buildings, while operational energy represents the excess 80% to 90%. The purpose and intention to reduce the dominant operational energy component is the main objective of an energy-efficient building design. Over the most recent twenty years, the incorporation of both active technologies and passive measures into "green" building design has radically decreased operational energy - in numerous examples, savings of more than 50% were accomplished. Contrary to this, reduction strategies for embodied energy are less prominent; while the more popular material resource strategies, for example, the use of recycled materials, are likewise not evaluated to affirm if they are yielding the ideal environmental benefits.

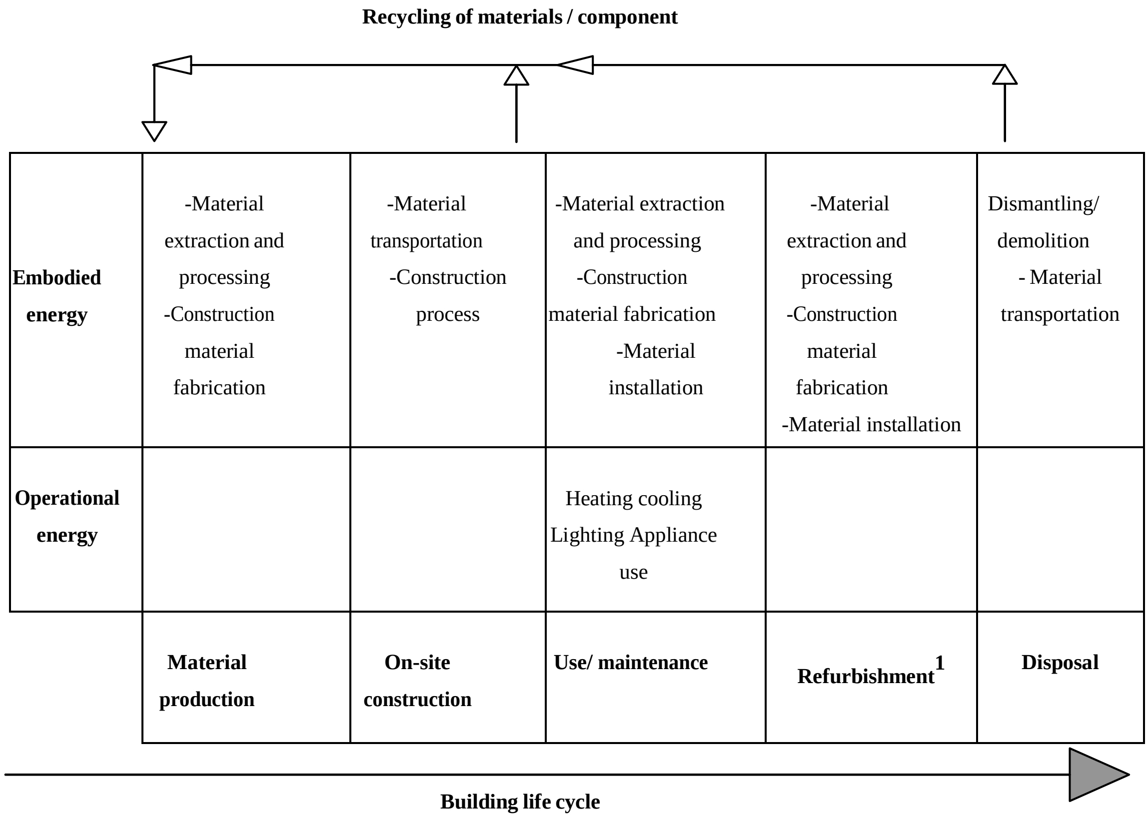

Figure 2.1 The make-up of embodied and operational energy over an illustrative building life cycle. Adapted from Yohanis and Norton (2002:78)

[1] Refurbishment is included for illustrative purposes only. Due to its highly uncertain nature, it is established practice to exclude it from actual embodied energy calculations

However, Sartori and Hestnes (2007) showed that as the operational energy is decreased, the life cycle energy is also diminished but the embodied energy part increases. For example, in a study which compared an energy-efficient house to a similar conventional house, a huge decrease in life cycle energy, namely, 60% was achieved. Moreover, for embodied energy an increase from 9% for the conventional home to 26% for the energy-efficient home was noted, while the operational energy followed a reverse trend and decreased from 91% for the conventional home to 74% for the energy-efficient home (Keoleian et al., 2001). This outcome was also found valid in sixty case studies, performed by Sartori and Hestnes, (2007) despite climatic differences, building type and other relevant factors. To achieve an energy-optimised building, it will require the ability to evaluate and audit both the embodied and the operational energy implications of alternative design options.

To predict the embodied energy contribution of an individual material is not as simple as green building practices assume. The choice of material infers the decision of essential constituents. Usually after construction, the embodied energy of the recycled material is greater than that of the virgin raw material. Therefore, by Trusty and Horst’s (2006) inferences, comparisons should be made with regards to building systems, rather than on a product-to-product basis. Subsequently the test for building designers is to comprehend the choices from a systems viewpoint; else it won't be conceivable to plan for optimal embodied energy, consequently LCA.

The measure of the environmental performance of a product over its whole life cycle is a science-based instrument that is known as the Life Cycle Assessment (LCA) concept. The cradle-to-grave analysis is where the extent of the inquiry ends with the transportation of the product to the point of disposal. If it incorporates the recycling potential, it is regarded a cradle-to-cradle analysis. Environmental performance is estimated over a wide scope of factors like potential impacts on human health, ecosystem health and natural resources. “Embodied effects”, in LCA is the potential environmental effects related with material production, use, maintenance, transportation and disposal where the word embodied alludes to the attribution/allocation which can be accounted for, rather than true physical embodiment. In the construction industry, the building community tends to refer only to “embodied energy” (Trusty & Horst, 2006). However, the detailed list of effects investigated by LCA (Table 2.1), implies that all the extractions from and releases to the environment are embodied effects. There are also embodied effects associated with the making and moving of energy which is known as pre-combustion energy. The Life Cycle Energy Analysis (LCEA) is where every aspect of life cycle energy use are evaluated in a study. On the other hand, the study scope could be restricted to either operational energy or embodied energy examination.

Table 2.1 Embodied effects typically investigated in an LCA

Inputs (natural extractions)	**Outputs (releases to environment)**
• Energy • Materials • Water • Land	• Acidification • Climate change • Eutrophication • Eco-toxicity • Human toxicity • Photo-chemical oxidant formation • Ozone depletion

2.2 Embodied Energy

Depictions of the life cycle energy of a structure recognize three particular categories of embodied energy, namely, initial embodied energy, recurring embodied energy, and demolition energy as described in the life cycle energy of a building. The initial embodied energy of a building is the amount of the energy embodied in all the material utilized in its construction. It is accrued during the material production and on-site construction life cycle stages that are influenced by material production energy, material mass, transportation distance, construction techniques and context of application (Figure 2.1). Recurring embodied energy is the amount of the energy embodied in the material used for maintenance and renewal of materials and components to restore a building over its life span. The most important factors affecting the recurring embodied energy of a material are its service life, replacement factor and nature and frequency of maintenance. Demolition energy is the energy required to break down or dismantle a structure and transport the remains to a disposal site. When demolition energy is compared to total life cycle energy, it is found to be minute regardless of material choice.

Construction materials play a significant role in the EEB/ green building construction and embodied energy of materials is given adequate attention in EEB and green building rating and certification processes and kept under major elements (including sustainable site planning, water and wastewater management strategies, energy performance optimisation, and quality of indoor environment). Recent studies also indicated the significance of the embodied energy in total life cycle energy (LCE) of the buildings

(Crawford & Treloar, 2006; Pullen, 2003). The material energy efficiency during the construction is ensured by choosing low embodied energy materials. Therefore, the embodied energy of the materials is assessed before adoption. Also, recycling and reusability of the construction materials after the useful life of the material is taken into account during the time of planning. Usually, in a lifespan of 50 years, embodied energy accounted for 45% of the total energy need, however, the percentage may vary with building typology, climatic conditions of the building location, and local availability of desirable construction materials. The recycling potential was estimated between 35% and 40% of the embodied energy (Thormark, 2002). The embodied energy is costed mainly in the initial construction stage of a building, whereas operational energy accumulates over the life span of the structure. The embodied energy can be reduced by approximately 17% or increased by about 6%, through material substitution, Thormark, (2006). A literature survey assessed the proportion of embodied energy between 9% and 46% of the overall energy utilized over the building's lifetime for low-energy buildings and between 2% and 38% in conventional buildings. The survey was conducted for a total of 60 cases, which include residential and non-residential buildings from nine countries (Sweden, Germany, Australia, Canada, Japan, etc.), Sartori and Hestnes (2007). The embodied energy of building materials depends on the production process of the material (Reddy and Jagadish, 2003), while the embodied energy of buildings depends on ten parameters: system boundaries, primary and delivered energy, methods of embodied energy analysis, age of data sources, geographic location of study area, technology of manufacturing processes, source of data, completeness of data, temporal representativeness, and feedstock energy consideration (Dixit et al., 2010).

2.2.1 Initial embodied energy

The initial embodied energy is made up of the energy needed for extraction and manufacturing of a material, as well as energy utilized for its transportation to the building site.

2.2.1.1 Material mass and material production

It is popularly known that in the construction industry, that material production constitutes the major portion of the initial embodied energy of a building (Cole, 1999). It is subsequently, considered to be an acceptable practice to select materials with only material production energy being taken into account. Notwithstanding, the initial embodied energy contribution of a material depends on the synergy between production energy and material mass. For example, in a study that compared the contribution of, materials to the initial embodied energy of a three-bedroom house it was deduced that regardless the generally low production energies (Table 2.2) of ceramic tiles, concrete and timber, their utilization in enormous amounts in development of the building implied that these three materials represents about 90% of the initial embodied energy. Notwithstanding the generally high production energy of aluminium, its' the initial embodied energy is negligible due to its limited use in the dwelling (Asif, et al., 2007). The new trend to utilize aluminium doors and windows can greatly impact the energy input of a building (Venkatarama & Jagadish, 2001). Since the results vary widely for individual materials, decisions regarding design need to be based on material selection.

From the study by Asif et al (2007), an applicable outcome which is supported by the results of other building-related energy studies shows that the common practice to utilize concrete in enormous amounts in building development for the most part makes it liable for an extremely huge portion of the initial embodied energy and related environmental impact of a structure.

Table 2.2 Initial embodied energy contributions of materials used in constructing a home. (Adapted from Asif, Muneer and Kelly, 2007)

Material	**Quantity (kg)**	**Production energy (MJ/kg)**	**Contribution to Initial Embodied Energy**
Concrete	130 000	1	61
Timber	5725	8	14
Ceramic tile	4030	5.24	15
Glass	313.6	13	2
Aluminum	25.3	232	3

2.2.1.2 Transportation distance

Material transportation may assume a significant part in the make-up of the initial embodied energy of a building and is, therefore, generally evaluated in a study. Based on the studies by Junnila et al. (2006) and Keoleian et al. (2001) where materials are sourced locally, within a distance of 50 km, transportation energy was found to be insignificant. However, due to the high reliance on imported construction materials, transportation can contribute greatly to the initial embodied energy. In the research by Chen, Burnett and Chau (2001) which focused on two high rise residential buildings in Hong Kong, it was found that the embodied energy of imported steel and aluminium contributed over 75% of the total embodied energy of each building. They reasoned that the change of the key building materials from virgin raw materials to the recycled forms could save over 50% on the total embodied energy of each building. This finding in regard of reused materials stands out strongly regarding with the previous example, reiterating the need to avoid a “one size fits all” approach when embodied energy is utilised as a measure for material selection. Tables 2.3 and 2.4, below, depict the energy used by different mode of transportation of building materials.

Table 2.3 The Relatively Small Values among the Data of Energy Use in Different Modes of Transportation

Method of Transportation	Energy Use (MJ/kg-km)
Deep-sea transport	0.216
Truck (road)	2.275
Coastal vessel	0.468
Class rail roads	0.275

Source: Atmaca, A., and Atmaca, N., *Energ. Build*., 102, 417–431, 2015.

Table 2.4 Energy in Transportation of Building Materials

Method of Transport	Energy Use (MJ/km)
Sand (m^3)	1.75
Crushed aggregate (m^3)	1.75
Burnt clay bricks (m^3	2.00
Portland cement (tonnes)	1.00
Steel (tonnes)	1.00

Source: Reddy, B.V.V., and Jagadish, K.S., *Energ. Build.*, 35, 129–137, 2003

2.2.1.3 Construction method

As indicated by figures originally recommended during the 1980s, the construction process most likely records for just 7% to 10% of the initial embodied energy of a building, Cole (1999). Therefore, it is generally excluded from related energy studies of buildings and statistics information are rare. However, the results drawn from the limited published studies emphasize a significant connection between materials their development strategies and the contribution to initial embodied energy. For example, a comparative study by Cole (1999) explored the on-site construction of wood, steel and concrete structural building assemblies found that the construction energy for wood and concrete assemblies are higher than for steel assemblies, it is a lower amount of the initial embodied energy than normally accepted (Table 2.5).

Table 2.5 Construction energy of alternative structural materials (Adapted from Cole, 1999)

Material	**Construction energy as a portion of initial**
Concrete	11-25%
Steel	2-5%
Wood	6-16%

The outcome in regard of cement and steel is upheld by a later report which found that when contrasted with steel, a concrete structural frame involves higher construction energy (Guggemos and Horvath, 2005). This is the case since concrete construction techniques need a more prominent utilization of impermanent materials, longer duration of equipment usage and larger transportation impacts. Then again, the painting, torching, cutting and welding of steel contributes significantly to emissions of Volatile Organic Compounds (VOCs) and heavy metals. Choosing steel in lieu of concrete would in this manner bring about a trade of embodied toxicity and embodied energy. Recommendations for energy-saving arising from the latter study in respect of concrete construction techniques incorporates modular design and off-site fabrication. Wastage of construction materials during the construction is very common and should be incorporated in the total embodied energy calculation. The values of waste factors depending on the type of construction materials are listed in Table 2.6. The actual waste factor may vary from these values according to the construction practices at different locations.

Table 2.6 The Value of Waste Factors for Different Types of Materials Used in the Construction of Buildings

Material	Waste Factor (%)	Material	Waste Factor (%)
Aluminium	2.5	Polystyrene	5
Coatings (paints and lacquers)	5	Polythene	5
Concrete (reinforced)	2.5	Polyvinylchloride (PVC)	5
Concrete (plain)	2.5	Steel	5
Copper	2.5	Tiles and clinkers	2.5
Glass	0	Timber (planed)	2.5
Gypsum wallboard	5	Timber (rough saw)	2.5
Mineral wool	5	Timber (shingles and shavings)	2.5

Source: Atmaca, A., and Atmaca, N., *Energ. Build.*, 102, 417–431, 2015.

2.2.1.4 Context of application

When analyzed with regards to building sub-systems, the dispersion of the initial embodied energy follows a similar trend, regardless of structural materials and building type, Cole and Kernan (1996) compared alternative wood, concrete and steel structural systems. They discovered that despite the difference in structural materials, the distribution of the initial embodied energy followed the similar pattern in all three buildings, specifically: envelope materials represent 26% to 30% that comprises the largest single part; structural materials contribute 20% to 24%, service materials contribute 20% to 25%; finishing materials represent the least, of about, 12% to 15%; the building structure and envelope together contribute approximately 50% of the initial embodied energy

The study by Keoleian et al. (2001) which researched the implications of the life cycle energy of a dwelling recommend that the latter finding is valid for houses.

2.2.2 Recurring embodied energy

The recurring embodied energy is a combination of embodied energies of the material used for maintenance, repair, restoration, refurbishment, or replacement over the entire service life of the building.

2.2.2.1 Service life

Service life is the timeframe after on-site construction or installation during which a building or its components comply with or surpass performance prerequisites (Kotaji et al., 2003). The designed service life (DSL) of a structure reflects the durability of the building system and envelope materials. Building designers ordinarily base the DSL on the actual service period of similar local buildings which generally may not be equivalent to the DSL. Consequently, a more limited DSL is frequently assumed for commercial buildings since it is more prone to functional obsolescence. The potential service life of a material/component can be obtained from manufacturers or obtained from the designers experience relative to service life.

Table 2.7 Building service life examples

Country	**Building service life (years)**	
	Residential	**Non-residential**
Finland	80	
Netherlands	75	20
Sweden	40-50	
United Kingdom	60	60
USA	60	60

2.2.2.2 Replacement factor

The replacement factor gives a mean to contrast the durability of finishing materials with that of the structural system and envelope materials. Chau et al. (2006) describe it as an indicator of the frequency, which includes the first installation that resource input is needed for installation of the material/component within the DSL. The initial embodied energy weighted up by the replacement factor is, accordingly, given by the material contribution to the life cycle energy of a building/structure. Moreover, the life span of certain construction materials may not be the same as the building itself and may need to be replaced several times during the whole life of building. The replacement factors for some common building materials and elements are given in Table 2.8.

The contribution of every material/component is obtained by utilising the following formula:

Replacement factor = DSL/material service life

When estimating the recurring embodied energy of a material it is common practice to include only routine maintenance and replacements in a research study and to exclude all unplanned activities such as refurbishment because the latter is unpredictable and difficult to forecast.

Table 2.8 The Replacement Factors of Typical Building Materials and Elements

Building Components	**Replacement Factor**	**Building Components**	**Replacement Factor**
Structural elements (columns, beams, etc)	1.0	Plastic carpeting	2.4
Flooring	1.0	Painting and wall papering	5.0
Walls and roofing tiles	1.3	Others	1.2
Ext./Int. walls	1.0-2.4	Doors	1.3-2.0
Windows	1.3-2.0	Paints and Coat.	5.0-15
Ceiling finishes	2.0-4.0	Acoustical tiles	2.5-3.75
Floor finishes	3.0-4.0	Vinyl flooring	2.5-4.16

Source: Chen, T.Y. et al., *Energy*., 26, 323–340, 2001; Atmaca, A., and Atmaca, N., *Energ. Build.*, 102, 417–431, 2015.

2.2.2.3 Nature and frequency of maintenance

Maintenance is required due to material use which ultimately determines the service life of a material. An embodied energy assessment differentiates between the embodied energy input of routine maintenance, which is included in the study, and purely unplanned maintenance which is excluded because the occurrence of later is uncertain. The recurrence of maintenance or service life is controlled by product manufacturers and shown on certificates or outlined in product information sheets.

2.2.2.4 Implications of recurring embodied energy

Up to this point, the belief that recurring embodied energy is not a major contributor to building life cycle energy, and consequently not a significant criteria for materials selection, became pervasive in the building construction community. The results of building-related energy studies, however, displays the converse to be valid. In the comparative investigation of three office buildings, Cole and Kernan (1996) found that regardless of the variations in structural materials, the recurring embodied energy followed a similar trend in all three buildings, specifically: the recurring embodied energy for a short DSL, of about 25 years, was always lower than the initial embodied energy; the recurring embodied energy for a longer DSL surpasses the initial embodied energy by age 50 years. For an exceptionally long DSL, state 100 years, the recurring embodied energy is 200% to 300% of the initial embodied energy. The largest contributor to initial embodied energy is envelope and structural materials, which contributes the least to recurring embodied energy. In contrast, finishes, the main source of recurring embodied energy contribute the least to the initial embodied energy. For over a 100-year service life, the building components that contribute the greatest to recurring embodied energy in ranked order of importance are finishes, building services, envelope materials and structural materials.

The results of Cole and Kernan (1996) have been validated in various ensuing studies. Particularly, in the Keoleian's et al. (2001) research which compared a conventional house and an energy-efficient house; it was observed that a finishing material that has high production energy, but a short service life, contributes significantly to recurring embodied energy. They inferred that a change over from carpet to a floor finish which is initially more expensive and requires routine maintenance but no replacement during the DSL would significantly decrease its recurring embodied energy share and also result in life cycle cost savings. In another comparative investigation of two office buildings, one located in Finland and the other in the United States of America, Junnila et al. (2006) found that frequent replacement of carpets and ceilings, and periodic repainting contributed the greatest to the recurring embodied energy of both office buildings. Chen, Burnett and Chau (2001) found that for buildings with longer lifespan, the recurring embodied energy is greater, and the initial embodied energy is relatively lower.

2.2.2.5 Demolition energy

Notwithstanding building type or constituent materials, demolition energy contribution is small when compared to the other aspects of the life cycle energy of a building. There is very little data on demolition energy because most studies disregard it or do not report it in the results. A study by Venkatarama and Jagadish (2003) of a three-storey office building found that demolition energy only adds up to 1% to 3% of the life cycle energy.

However, when structures are demolished and materials recycled and their embodied energy is lost and not usually accounted for in building-related LCEA, it is clear that the end-of-life (EOL) management of buildings/structures is not consistent with the concept of sustainable construction. Approximately half of all materials extracted by mining are converted into building materials and products. Koroneos and Dompros, (2007) noted that when these same materials are part of the waste after demolition, they account for about half (50%) of all waste accumulated prior to recovery. Globally, the rates of recovery of construction and demolition (C&D) waste are not properly recorded, yet is presumably low – for example of the nearly 136 million tonnes of C&D waste that is generated yearly in the USA, probably less than one fifth (20%) of the total mass is salvaged in some way or another (Kibert et al., 2000).

Considering the conceivably negative environmental impacts related with the excessive waste of materials and their embodied energy loss, there is a need for the stakeholders in the green building sector to engage to ensure that steps are taken to create a mind-set shift from waste management to recovery management. The key ideas and procedures recommended in support of a more sustainable EOL management for buildings/structures is outlined. A closed loop construction sector system to assist and coordinate the reallocation of C&D waste and products back into the building industry for purposes of either recovery or waste management (Kibert et al., 2000). An industrial specified building LCEA model which extends its boundaries beyond mere accounting for demolition energy but to evaluate the potential for lessening the embodied energy requirements of proposed structures through material recovery management practices (Sartori and Hestnes, 2007). Classification of recovered materials into waste management or product recovery management (PRM) for direct reuse; and the implementation of an LCA-based energy cost model, namely, energy saving value (ESV) to assess the amount of energy that is saved when secondary materials are replaced for primary materials (Schultmann &Sunke, 2007). An extended producer responsibility (EPR) policy requires producers to take responsibility for their products after their end of life (EOL). The fundamental drivers of EPR are lower pollution rates and resource use over a product's life cycle. For buildings, EPR creates the possibility of diverting recovered materials away from landfill sites and into direct reuse, PRM, and incineration associated with energy recovery.

However, closing the loop would mean a paradigm shift in design which encourages dismantling instead of demolition. The quantity of potentially recoverable material is assessed by building design but presently, the idea of design for dismantling in the green building sector is the exception rather than the rule.

From the turn of the new century, attempts to adjust the life cycle energy performance of buildings with the criteria of sustainable construction essentially focused on diminishing the predominant operational energy part. However, as the green building community progresses towards the ultimate “net-zero energy building” (nZEB), embodied energy has surfaced at the forefront in building life cycle energy management.

Analysis of the results from various building-related energy studies identified the following issues as the main shortfalls of the existing material selection process. Production energy, also commonly known as “embodied energy” in the building construction community, often serves as the only measure for material choice. However, it may not generally be the main factor to determine the initial embodied energy contribution of a material. The “one size fits all” practice of determining recycled materials in order to avoid the production energy of raw materials may be environmentally favourable on the one hand but may not benefit the environment positively in another instance. The choice of a material has systems implications, meaning that it constitutes the choice of materials such as glue, grout, insulation or steel reinforcement. However, there is a tendency to compare materials on a simple product-to-product basis. Recurring embodied energy, which emerges from routine maintenance, is perceived as a minute part of total life cycle energy. However, the results of embodied energy studies repeatedly show that due to long DSL of buildings, recurring embodied energy is often greater than the initial embodied energy. Service life is related to durability and may be the most significant criteria in the selection of interior finishing materials such as floor covering or paint. However, green practices place very little emphasis on the relationship between service life and contribution to recurring embodied energy. Designers of green buildings rarely consider the fate of materials and their embodied energy at the EOL cycle for a building; therefore, building designs which incorporate disassembly and re-use of materials are the exception instead of the rule.

Furthermore, the study should demonstrate:
The comparative values of embodied energy using components of building structures that are built with different construction materials in varying proportion and the whole life- cycle for buildings in different construction scenarios and their sustainability. Holistically, the life cycle perspective which incorporates service life is the only way to ensure true equivalence of the various other options.

2.3 Road Map for the Material Selection Process

Given the unique nature of buildings/structures, individual case LCEAs would form the ideal framework for assessing embodied energy which plays a crucial role in material selection in modern housing construction. While there are numerous software packages available in South Africa for conducting LCA, competencies and logistical issues such as specialised skills, data challenges, costs and time are typical constraints to credible results. In the absence of national-specific tools and data set, the strategies that follow can serve as a basic framework for optimising the embodied energy of buildings, namely:

2.3.1 Overall strategy

Numerous factors determine the initial embodied energy and recurring embodied energy contribution of a construction material. These are material mass, production energy, context of application, construction method, service life and transportation distance. In addition, obtain as much information as possible on these factors and utilise it as a check list when comparing alternative materials. Do not base your options on environmental attributes, like recycled content. Identify and act on environmental trade-offs, like avoiding the toxic effects of an internal finishing product should override avoiding embodied energy. Consult LCA-based product information sources to support your choices.

2.3.2 Design strategy

Design taking into consideration facility maintenance and EOL. Focus on innovative detailing and durability which facilitates dismantling rather than demolition.

2.3.3 Specification strategy

Select envelope and structural materials when considering the chosen DSL. The materials selected should have a long lifespan and last with minimal maintenance. Optimise initial embodied energy and reduce recurring embodied energy. Consult product datasheets and suppliers when choosing finishes. Long-life finishes which require periodic maintenance are generally preferable to short DSL finishes which require frequent replacement.

2.4 Elements of Comfort

Carlucci (2013) stated that buildings/dwellings are an expression of our basic need for shelter which is influenced by different factors including the need for security and comfort. The selection of construction materials assumes a significant role with respect to indoor thermal comfort in a building. Our responses to and perception of our dwellings are inseparable from the manner in which our buildings respond to the environments and climate in which they are constructed. At the point when occupants of buildings find the indoor environment to be uncomfortable, the impulsive response is to utilise mechanisms to accomplish improved comfort levels (ASHRAE, 2013). These reactions incorporate either voluntary or involuntary mechanisms. Involuntary mechanisms are normally physiological while voluntary mechanisms require some effort to vary the surrounding environment either by altering it directly such as opening a window or adjusting the thermostat, adjusting our state (activity levels or clothing) or moving to a space that is more comfortable.

Figure 2.2: Elements of indoor Comfort (CIBSE 2006)

A huge portion of energy utilization in numerous residential and commercial buildings relates to the management of thermal comfort levels via heating and cooling of indoor spaces (Lam 2000; Perez-Lombard, Ortiz & Pout, 2008). Hence, the study focuses on these elements which have the potential to drastically impact the energy utilization of our buildings directed by our behavioural patterns, such as adjusting temperature control set-points or opening and closing windows to obtain improved comfort.

The components viewed as significant in this regard are:

- Thermal comfort
- Aural comfort (Acoustic)
- Visual Comfort (Lighting)

Secondary aspects which may serve as confounding or compounding factors include:

- Air movement
- Air quality

2.4.1 Thermal comfort

A detailed list of international research has been developed over the century to acquire a comprehensive understanding of the different subtle parameters that determine thermal comfort. Carlucci in his book *Thermal comfort assessment of Buildings,* (2013) has compiled a summarised list of more than 70 different models and indices that can be used for predicting human thermal comfort. These indices can be statistically classified as cumulative values, percentages, risk or averaging indices and are determined from combinations of the heat balance of the body, physiological strain and physical environmental parameters (Carlucci 2013). The common trend in most of these models is that it is rarely possible for inhabitants of a building to reach an agreement as to which conditions provide a comfortable indoor environment.

The six principal factors that contribute to the sensation of thermal comfort are:

- Air temperature
- Air movement
- Clothing levels/insulations
- Humidity
- Metabolic rate
- Radiant temperature

Uniformity of sensation also plays a vital role in perceived levels of indoor thermal comfort (CIBSE, 2006). This refers to instances where variations in skin temperature for different sections of the body have extreme values but individually within the comfort band range. Also, spaces tend to become stuffy when the indoor air temperature is higher than the radiant temperature. This can occur with convection air heating systems. In an ideal situation, the radiant temperature should be only slightly higher than the indoor air temperature. In order to prevent further discomfort however, the temperature difference should be small (CIBSE, 2006). The average radiant temperature can be obtained with a black-globe thermometer. It has proven to be impossible to target a condition where occupants of a building will always feel comfortable (Carlucci, 2013; ASHRAE, 2004; CIBSE, 2006). For this reason, when designing for thermal comfort, a model using static comfort equations developed by Fanger, (1967) should be used. The model is based on the six main factors listed above to create a predictive comfort index on a thermal sensation scale referred to as the predicted mean value vote (PMV) and percentage persons dissatisfied (PPD) (Ole Fanger 1970; Fanger et al., 1974; ASHRAE, 2013). The model which considers the six factors allows designers to develop interior conditions where most of the occupants of the building are thermally comfortable most of the time. Field studies designed to validate the PMV-PPD model by de Dear and Brager (1998) have proven that the model does not apply to free running indoor conditions as found in naturally ventilated spaces. Accordingly, the PMV-PPD model assumes an environmental steady-state and makes no allowance for adaptation or acclimatization (De Dear & Auliciems 1995; de Dear & Brager 1998). This then implies that these early models are limited and inadequate for predicting thermal comfort levels in naturally ventilated indoor spaces that do not have closely controlled conditions. This then effectively excludes those buildings or dwellings that adopt passive comfort control measures from a reliable assessment.

2.4.2 Adaptive thermal comfort

As the utilisation of electric heating and cooling continues to increase in South Africa (Barnes et al., 2009), it is becoming important to obtain ways to increase the comfort envelope for different types of buildings to reduce the energy required for indoor comfort control. Gonzalez et al. (1974) states that the reason for the failure of the PMV-PPD model is that the sensation of thermal comfort is not limited to empirical measures but is also influenced by physiological and psychological adaptation. The effectiveness of the modes by which our bodies exchange heat changes with the environment. Similarly, our capacity for thermo-regulation changes between different types of buildings/structures and environments.

The ASHRAE's 55 latest revisions have accepted the findings and adopted the recommendations of de Dear and Brager (2002) in that a thermal comfort model is required which incorporates the issues of adaptation and acclimatization (Brager & de Dear, 2001; de Dear & Brager, 2002, 1998). This standard was developed in alignment with and to satisfy the ISO 7730:2005 standard (ASHRAE, 2013).

"The adaptive hypothesis predicts that contextual factors and past thermal history modify building occupants' thermal expectations and preferences" – (de Dear and Brager, 1998)

It has been observed by de Dear and Brager that over the past four decades, building designers and engineers may have been chasing an elusive theoretical sweet spot to lower energy consumption by developing increasingly complex heating, ventilation, and air conditioning (HVAC) systems thereby satisfying the PMV-PPD model; and meanwhile, the art of creating net-zero buildings (nZEB), which can adapt to the environment and can be adapted to, is ignored.

The level of perceived comfort in nZEB structures can be further improved if people occupying the building are given a certain level of control over their environment. Studies indicate that people are more physiologically stable when they are given the ability to control at least some aspects of their indoor environment even though the control is merely over aesthetic elements (Rodin & Langer, 1977). Simple control over opening blinds, windows, dress code and location within the indoor environment are highly effective in this regard (CIBSE, 2006). The challenge lies in designing spaces which are not restrictive with respect to these aspects but remain efficient and functional.

An exemplar from the many associated studies, is the one conducted in Libya in 2001, which found that the PVM model in theory predicted that a sample of old style, naturally ventilated buildings with courtyards and porches would show high levels of occupant thermal stress. The actual mean vote (AMV) for these dwellings resulted in similarly high level of thermal comfort when compared to a group of modern designed insulated and air-conditioned buildings. Surprisingly, it was noted that the occupants of the older design buildings were generally more comfortable with their indoor thermal environment (Ealiwa et al., 2001; Emmerich et al., 2011).
Unfortunately, it is rare to achieve year-round adaptive comfort in a nearly nZEB structure since climatic conditions would naturally not allow it. For this reason, most commercial buildings would at least need some form of seasonal mixed-mode comfort control. The mechanical section of these HVAC systems would provide cooling or heating only when the climatic

conditions would force the interior conditions to extreme levels of adaptive thermal comfort. Zonal mixed-mode systems should be used in sections of a building where occupants cannot adapt to fluctuating conditions.

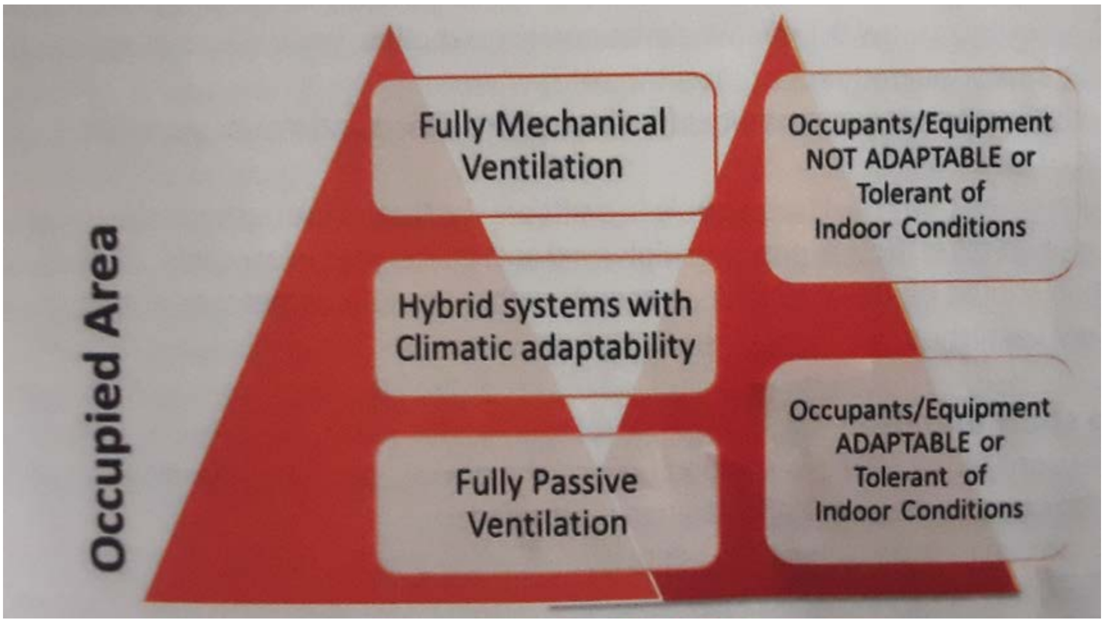

Figure 2.3 Indicator and demonstration of the principle that the proportion of occupied areas that have very restrictive requirements are relatively low

In view to promoting the adoption of a hierarchy of design solutions, with passive ventilation and comfort being given priority over mechanical control systems as depicted in Figure 2.3, where feasible, CIBSE have presented flow charts or decision trees in the CIBSE Guide for Natural Ventilation in Non-Domestic Buildings (CIBSE 2005) and the CIBSE Application Manual AM 13: Mixed-Mode Ventilation (CIBSE 2000). Figure 2.4 demonstrates what is commonly known as the "DIKW Pyramid" and it should be stressed that the building simulation and modelling software can only occupy the information tier of this hierarchy. These software tools invariably rely on the quality of the data input and the skills of component designers to extract knowledge from the information they provide, and apply it with wisdom.

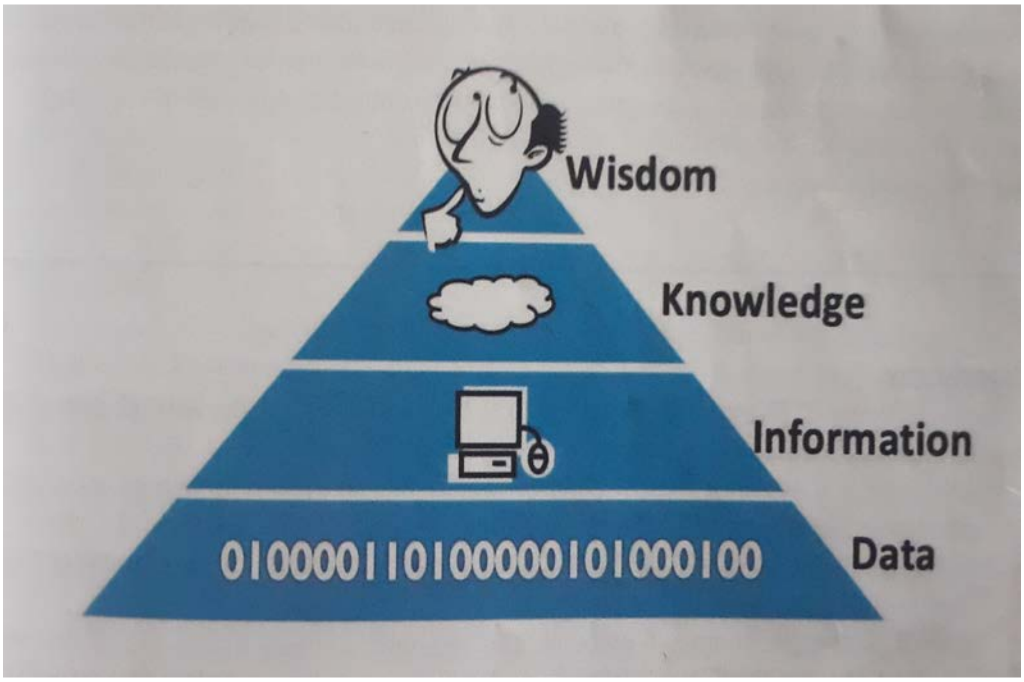

Figure 2.4 DIKW Pyramid

2.4.3 Air movement

According to Arens’ et al. (2009) study, it is highlighted that most occupants of a building would prefer greater air movement than is generally available. Air movement can contribute to the occupants’ ability to lose heat to the surrounding and keep cool under conditions that would be considered too warm in air-still environments (Arens et al., 2009). This will ensure indoor thermal comfort for inhabitants of a building. Comfortable air velocities in the occupied zone are generally in the range of 0.1-1.0 m/s. From ASHRAE, (2013) velocities below 0.3 m/s would be barely perceptible while velocities approaching 1.0 m/s would be considered “breezy”. It can be deduced that the following conditions need to be within narrow limits for thermal comfort to be accomplished:

- Air Temperature
- Air Movement
- Relative Humidity
- Radiant Conditions

These, however, rarely combine in nature to give perfect conditions and here buildings must intervene. Measuring 'comfort' can prove to be more difficult than expected as variations in individual perceptions of what is comfortable differ. Basically, the comfort prerequisites of inhabitants can be less rigid when they have ordinary expectations. As we adopt passive systems to meet the inhabitants' functional requirements it is critical to understand how the occupants' acceptance criteria or expectations can be accommodated or modified to satisfy their needs.

2.5 Summary of Housing Policies in South Africa

The key focus area in South Africa and many developing countries has been the development of housing policies for the building of modern government-subsidised houses. These governments worldwide are faced with the challenge of providing housing for their growing populations. Despite the fact that there has been a National Building Regulation (NBR) in the country since 1977 that outlines general construction practices for residential buildings, the implementation of the code is difficult to enforce due to the rapidly growing populations. The African continent has encountered population growth at a rate of 2.3% per year and is expected to add one billion more people by 2044 (Crossette, 2011). Creating adequate communities and houses for the ever-growing population is a challenge for the governing party of these nation states. Since countries are battling to cope with providing housing for the increasing population, this is forcing many people to use materials and strategies to construct homes which only provide for basic shelter. For instance, housing structures in the informal settlements of South Africa are often made of corrugated metal outer panels with old newspaper inside acting as a windbreak.

While South Africa does has a particular section of its constitution pronouncing that "everyone has the right to have access to adequate housing" (Republic of South Africa Constitutional Assembly, 1996: 10), the 2001 census shows that an estimated 1.3 million families lived in the informal settlements (South African Human Rights Commission, 2004). There is a huge global effort to find solutions for the housing crisis in these countries. The United Nations Population Fund is promoting the requirements for urban solutions since the general migration of population is toward metropolitan regions (Crossette, 2011). While this does create densely populated but complete communities, it is not the ideal solution for all occupants, as many would like some portion of land and space to call their own.

Socially, there is still a need for both rural and suburban communities, even though such settlements may be a less resourceful method of housing people in South Africa. The citizens of the country living in informal settlements are proof of this cultural influence. In spite of the fact that the occupants in these communities do not have adequate housing, they are proud to possess a portion of land to call their own, so they maintain that property and wait for building development opportunities to improve their housing circumstance.

The South African government has set up a program to give every individual an adequate safe house. This mandate is directed in Section 26 of the original constitution of South Africa: “The state must take reasonable legislative and other measures, within its available resources, to achieve the progressive realization of this right” (Republic of South Africa Constitutional Assembly, 1996: 10). The provision shows that the government leaders recognise the importance of providing housing for their expanding constituency and the advantages this has on the holistic prosperity of the country. Before the constitution was set up, the country had already taken the initiative to develop a housing program named the Reconstruction and Development Programme, or RDP. The program is intended to facilitate the development of housing for low-income groups by providing a subsidy for homebuilders in suburban and rural areas. The recipients of RDP houses, with an income of 3 500 South African Rand (ZAR) per month or less, qualify to receive a one-off award for land, administration services and building development costs (Landman, 2010).

In the initial phases of this program, there were insufficient funds and resources available to supply housing to all, especially taking into account the high levels of poverty directly after the fall of the politically-sanctioned racial segregation apartheid system in 1994. The program could only provide a small subsidy as a contribution to those wishing to construct a house. The People’s Housing Process (PHP) was presented in 1998, which put the obligation on the residents to construct their own homes with government-subsidised materials. The government could hence focus on providing citizens with the necessary infrastructure such as water and electricity utilities and transportation services. Normally the course is taken by the individuals who do not qualify for an RDP house but cannot afford a house in the private sector. The RDP supply mechanism is effective for the lowest-income population because it prevents the requirement of a building loan, for which most citizens in that income bracket cannot qualify. The South African government indicated that as of 2004, the RDP housing initiative has provided to 1.6 million households (Housing, 2004).

The RDP houses are approximately 40 m^2 in plinth area on 250 m^2 plots of land, and they are built almost mainly of concrete blocks or bricks. Builders have explored many variations on the standard geometry, including joining houses and building duplexes for larger families, as well as reconfiguring the structure with the supplied materials. In 2004, the Department of Housing in South Africa indicated the need for improvements in the implementation of housing to build sustainable communities, which was defined as "well-managed entities in which economic growth and social development are in balance with the carrying capacity of the natural systems on which they depend for their existence and result in sustainable development, wealth creation, poverty alleviation, and equity", (Housing, 2004: 11). This government initiative shows that the long-term RDP housing requires due consideration of not only exclusively providing people with houses, yet additionally establishing a climate for the future development of the community as a safe and healthy entity. This should incorporate proper access to resources and infrastructure. The RDP house design is specifically reviewed to assess the sustainability of the large-scale housing rollout. The design and quality of the RDP-houses are to be improved to change the face of the typical house and the associated stereotype that it as an undesirable house. The Department of Housing's goal was to "investigate measures and incentives to enhance housing design and promote alternative technologies" and to improve building quality with better construction standards (Housing, 2004: 16).

2.6 Improvements in Residential Building Codes and Energy-Efficient Construction

At present, the housing policies for residential building codes and energy-efficient construction is not strictly adhered to in South Africa. There is currently a dedicated section in the South African National Standards (SANS) 10400 that must be followed for all new building construction. The scope of this document includes all types of construction; for residential houses, the specification of requirements comes in the form of minimum thermal resistance values for the various components of the house

(South Africa National Standards, 2011). The inclusion of these requirements in the standard shows the vision of the South African government to control the consistently increasing energy requirements of a quickly developing nation.

This mission may be difficult to achieve since the RDP houses fail to meet the national energy code in most categories, (Haripersad et al., 2015). This is supported by thermal comfort testing in RDP houses, where Makaka and Meyer, (2006) showed huge temperature variations between day and night, as well as across the different seasons. The thermal response time, indicating how the interior temperature responds to outside changes of RDP houses is relatively short for a residential building, indicating the low thermal resistance of the structure, which prompts higher energy utilisation and greater operating expenses. In colder climates like the South African central region, this could lead to unsafe conditions for the occupants when the temperature drastically drops during the night. The method of space heating used by most RDP home occupants supports this concern. Many utilise compact space electric or kerosene heaters during the colder months, which are moved around to the different sections of the house. In a house that is poorly insulated, the heating devices' maximum capacity can be exceeded, and the internal temperatures will drop to uncomfortably or dangerously low levels. The heat-absorbing concrete walls, in combination with the irradiative heat source, intensify the challenge of obtaining indoor thermal comfort by not reflecting the radiated energy into the building. Instead, the heat is directed through the walls to the exterior of the house.

One outcome of utilising a lowest-cost design for RDP homes is the poor reputation the houses have among the citizens. The RDP buildings can only perform the essential function of providing shelter for the people with no other options; the houses are not comfortable internally and are not aesthetically appealing on the exterior. Many potential inhabitants utilise RDP housing if all else fails and would prefer to live in a more traditionally built house of greater quality that provides better indoor comfort consistently throughout the year. The housing organisations of South Africa are proposing a more sustainable housing strategy that develops design guidelines to create a dignified housing product. Instead of implementing a base design, the governmental institutions intend to expand on local construction techniques and to utilise the expertise of the local community in each area so that the RDP houses can blend into the surrounding, instead of creating a new landscape. The design upgrade of RDP houses will improve its quality and make it more appealing to the people of the country who are in need of housing. By improving the design, the government of South Africa would like to encourage public acknowledgement of the Reconstruction and Development Programme and to improve housing quality across the country (Housing, 2004).

The implementation of an energy code in South Africa is a move in the right direction. Considering the nationwide need for housing there is a great opportunity to highlight the benefits of the energy code if it is applied to the construction of the huge number of government-planned homes that will be developed in the future. The design can provide the citizens of the country with appropriate building methods and educate them on the significance of energy-saving and improved indoor thermal comfort. Not all homeowners will be able to comprehend the energy code; but rather by including new energy efficiency measures into the design of future RDP houses, the benefits of the energy code can still be realised.

2.7 Review of Building Energy Modelling in Small Residential Buildings

In many design and manufacturing sectors, the utilisation of computer simulation is rapidly replacing many past procedural standards including general guidelines and physical prototyping. Analytical simulation practice allows for the optimisation of a design before a large number of resources are invested for constructing and assessing the design. The residential construction sector is no different, with several building information modelling (BIM) software to assist designers to upgrade and optimise design plans. The building simulation and modelling program incorporating the appropriate hardware is more affordable, prevalent and user-friendly and access to these tools has improved. The benefits of building energy modelling are most apparent in large-scale construction projects with complex designs and energy usage components. The dedicated modelling program is applied to this type of building due to the complex nature of assessing energy use by manual calculations and basic spreadsheets.

While this has opened the gateway for intelligent indoor environmental quality (IEQ) solutions across a wider spectrum of construction types, a real risk is latent in the detail. An important point to note is that “a tool is not a solution”. This is most relevant in the complex field of simulation software. It should be emphasized that building simulation and modelling software can only occupy the information tier of this hierarchy as depicted in Figure 2.4 which demonstrates what is commonly known as the “DIKW Pyramid”. These software tools constantly depend on the quality of data to be input and the ability of skilled and competent designers to extricate the information provided and apply it with wisely.

Despite the fact that the utilisation of BIM is expanding as the product becomes more mainstream, small houses are not usually subjected to energy modelling software due to the relative simplicity of the structure. Building contractors, developers and designers frequently utilise their construction knowledge and general guidelines to estimate energy usage of a particular house.

To estimate the savings due to design variations to small houses, numerous techniques have been utilised. Uygunoğlu and Keçebas, (2011) suggest that one simple strategy is to use the conductance of a material and to compute heat flux through the material given a standard indoor temperature and the average temperature outside over a season, using heating degree-days to find total heat transfer through the material. At the opposite end of the spectrum are sensitivity analyses which take the architectural plans for a building and import them into a dedicated software tool such as a DOE-2 program, which automatically calculates energy utilisation based on varying building component properties (Tavares & Martins, 2007). This methodology is normally reserved for larger and more costly houses where the effects of energy are more substantial to the designers and future proprietors. For small houses, the construction project usually has a lower financial plan, limited timeframe, and complex building energy modelling software is typically not used.

The small size of the dwelling could mean the effect of the inhabitants, however very few, greatly impact the heating energy use of the house. The impact of inhabitants on energy use has been studied in residential buildings (Olofsson & Mahlia, 2012), alongside the establishment of comfort norms for indoor air quality (Nicol, 2009). In an investigation especially geared towards analysing different types of masonry walls with insulation in a hotter climate, Monteiro and Freire (2011) performed a life-cycle analysis of various insulation and facade materials to compare heating and cooling energy use to initial embodied energy. The study found that, when normalising wall thermal conductivity by changing the wall thickness, the double brick and concrete construction types had the largest complete environmental effect. This might be credited to the additional thickness of brick and concrete to accomplish an equivalent thermal conductivity as a wood-framed wall, thus adding material and embodied energy. An interpretation of these results is that masonry construction products should be used only for structural purposes and not as insulation because of the high embodied energy and environmental impact.

2.8 Overview of Building Energy Modelling Software

There are several types of building energy modelling software being used for the design of small residential buildings. However, both software used in this study has been more widely accepted in the building energy modelling community. The calculation of building space conditioning prerequisites depends on heat transfer calculations by means of conduction through envelope materials, fluid mass transfer, and radiation gains. A wide assortment of user applications has been created to complete these calculations, and each has various methodologies, techniques and user interfaces (Judkoff et al., 2001). The two dedicated simulation programs used in the study that display different approaches to building energy modelling are featured.

EnergyPlus is a calculation engine utilised for obtaining cooling and heating loads in buildings. The software is developed from an algorithm created by the United States Department of Energy (DOE) called DOE-2. The software is normally used in conjunction with a graphical user interface (GUI) overlay to facilitate user inputs and program outputs. The software is generally regarded to have a complete and moderately precise calculation which does well in modelling validation procedures such as the Building Energy Simulation Test (BESTEST), which evaluates the accuracy of building simulation programs. The open-source nature of the software permits the user to develop customised extensions to achieve expanded assignments such as batch operations and parametric simulations.

TRNSYS is rather a heat transfer calculation engine, specifically a building energy modelling software but is utilised for a wide variety of thermal transfer design projects. The TRN Build segment of TRNSYS focuses on building assemblies and offers specifications on different building component and usage aspects, which make it valuable as an instrument to cross-reference results from other modelling programs. TRNSYS focuses mostly on heat transfer simulations and is profoundly respected in the field for precisely assessing energy transfer. The source code is accessible and allows for easy parameterisation of variables and batch simulations.

The software is an instrument focused on designers attempting to develop an energy-efficient building early in the product life cycle. The software is developed around a graphical user interface that outwardly shows the user the impacts of changing geometry and materials of the structure in the form of indoor thermal comfort, daylight exposure, and resource consumption. It is a powerful instrument for comparing various plans rapidly and effectively observing the overall impact of various components. The essential goal of the software program is to provide sustainable design analysis tools with a generally short turn-around time to facilitate expedited comparisons between design plan options. A few restrictions of the program include batch runs which are difficult to perform and leads to a labour intensive process of varying design parameters. Certain simulations aspects of EnergyPlus and TRNSYS will be compared.

Since this study will incorporate a comparison of EnergyPlus results to TRNSYS results, a brief overview of the cutting-edge technology of energy modelling is presented. There is an expanding collection of research comparing different building energy analysis software (Brun et al., 2009; O'Neill et al., 2011; Andolsun et al., 2012). These researchers examined some of the principal differences in energy modelling programs that use iterative energy balance techniques. A couple of pertinent studies are reviewed due to their relevance and significance in this study, as the outcomes demonstrate best practices for a physically precise energy model.

An investigation utilised EnergyPlus and TRNSYS, among others, in an evaluation of the required energy to heat a low-energy building (Brun et al., 2009). The two-storey building had an absolute plinth area of 127 m^2 and was modelled with one thermal zone per storey. A heating system with a boundless limit was utilised, ensuring that regulated indoor temperatures would be maintained. The study focused on convection coefficients at zone limits. Two scenarios were utilised. The first displayed all surface heat transfer coefficients to the same values across all simulation programs. The values utilised were the average coefficients calculated in another software, subsequently not utilising the default settings of EnergyPlus or TRNSYS. The second scenario used each program's default values to compute surface convection heat transfer coefficients. In the first scenario, all programs simulated similar heating energy usage over the evaluation period. When the programs were each set to their default techniques, however, there was a huge contrast in energy use. EnergyPlus predicted less energy use than TRNSYS, as the convection coefficient internal calculation method results in lower average coefficients, which were determined at each time step. In contrast, TRNSYS does not internally calculate convection coefficients, but they are set by the user as a constant value or input from another TRNSYS module. The default TRNSYS recommendation for convection coefficients on inside surfaces is 11 $kJ/hr/m^2$, or 3 W/m^2K, while EnergyPlus averages around 1.0 - 2.3 for inside surfaces. This correlation will be repeated for the current study to assess the contrasts between EnergyPlus and TRNSYS inside and outside convection coefficients. Regarding the calculation of the convection coefficients for each surface in EnergyPlus, the engineering reference for the program gives the pertinent conditions and relevant equations. The Thermal Analysis Research Program (TARP) method is the technique for calculating the convection coefficients, which uses curve fit models for calculating convection coefficients based on empirical data collection. The exterior surface coefficient has a natural and forced convection component. Natural convection originates from temperature contrasts between the surface and the surrounding air and forced convection originates from air flow which is dependent on wind speed. The interior surfaces also utilise the TARP method, with the relevant equations shown in Figure 2.5. According to the reference manual, these equations, created by G. N. Walton in 1983, fit the ASHRAE handbook calculations in the turbulent range for both horizontal and vertical surfaces with a high degree of correlation (USDoE, 2012).

For no temperature difference OR a vertical surface, the following correlation is used

$$h = 1.31|\varDelta T|^{1/3}$$

For ($\varDelta T < 0.0$ AND an upward facing surface) OR ($\varDelta T > 0.0$ AND a downward facing surface) an enhanced convection correlation is used:

$$h = \frac{9.482|\varDelta T|^{1/3}}{7.283 - |cos\Sigma|}$$

where Σ is the surface tilt angle.

For ($\varDelta T > 0.0$ AND an upward facing surface) OR ($\varDelta T < 0.0$ AND a downward facing surface) a reduced convection correlation is used:

$$h = \frac{1.810|\varDelta T|^{1/3}}{1.382 + |cos\Sigma|}$$

Figure 2.5 Equations to determine inside surface convection coefficients in EnergyPlus (USDoE, 2012, p. 89). The convection coefficient *h* is a function of temperature *T* and surface angle∑.

Andolsun et al. (2012) considered the modelling of a slab floor and the effect on heating energy use for a simulated house. These specialists highlighted the contrasts between EnergyPlus and TRNSYS techniques of slab load estimation. They modelled a composite slab of concrete, soil, and the air film between the layers. The effective resistance of the slab was utilised. Underlined in the investigation was the significance of representative ground temperature contribution to simulation models since the default values will produce inaccurate results. The research also showed that the Slab preprocessor for EnergyPlus has problems with smaller structures that have changing interior temperatures. Convergence is not always accomplished when the interior temperature is influenced by the slab temperature, and with the Slab preprocessor, iterations are performed with input from the house model for slab internal surface temperatures. Due to this, either a user-entered ground temperature set ought to be utilised or the indoor temperature of a zone in contact with the slab should be kept constant. For this study, a user-entered ground temperature set will be utilised for both EnergyPlus and TRNSYS.

Loutzenhizer (2007) analysed the solar irradiance models of various energy modelling programs with recorded data from a physical model reproduced in the software programs. Estimation of incident irradiance on vertical surfaces were determined using each program, which included TRNSYS and EnergyPlus, and these values were compared to the actual data from the physical model. The researchers found that the experimental data depicted an average of 186.2 W/m^2 over the test period. TRNSYS averaged 187.1 W/m^2, while EnergyPlus averaged 191.0 W/m^2. For the current versions of TRNSYS and EnergyPlus used in this study, the same model for irradiance calculations is utilised (USDoE, 2012; UW-SEL, 2010), so this degree of accuracy should be maintained.

The different calculation methods and procedures to implement model parameters affected the output results in different ways. For example, the convection heat transfer coefficients can be calculated in a variety of different ways in EnergyPlus, each having a particular application where it best suits the environmental conditions. By reading the Engineering Reference document and other EnergyPlus documentation, the proper method can be selected for the particular simulation. In this case, the small size of the houses modeled increased the sensitivity to choosing an accurate representation of the convection coefficients. The large surface-to-volume ratio of the models, coupled with the low insulation values for the current construction parameters, made these convection heat transfer coefficients very important in the calculation of total heat transfer through the envelope surfaces. For this reason, the difference between the two programs' methods was highlighted in the energy usage results. While it was possible to calculate the inside face convection coefficients in TRNSYS, it was not possible for the outside face, where the convection coefficient can change dramatically based on exterior temperatures and wind speed, surface temperatures affected by solar irradiance, and so on.

The default value in TRNSYS for the exterior convection coefficients was much different than what EnergyPlus calculated using more input parameters with an equation that aligns well with ASHRAE data, so the value was over written with the EnergyPlus calculated average. The constant value is still not representative of the true convection coefficients. In a larger building, and as more insulation is added and the overall conductivity of the envelope component decreases, the convection coefficients become less critical to estimate properly, but that was not the case for the models used in this study. With an additional calculation parameter input in TRNSYS, it could be possible to develop a more realistic convection model, but that was not explored in this study, as equations would need to be developed for the variety of surface conditions— vertical, horizontal, tilted, heated, and colder than ambient—for each house individually, and they would need to be modified as the insulation levels increased throughout the study.

The benefit of TRNSYS in this study is that the model has minimal default settings, and it is up to the user to input the parameters as they become pertinent. This generally allows one to create a simple debugging model. Especially in the case of a simple model such as those used in this study, the input file is more manageable because the parameters are created and adjusted to the proper levels. The OpenStudio plugin, by contrast, starts by creating many default items including construction, HVAC systems, internal loads, and schedules. The model is immediately very complex. This is perfectly acceptable for a model which can be completely created in the OpenStudio application, because the graphical user interface hides much of the complexity from the user and provides an easy modeling interface to work with. The difficulty in OpenStudio arises when there is a component which cannot be created in OpenStudio. There is no way to add it without exporting the data file and then continue working with the EnergyPlus file alone. In this study, the item that was not available was the convective space heater that was necessary to properly represent the small houses' heating system. Once the OpenStudio application is exited, the complexity it creates must be dealt with in text format. At this point, the file must be significantly cleaned up (the models for this study decreased in size by 75% to their final state from the OpenStudio-exported file) before the file becomes as easy to handle as the TRNSYS input file. This may not be the case in the future, as the OpenStudio application is still in the early stages of development and will likely incorporate more features and components which are available in EnergyPlus. To create a simple model anew, it is still easier to follow the TRNSYS procedure. Although the programs have different approaches to modeling a building in some aspects, both are very capable of creating representative models of a very wide variety of building structures. In summary, further advancements and study of the software programs can help eliminate the gaps between the programs.

2.9 Preliminary Life Cycle Analysis on RDP Houses

The total energy inputs, outputs, and flow through the life cycle of the building are estimated using the detailed life cycle energy analysis (LCEA) approach (see Figure 2.1). The system boundaries are extended in order to take both the embodied energy and the operating energy into account, (Chastas et al., 2016). That means that the LCE of a structure includes the energy usages in production of building material, construction, operation, maintenance, disassembly, and waste management (Adalberth, 1997, Gustavsson, & Joelsson., 2010).

Stephan et al. (2012) and Stephan and Crawford (2013) have assessed the general LCE profile for different residential structures in Australia, Belgium, and Lebanon. In their study, they have included operational, embodied energy, and transport requirements, however, financial requirements have been ignored. Recently, 90 case studies of residential buildings evaluated between 1997 and 2016, around the world, were reviewed, Figure 2.6. The building life span of the studied cases ranges between 30 and 100 years with a mode of 50 years. The embodied energy shares in the overall LCE of the assessed buildings varies between 5% and 100%, (Chastas et al., 2016). For nearly zero balance, nZEB, the embodied energy portion ranges between 69% and 100%. There exists a significant gap of 17% that was identified as the difference between the minimum embodied energy share of an nZEB and the maximum embodied energy of a low-energy building. The gap seemed to increase for the passive and conventional buildings, respectively.

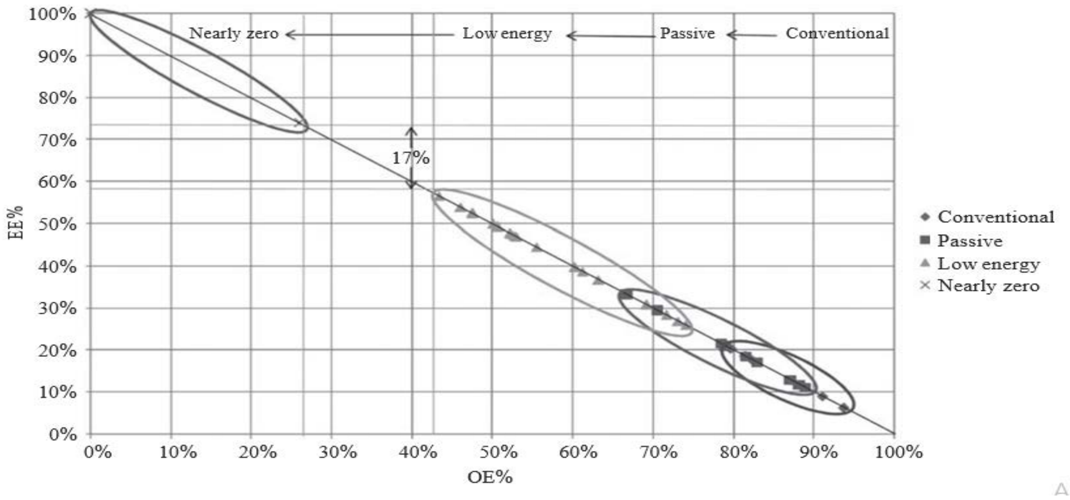

Figure 2.6 Total share of embodied (EE%) and operating energy (OE%) in the Life Cycle Energy Analysis (LCEA) of the case studies of residential buildings.

(From Chastas, et al., *Build. Environ.*, 105, 267–282, 2016.)

Ramesh, Prakash & Shukla (2010) showed that the embodied energy represents a share between 5% and 60% in residential buildings, (Figure 2.7). Their conclusion indicated that the embodied energy of buildings should not be neglected, particularly since operational energy is continuously diminished via multipronged endeavours related to policy and innovation aspects, such as improvement of HVAC performance, utilisation of renewable and sustainable energy, adoption of the zero-energy building (nZEB) design concepts, and implementing of green building policies.

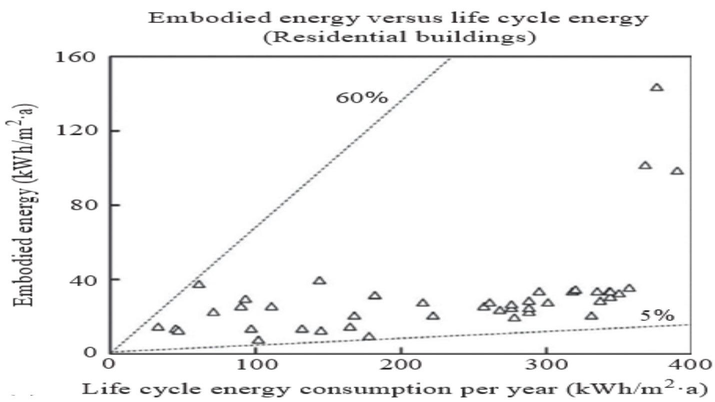

Figure 2.7 Embodied Energy versus Life Cycle Energy in Residential Buildings
(From Stephan, A. et al., *Energ. Build.*, 55, 592–600, 2012.)

The life cycle analysis performed in this study is a follow-up to an investigation conducted by Ramsdell et al. (2012). Autodesk Ecotect software was utilised in that research to simulate annual heating energy use. The investigation selected appropriate solutions to improve the energy efficiency of houses in South Africa. The cost estimates for the houses including and without the efficiency measures were developed and used to perform a life cycle cost analysis to determine the payback period and energy savings over a period of time. A month-to-month cash flow model was generated for each house scenario utilising local utility and loan costs. The results demonstrated a large decrease in energy use, as well as significant monetary savings, could be accumulated through simple energy efficiency measures, over a thirty-year mortgage life. This current study compares the EnergyPlus and TRNSYS simulation results and by recalculating the life cycle energy costs for the five houses of different case scenarios. Construction and material costs for the different cases from Table 2.5, and the impact of the embodied energy on the different components of the houses of different plinth area will also be investigated.

Table 2.9 Materials and approaches adopted in the construction of conventional houses

Case	Construction pattern
A	Base Case – No ceiling or insulation. Double brick wall w/o cavity
B	Cavity Wall – 40 mm
C	Cavity Wall w/40 mm Extruded Polystyrene
D	Gypsum Ceiling w/Blown Cellulose
E	Double Pane Windows w/Wood Frame
F	C and D combined

2.10 Theoretical and Conceptual Framework

Predictive modelling of energy utilisation in residential structures has become popular as a successful instrument for deciding productive designs and components. The effort and time to examine a residential structure configuration regularly limits the use of investigative modelling to larger and more prominent tasks. While the facts confirm that a larger structure can save more energy when contrasted with a more modest structure, the quantity of smaller houses may far surpass the number of larger houses that will be inherent in the coming years, particularly in emerging nations (Crossette, 2011), and subsequently, even the small homes provide a target for significant energy savings. The concept of this study is to simulate the critical variables and develop a model that impact on the life-cycle energy of buildings. Introducing energy-efficient passive interventions for the different buildings takes into account the various factors to observe energy performance.

2.11 Chapter Summary

From the literature survey elaborated above, it has been found that there are limited systematic studies been conducted in South Africa or worldwide for energy conservation opportunities in residential buildings through passive/hybrid systems.

Most of the researchers investigated the energy conservation opportunities in commercial/residential/industrial buildings and in terms of operational energy and embodied energy separately. Hardly, any researcher has been emphasized to study the total energy performance in the coupled system of the life-cycle of the building. Therefore, in this thesis, efforts have been made to optimize the different building geometry and passive energy-efficient interventions as per local climatic condition. The basis of such a study is the primary data regarding energy consumption, possibilities of energy conservation and techno-economic feasibility.

CHAPTER THREE: METHODOLOGY

3.1 Research Approach and Design

The research methodology employed in the study is a quantitative approach involving a pseudo-experimental research design that used a control and experimental group of houses. The chosen RDP house was a 40 m^2 house with three rooms, built according to an approved architectural plan and specifications outlined by the National Home Builders' Registration Council (NHBRC). In order to replicate standard space heating conditions in the RDP house, no ceiling was added, and the building was positioned on site disregarding thermal comfort requirements. The following conventional material technologies characterise RDP houses:

- Sub-structure: concrete strip foundation on hardcore fill; solid concrete block foundation walls; and 75 mm concrete floor slab on hardcore fill.
- Super-structure: solid concrete blocks
- Finishes: 25 mm thick floor screed; and StippleCrete outer wall

The conventional house (CH) has the same plinth area, room capacity and purpose when contrasted to an RDP house. To optimise the thermal performance of the conventional house, passive solar principles, for instance, appropriate north-south orientation; north-facing windows, cavity walls, insulated ceiling and plastered external walls were included into the building plans. The modern technology material innovations that differentiate the CH from the RDP house are the following, namely:

- Sub-structure: 50 mm thick concrete raft foundation on stabilized fill
- Super-structure: modular, hollow concrete blocks; and 4 precast concrete window frames out of seven windows to limit thermal bridging.
- Finishes: insulated ceiling board; and plaster to outer walls.

Table 3.1 Material groups categorised and applied to model CH and RDP

Material group	Conventional House (CH)	RDP House
Concrete elements	Stabilized fill Reinforced concrete window frames 50 mm thick concrete raft foundation Reinforced, site mix block core fill Non reinforced, site mix concrete apron	Non reinforced, ready mix concrete strip foundation Non reinforced, ready mix ground floor slab
Concrete block	Modular, hollow concrete block	Solid concrete block
Finishes	Floor screed Insulated ceiling panel Perlite plaster Paint (outer wall) Polystyrene cornice	Floor screed StippleCrete (outer wall)
Mortar	Sub-structure Super-structure	Sub-structure Super-structure
Steel	193 mesh 75 mm Brick-force Y10 rebar	75 mm Brick-force

Two major components are considered in the analysis: initial and recurring embodied energies. The initial embodied energy and recurring embodied energy demand of the two houses were quantified at the entire building level and analysed over a DSL of 50 years. The embodied energy content for a building is generally estimated using the bottom-up approach, also known as process-based approach, (Heinonen and Junnila, 2011; Peuportier, 2001 & Junnila, 2004). In the bottom-up approach, the embodied energy databases for building materials including drawings, specifications, and/or data from the actual buildings were utilised in the computation.

The approach is generally accurate and reliable when information on building quantities, final drawings, and environmental impact databases for construction products are accessible. The distance of the building construction site from the construction material suppliers and waste management operators also plays a significant role in the accurate estimation of the embodied energy of a building. The scope of materials listed in Table 3.1 is included in the embodied energy analysis. Materials that are considered equivalent were not utilised in the scope of analysis;

were not assessed. Similarly, the demolition energy was excluded on equivalence basis. Material service life assumptions and replacement factors are illustrated in Table 3.2.

Table 3.2: Service life and material replacement factors assumed for case study

Description of material or assembly	Service life (Years)	Replacement factor
Bricks & blocks	50	1
Concrete	50	1
Paint	10	5
Plaster	20	2.5
Polystyrene	Indefinite	none
Rebar	50	1
StippleCrete	8	6.25
Screed	20	2.5
Thermal insulation	50	1

The design of an energy-efficient standard home can be prepared by utilising the current plan as a benchmark and altering the different structure segments to ascertain where the best gains can be made regarding energy utilisation decrease and improved indoor thermal comfort. It is important to analyse the impact of the structure size on the structure's affectability to insulation materials. Since the buildings are small, at 40 m^2 to 100 m^2, extraordinary consideration is required in the modelling of such houses for energy use. With the generally small models, sensitivity to appropriate modelling parameters can be chosen by fluctuating boundaries autonomously and investigating the structure's sensitivity to such changes in design (Mechri, Capozzoli & Corrado, 2010). Also, the cost limitation of the standard designs requires suitable materials that are locally accessible and monetarily feasible. A few existing structures will be modelled utilising energy simulations to distinguish changes in heating seasonal energy use and interior temperatures. Different energy programming packages will be used to verify that modelling parameters and boundaries are utilised effectively and that anticipated energy use patterns are predictable.

3.2 Research Framework

This research study investigated the relative improvement capability of different efficiency best practices on small masonry-based homes. In doing so, the standard design of such houses can be improved, or adapted for government-built housing intended to improve the quality of life in emerging economies such as South Africa. These upgrades will lower life-cycle costs of houses and reduce energy burdens on the government when building on a large scale, as many non-industrial nations need to do. Using building energy modelling and simulation techniques, the contribution of building elements of the houses was contrasted to determine which components become more significant as the building's size is reduced. The study utilised two energy simulation software packages, viz, EnergyPlus 7.2 and TRNSYS 17, both to test the integrity of the models and to compare how each software models the small structures. Figure 3.1 provides a graphic representation of the process used to conduct the analysis.

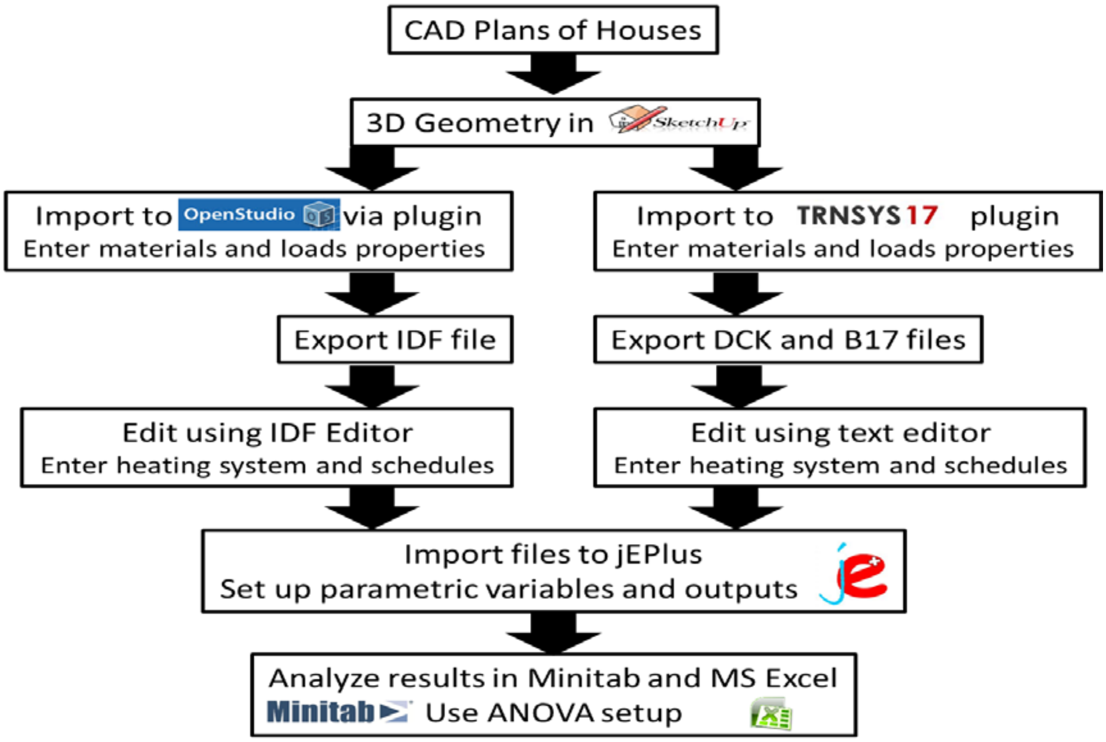

Figure 3.1 Overall process flowchart for the study.

The assessment of inhabitants' behaviour is based on a random sample of homeowners. Depending on the inhabitants, the usage patterns and times of occupancy in different sections of the dwelling can change greatly. If the effect of human inhabitancy essentially influences the heating energy utilisation in the house, then the assumptions of occupant behaviour can become a key factor in the energy improvement suggestions. Actual energy usage results may vary since these assumptions are based on a small sampling of occupants.

Simulated data was validated when compared to experimental data for actual houses. A techno-economic analysis will be performed using suitable analysis tools, (UW-SEL, 2010).

3.3 Area of Study: House and Climate Information

Apart from thermal comfort and insulation, there are many other factors to consider for mild climates when designing a simple structure for rapid construction. From any developing areas, the climate is considered mild if there are no huge temperature changes between the interior and exterior of the house with its main purpose being to provide protection from sunlight, wind and water, and to provide safety, security and privacy to the occupants. Makaka and Meyer (2006) presented an apt description of the typical construction of the RDP house. The RDP houses are normally single-family houses of concrete or brick wall construction. Since concrete materials are readily available and construction is quick and easy, concrete building materials are commonly used worldwide for durable low-cost housing. RDP houses that use a concrete block construction have a 150 mm (6 inches) thick wall, while a double layered brick wall with no air gap, infused, has a thickness of 220 mm (8.7 inches). Walls are 2400 mm (7 feet 11 inches) in height. No insulation is used (Makaka & Meyer, 2006). The roof is often made of corrugated metal with wooden rafters. This material is readily available and easy to install atop stone walls. Again, the purpose of the roof is to provide protection from the natural elements. The single layer metal roof accomplishes these tasks. The gaps around the edge of the roof are sealed with plaster to block out the elements. The pitch of the roof is low at 25 degrees or less above horizontal, with overhangs of about 100 mm (4 inches). No ceiling is installed in the house, leaving the corrugated metal roof as the sole boundary between the interior of the house and the exterior environment. The floor and footing consist of an 80 mm (3 inches) thick concrete slab, which is poured on grade with a perimeter footing along the outside walls of the house to a depth of about 300 mm (12 inches). Windows are often built on-site with single panes of glass and custom-fitted wood or metal frames for placement in the walls. The three to four windows have a fenestration area of approximately 1 m^2 each and are placed on the north and south sides of the house to promote ventilation. The doors are made of metal.

The houses that were selected for this study represent a range of sizes and designs of homes in central South Africa. All were concrete or brick-walled with slab-on-grade construction. The houses varied from 42 m^2 to 105 m^2 in plinth area (Appendix 1). These houses were selected because they offer a realistic scenario of building layout and construction. A review of the RDP house development demonstrates that the smallest house in this group is similar to the RDP specification and is, therefore, a good sample of the program's expected design. The bigger houses represent optional larger sizes of the RDP specification and present distinctive design features such as sunrooms, greater glazing percentages, and higher roof pitches. By investigating the energy utilisation normalised for total plinth area, the impact of these geometric contrasts in the houses was identified during the analysis. The smallest house was intended for three to four people, while the biggest house could accommodate a family of six or seven. The sample of the four actual houses that are the premise of this study are slightly different in terms of its construction (Appendices 1 & 2), however, are comparative enough that normalising parameters will not change any house's fundamental thermal behaviour. All the houses are one storey, having a similar north-south orientation, and spaces that can be categorised as either lounge/kitchen/dining or bedrooms, which can be simplified into day use or night use. Table 3.3 shows a summary with the floor area, envelope area, and glazing percentages of the houses. Each house has some unique geometry, which creates a fifth parameter: geometry. By examining the various geometry of each house when assessing energy use normalised for floor area, the contributions of some of the unique aspects of each house were analysed. For example, House 3 has the greatest window area of the group, so the sensitivity of that model to variations in window properties is required to be greater than for House 1, which has a lower ratio of window to envelope area.

The space available to be occupied in the category of conventional houses (CH) includes between 1 and 4 bedrooms according to the plinth area and design of the house. The details of the bedrooms and other compartments in the CH houses according to their plinth area is shown in Table 3.4. It is observed that the typical RDP house construction is almost similar to the lowest plinth area in the CH category. The houses were designed, as per the National Building Regulations, South African Bureau of Standards (South African National Standards, 2011).

Table 3.3 Summary of parameters of the four houses modelled

	Units	1-J/CH 42	2-S/CH 62	3-V/CH 84	4-A/CH 105
Interior Floor Area	m^2	42	62	84	105
Envelope Area	m^2	150	197	305.1	326.6
Glazing Area	m^2	3.3	6.7	14.9	12.2
Glazing Percentage of Envelope	%	2.2	3.4	4.8	3.8
Glazing Percentage of Interior Floor Area	%	7.8	12.2	17.6	11.7

Table 3.4 Compartment details of the different houses

House	Plinth Area	Bed-Room 1 (m^2)	Bed-Room 2 (m^2)	Bed-Room 3 (m^2)	Bed-Room 4 (m^2)	Open-Plan Area (m^2)	Kitchen (m^2)	Toilet / Bath (m^2)	Passage (m^2)
RDP	40	9	9	-	-	9	7	6	-
1-J/ CH 42	42	9	9	-	-	9	9	6	-
2-S/ CH 62	62	12	12	-	-	16	12	6	4
3-V/ CH 84	84	12	12	16	-	16	12	6 x 2	4
4-A/ CH105	105	12	12	16	16	20	12	6 x 2	5

The baseline development for the models follows the regular RDP house construction depicted in Chapter Two. Models all utilised a double brick layer wall construction. Each layer of brick is 110 mm thick with a thin layer of mortar between and five millimetres of cement rendering on the internal face. The baseline rooftop is a single layer of corrugated metal laying on rafters with no insulation or radiant barrier underneath. The slab is concrete with no flooring nor insulation on it. Windows are single-paned with a metal frame, and the door area is a single layer of steel.

All the houses are situated in the central South Africa, the Vaal area close to Johannesburg. This region is part of the central plateau of the country, with a height of around 1 400 metres (4 600 feet) above sea-level and is known to have a semi-arid climate with cool and dry winters where frost is common during the night. This area is the coldest region in the country and its climate is grouped in South African Bureau of Standards (SABS) 10400-XA as Climate Zone 1. During the colder months of July and August temperatures at night can normally drop below freezing outdoors, and daytime temperatures regularly do not rise above 5° C during a cold stint.

Weather information was obtained from the Energy Efficiency & Renewable Energy website for Johannesburg, South Africa. The data is openly accessible in EnergyPlus format (EPW) and it was converted for use in TRNSYS for this study. To change over the file from the EPW format to the TRNSYS-required TMY2 format, the sections of the data columns were changed. This was accomplished by importing the EPW climate data into a spreadsheet and revising the sections to fit into the TMY2 climate file formatting prerequisites. A few units needed to be converted between the programs, but the actual data was identical. Utilising this technique guaranteed that similar weather data was utilised for the two programs. Weather data represents a regular year and was created through the examination of many years of climate data according to International Weather for Energy Calculations (IWEC), which was created by ASHRAE in 2001.

Since the climate information is intended to represent an ordinary year, any particular year of weather data may not exactly correspond with the typical weather data, however, over longer periods (over 10 years), the mean recorded weather data should correlate to the climate data file provided for the energy modelling programs. Figure 3.2 shows the dry bulb temperature range for each month of the year, extracted from the climate information file. The houses are in the Vaal area alongside the boundary of the Free State and Johannesburg. The region is marginally colder throughout the colder time of year, implying that the heating energy use determined during simulations is to some degree conservative since the heating energy use would be higher due to the colder temperatures.

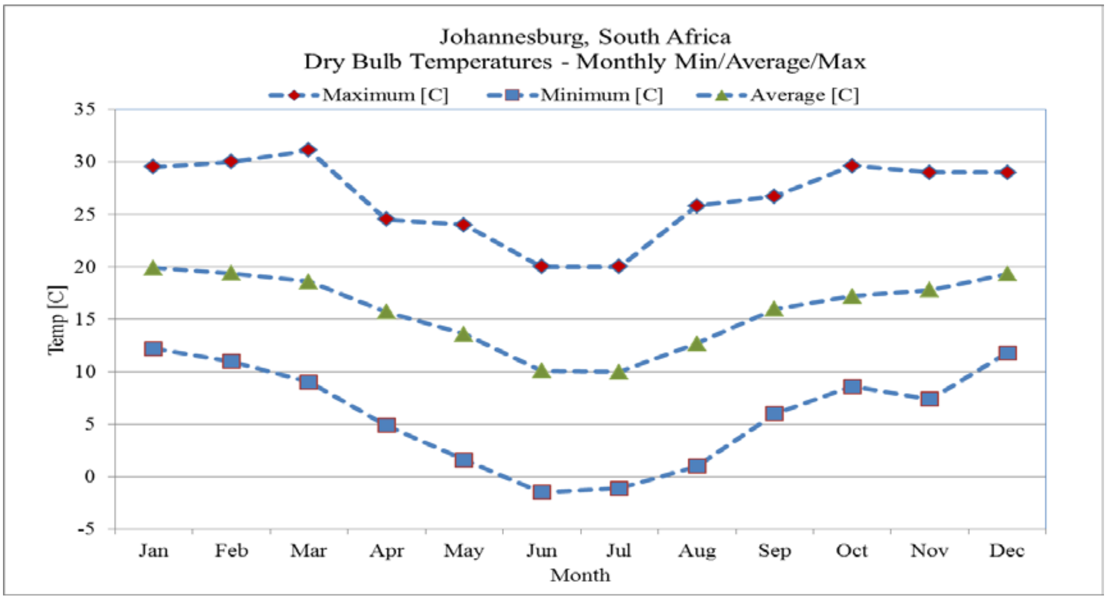

Figure 3.2. A summary of dry bulb temperatures in Johannesburg, South Africa, as indicated by the supplied weather data file.

The climate zone rating defines the insulation values required for the surface envelope utilising the IECC standard. The climate in the area of the houses follows the IECC, 2012 rating of Climate Zone 4A. A synopsis of the climate zone ratings is shown in Table 3.5, which recreates Table C301.3(2) from the IECC 2012 norm (International Code Council, 2011: 25-26). The rating depended on the number of heating degree days and cooling degree days as well as on yearly precipitation. As indicated by the climate information, yearly precipitation for this region averages 46.8 cm and has a yearly mean temperature of 15.85^0 C, which equates to a “moist” area rating. The number of cooling degree days above 10° C (CDD10C) is 2304, and the heating degree days below 18° C (HDD18C) was determined as 1263. The IECC tables classify this area as Climate Zone 4 for temperature, and “A” for moisture. These computations were determined utilising the weather data information for Johannesburg. While the Vaal area statistics may be marginally different, both the number of heating and cooling degree days are well within the range for maximum and minimum values, so the climate zone is still applicable utilising this information.

Ground temperatures are excluded from the weather data files, so this limit condition for the models was produced dependent on the surrounding temperature data for the year. The ground temperature approximation was set up as a cosine equation that reflects the mean air temperature for the year. This cosine equation results in ground temperatures of 16° C ±5° C, in phase with the varying ambient temperature. The direct relationship is because of the small size of the models and the slab-on-grade construction of the floor, resulting in ground temperatures at shallow levels without much insulation from the structure.

Table 3.5 Excerpt from the IECC2012 specification, showing the classification for international climate zones based on temperatures and precipitation (International Code Council, 2011: 25-26).

Zone Number	**Thermal Criteria**	
	IP Units	**SI Units**
1	9000 <CDD50F	5000 <CDD10C
2	6300 <CDD50F≤9000	3500 <CDD10C ≤ 5000
3A and 3B	4500 <CDD50F≤ 6300AND HDD65F≤ 5400	2500 <CDD10C≤ 3500 AND HDD18C≤ 3000
4A and 4B	CDD50F≤ 4500 AND HDD65F≤ 5400	CDD10C≤ 2500 AND HDD18C≤ 3000
3C	HDD65F≤ 3600	HDD18C≤ 2000
4C	3600 < HDD65F≤ 5400	2000 < HDD18C≤ 3000
5	5400 < HDD65F≤ 7200	3000 < HDD18C≤ 4000
6	7200 < HDD65F≤ 9000	4000 < HDD18C≤ 5000
7	9000 < HDD65F≤ 12600	5000 < HDD18C≤ 7000
8	12600 < HDD65F	7000 < HDD18C

Key: CDD – Cooling Degree Days and HDD – Heating Degree Days

South Africa characterises climate zones contrastingly dependent on the general conditions across the country. The South African National Standard (SANS)10400-XA:2011 defines these climate zones. The climate zone definitions are depicted in Figure 3.3, overlaid on a map of South Africa. The Vaal near Johannesburg falls into Climatic Zone 1 – Cold Interior. As with the IECC standard, the climate zone classification directs the building envelope insulation prerequisites.

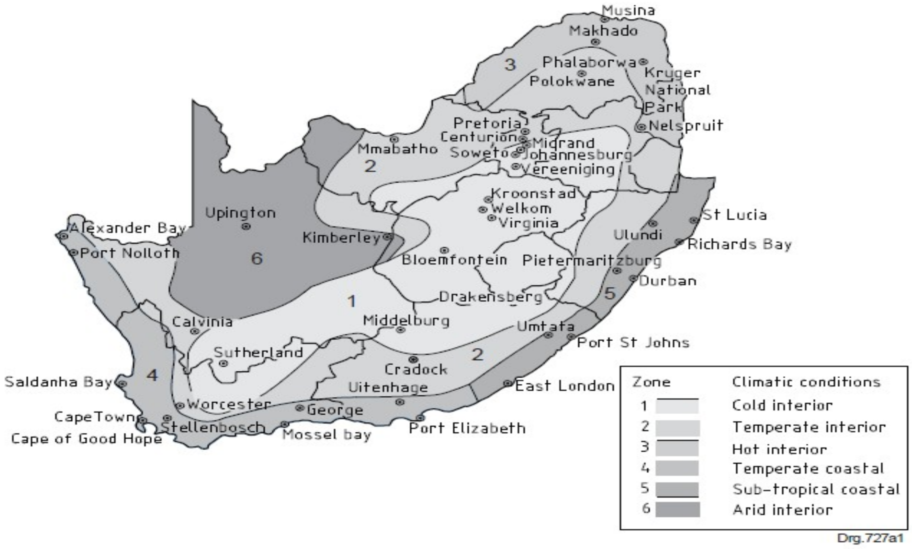

Figure 3.3 Climatic Zone definitions in South Africa, taken from SANS 10400-XA (South Africa National Standards, 2011: 12).

3.4 Building Parameters Varied for Sensitivity Study

Four diverse building parameters were changed in this investigation. Every parameter was changed to have one of three values. The first level represents how the normal RDP house is constructed. The second level represents the minimum requirement determined by the SABS specification SANS 10400X-A, which is the base requirements for new building developments in South Africa. Since the South African building energy code is relatively new and not generally followed, it was chosen as the second parameter level. The third level was the base prerequisites specified by the IECC2012 building standard. A table of the required conductivity values is depicted in Table 3.6. For the present construction level, the assembly-level conductivity values shown in Table 3.6 were calculated from the actual construction methods.

Table 3.6 Envelope insulation requirements as per the relevant specifications

Conductivity (W/m^2K)	**Mass Wall**	**Fenestration**	**Ceiling**	**Slab-on-Grade**
IECC2012 Zone4A	0.69 (insulation layer)	1.988	0.148	0.566
SANS10400-XA Zone1	2.86 (assembly)	4.22	0.271	1.00
Present Construction	5.65	7.90	48.9	5.88

Table 3.7 Constructions compliance with each level's requirements

Level		Mass Wall	Fenestration	Ceiling	Slab-on-Grade
First	Present Constr.	Solid Brick	Single	No insulation (roof only)	80 mm slab no insulation
Second	SA Code Min.	Brick cavity wall -40mm air-gap	Low-end double pane	Roof with 18 cm batt insulation	Insulated slab
Third	IECC2012 Min.	Brick cavity wall -40mm XPS foam	Mid-range double pane	Roof with 33 cm batt insulation	Insulated slab including perimeter

Table 3.8 Assembly Conductivity Values of the Constructions Summarised in Table 3.6

Assembly U Values	First Level	Second Level	Third Level
Walls	5.619	1.420	0.599
Ceiling	48.799	0.269	0.150
Windows	7.898	4.229	1.970
Slab	5.899	0.879	0.530

The categories of constructions these prerequisites represent are summed up in Tables 3.7. and Table 3.8. The wall system starts with using a solid brick wall to using an air-gap between layers, which is a typical construction practice in South Africa, although normally present in the hotter climates where the building is utilised to decrease overheating inside the structure. One issue with modelling an air-gap more than 25 mm is that a convective current can form, henceforth increasing heat transfer between wall layers. This was accounted for in the simulation models by utilising the conductivity of the air and additionally by calculating the overall convective coefficients on the internal surfaces of the wall layers and creating an overall conductivity value that includes both the material conductivity and the loop convection value. The third wall level fills the 40 mm gap between brick layers with a solid layer of extruded polystyrene foam. This construction modifies the general building method of an air-gap by simply inserting a standard size foam board between the layers, hence representing a suitable option in contrast to the air-gap.

The rooftop starts off with no insulation and moves to the second level by adding roughly 18 cm of batt insulation. The third level increases the insulation value to have approximately 33 cm of batt insulation. On account of the roof insulation, the extra space considerations needed by this thick layer of insulation were not considered and are not represented in the model. As such, the inside volume of the house did not change with this additional insulation. A physical representation of this level of insulation would be to raise the roof by the required amount to fit in the insulation without decreasing the head clearance underneath.

Windows are referred to as single-pane glass with a metal frame for the lowest level and move to a basic double-pane window to meet SABS prerequisites. A better double pane window is needed to satisfy the IECC requirements, with a lower U-value and carrying with it a lower solar heat gain coefficient (SHGC). The slab obtains two levels of insulation both horizontally (underneath) and vertically (perimeter) to meet the basic insulation prerequisites for the second and third levels. The ground models utilise a sinusoidal ground temperature variation, which applies both at the edges and underneath the slab, so insulation on both surfaces is required. For the moderately small footprint of these houses, the ground temperature below the houses can fluctuate greatly when contrasted to bigger structures, since the building itself does not separate the soil from the surrounding conditions as much as in a bigger structure. Therefore, the insulation may not exclusively be important on the perimeter, but also underneath the slab.

It should be known that while the various envelope components vary in thickness as insulation is included, this thickness does not change the inner volume of the structure. When the heat transfer properties were computed, the thickness values were discarded, and the heat transfer components were carried forward as absolute conductivity and heat capacitance. Consequently, each floor, wall, window, and roof system has a different thickness without varying the air capacitance inside each room.

3.5 Model Outputs for Analysis

The principle output of concern is the yearly heating energy used by the house. The unit was expressed in kilowatt-hours per year and represents the quantity of energy used by the space heater within the house all through the whole year. An electric heater was modelled, which has an efficiency of 100%, or a coefficient of performance (COP) of 1.0. This implies that all energy utilised by the heater in the house is used as heat energy, regardless of whether by convection or radiation. The amount of energy accumulates over the whole year, not just during winter. This implies that whenever the temperature inside drops lower than the thermostat setting, the heater will be activated. While the heater are generally not be activated in the actual houses, the impact should be minute, since the heating load will be small when the temperature temporarily drops during the hotter time of the year. This plan may also balance the occasions where the heater may be left on in any event when the temperature is higher than the thermostat setting, a situation that probably occurs in the real houses, but is missing in the models.

Notwithstanding yearly heating energy, the inside temperatures of the models were logged and examined for specific situations as a probe on the operation of the models. The capacity of a house to maintain an inside temperature with varying exterior conditions is another approach to compare the energy demand of the models. A house with better insulation is able to maintain comfortable indoor conditions, and the inside temperatures can be closely examined for energy use to understand how demand varies for the duration of the day and year. The indoor temperatures were particularly helpful for this examination since finding accurate energy use for the actual houses was not possible, so estimations of real inside temperatures provided a state of correlation with the simulated models in the effort to create representative models of the houses.

During the model creation process, countless different boundaries were investigated for debugging and changing the model inputs and estimation techniques. While energy use and inside temperatures were significant parameters during model creation, it was likewise important to look at irradiance on surfaces, surface temperatures (instead of air temperatures), and gains from inner loads and outside air exchange. Checking a wide assortment of boundaries guaranteed that the two software programs, EnergyPlus and TRNSYS were set up with the same inputs and comparable computation techniques. Examination of these supplementary outputs made the calibration and correlation between the two models possible, as the complexity of the simulation software program cannot be expressed by utilising just the energy use and inside temperatures.

3.6 Software Programs used for Simulations

EnergyPlus models were developed through a progression of modules and auxiliary interface programs. The freeware program OpenStudio serves as the interface to apply materials and thermal zones to the model geometry, which is formed in the freeware Trimble Sketchup utilising an OpenStudio module. The last adjustments to the model before performing the parametric assessment were made in the IDF Editor program distributed in the EnergyPlus modelling software program. The final models were executed in the jEPlus batch simulation program. The detailed method for producing and simulating the house models utilising the EnergyPlus program is outlined. A comparable strategy using EnergyPlus was employed for building and simulating models using the TRNSYS engine. Model geometry was imported from a Sketchup file utilising the TRNSYS3D plugin into the Simulation Studio software, where materials and loads were applied. The simulation and building files were converted into text format in their final stage and imported to jEPlus for simulation. An itemised technique for developing and simulating the house models utilising the TRNSYS engine is also depicted.

Crucial to this process is a technique for automating the yearly simulations while varying the ideal parameters to pre-defined values. The freeware program jEPlus, produced by the Institute of Energy and Sustainable Development (IESD) at De Montfort University, achieves this assignment for both EnergyPlus and TRNSYS simulations. The program uses search strings put in the information record to discover parameters and to perform batch simulations while systematically changing the chosen parameters. Yields from the simulations were composed into tables for analysis.

3.7 Common Modelling Parameters

Despite the models been created in both EnergyPlus and TRNSYS, the parameters of the models were kept as comparative and conceivable over the various houses and programs. All parameters that were communised between the two are discussed in this section.

The simulations utilised the hourly conditions over the year, including dry bulb temperature, relative humidity, irradiance, wind speed, and wind direction. The simulation programs offer simulations of design conditions to assess the greatest energy demands for heating and cooling. These alternatives are commonly used to determine the required cooling and heating limits. Since this study worked distinctly with space heaters that have a known and restricted capacity, the design day investigations were not conducted, so the design conditions were not be included in the simulation file.

3.7.1 Envelope component constructions

Utilising the prerequisites for each level and the constructions outlined in Table 3.7, the model constructions were produced using materials in the program libraries. The wall material properties appear in Table 3.9. Mortar was utilised for the first level wall, followed by an air-gap and polystyrene embed for the second and third level walls, respectively.

Table 3.9 Wall layer properties, including U-values at the specified thickness

Property	Units	Brick	Mortar	Air-Gap	XPS Insert	Int. Render
Thickness	Metres	0.11	0.001	0.04	0.04	0.006
Conductivity	W/m*K	1.298	0.52	0.07567	0.026	0.80
Density	kg/m^3	1980	1280	1.2406	265	1331
Specific Heat	J/kg*K	732.1	840	1006.5	836.7	1000
U-Value	W/m^2*K	11.9	530.1	1.8	0.69	157.9
R-Value	m^2*K/W	0.0849	0.0018	0.5287	1.4816	0.0062
R-Value	Ft^2*F*hr/Bt	0.480	0.012	2.998	8.400	0.035

The window assembly properties are depicted in Table 3.10, which were chosen from the accessible component library in TRNSYS and applied to EnergyPlus. The chosen windows represent the requirement at each level in accordance with the standards. Note that these properties incorporate just the window assembly without inward and external air films. The properties of the air-gap between glass panes were included in these properties. Windows were constantly viewed as shut during the simulations.

Table 3.10. Window Fenestration Properties

Property	Units	First Level	Second Level	Third Level
Window Type	NA	Single Pane	Double Pane	Double Pane
U-Value	W/m^2*K	5.681	2.830	1.410
SHGC	Fraction	0.856	0.754	0.588
Visible Transmittance	Fraction	0.899	0.816	0.705

The modelling technique for the roof began with a single layer of metal and insulation was included underneath as per norms prerequisites. Since a layer cannot be included during the parametric assessment, a very thin layer of insulation material was part of the model when simulating the first level roof situation. The layer was made thicker for the second and third levels to obtain the necessary insulation level. Table 3.11 shows the properties of the various layers to represent every one of the three levels of the roof system. The U-values estimation of each layer shows how the extremely thin layer of insulation at the first layer is negligible when contrasted with the second and third level values, as it has 180 multiples of the conductivity of the second level.

Table 3.11 Roof Layer Properties

Property	Units	Metal Layer	First Level Insulation	Second Level Insulation	Third Level Insulation
Thickness	Metres	006	0.002	0.182	0.332
Conductivity	W/m*K	62	0.048	0.048	0.048
Density	kg/m^3	7311	266	266	266
Spec. Heat	J/kg*K	225.8	837	837	837
U-Value	W/m^2*K	12217.1	48	0.26	0.148
R-Value	m^2*K/W	0.0001	0.03	3.6	6.78
R-Value	Ft^2*F*hr/Btu	0.0005	0.13	20.99	38.49

Table 3.12 Slab Floor Layer Properties

Property	Units	Concrete	First Level Insulation	Second Level	Third Level Insulation
Thickness	Metres	0.1000	0.0010	0.0270	0.0477
Conductivity	W/m*K	0.7531	0.026	0.026	0.026
Density	kg/m^3	3800.0	265.0	265.0	265.1
Specific Heat	J/kg*K	657.0	836.9	836.9	836.9
U-Value	W/m^2*K	7.51	27.0		0.61
R-Value	m^2*K/W	0.12	0.03	1.00	1.77
R-Value	Ft^2*F*hr/Btu	0.74	0.20	5.66	9.98

The slab concrete and insulation properties are depicted in Table 3.12. Likewise, with the roof system, the thickness of the insulation layer was transformed from an exceptionally thin layer to the necessary qualities for the second and third levels. All insulation material properties remained constant. The door was made of a single layer of steel for all scenarios. The properties of the door are illustrated in Table 3.13. Note that these are the material properties of the metal and do exclude air films on either side of the entryway, which are allocated by each program's algorithm for vertical surfaces.

Table 3.13 Door Material Properties Used in All Simulations

Property	Units	Metal Door
Thickness	Metres	0.011
Conductivity	W/m*K	45
Density	kg/m^3	780
Specific Heat	J/kg*K	836.9
U-Value	W/m^2*K	4500.
R-Value	m^2*K/W	0.000
R-Value	Ft^2*F*hr/Btu	0.001

3.7.2 Internal loads and schedules

All scenarios had similar internal load structures. Table 3.14 summarises the internal loads present in each house. The values utilised were constant all through the simulation. This was a concession made to simplify the simulation, since a more in-depth schedule of the loads in the house would require surveying the occupants for load utilisation conduct and creating daily and weekly plans around the actual behaviour. This is an area where this study could be expanded for future research and henceforth give more precise utilisation patterns for the internal loads. For this research, the loads were kept constant for the duration of the day and year. The lighting value was on the slightly higher end of consumption because of the blend of incandescent and compact fluorescent lighting strategies in the houses. A new energy-efficient public structure would strive to achieve a lighting load of 10W/m^2 or less, particularly if an energy efficiency certification is desired.

The loads from inhabitants of the building were estimated as around one individual for each room at early resting state, as expressed in the EnergyPlus documentation. This is equivalent to 80 watts per individual, consequently giving the load of 80 watts for each zone in this simulation. Since the bigger houses are probably going to have more occupants, this load was programmed to be one individual per room to account for that situation. Plug-loads were averaged for a daily period including all non-heating appliances in the house such as irons, ovens, refrigerators, televisions. This value was changed to reach the correct equivalent loads, however, could likewise be more closely examined for future research of occupant behaviour and electricity use in the RDP houses in the area. The infiltration values were assessed dependent of the type of construction, which incorporates almost no weatherproofing around openings, the climate and the normal conduct of the inhabitants in opening doors and windows.

Table 3.14. Internal Loads for All Simulations, Including Outdoor Air Exchange Rate

Load Type	**Unit**	**Value**
Lights	Watts/m^2 floor area	15
People	Watts per zone	80
Plug Loads	Watts per zone	200
Infiltration	Air changes per hour	2.0

3.7.3 Thermal zone and thermostat setup

One thermal zone was characterised as just containing one room in all models in the two programs. In simulating a building structure with thermal zones, the simplest model was utilised without compromising how the model represents an actual structure of the similar design. For the houses utilised in this research, which are commonly small and with a simple design, each room was modelled as a solitary zone, and the addition of rooms into fewer zones would not provide much savings in terms of computation times, so each room is a thermal zone. Also, in light of the different types of rooms in each house, each room has a varying interaction with the surrounding, so it makes sense to model each room as a discrete thermal zone. Thermal zones are labelled according to the approved building plans. The thermostat schedules were set up dependent of room utilisation. To simulate a single space heater providing heat to the whole house, the heating was just accessible either in the bedrooms or in different rooms, however never in both kinds of rooms simultaneously. This plan was set up with thermostat schedules where the day and night heating timetables did not overlap each other during the daily cycle. In the model, the heating system for the rooms had an indoor regulator that turned on only between the night periods of 6:00 pm and 6:00 am, while the rooms occupied during the day had the heating system available between 6:00 am and 6:00 pm. The temperature setpoint was 18° C for both room types, as done in previous investigations, demonstrates that 18° C or higher is a comfort point for naturally ventilated buildings (Harris, 2005).

While evidence found in estimations of actual inside temperatures of the houses indicated that there were no effective thermostat setting regarding temperature control, the setpoint of 18° C was utilised for motivations behind reproducibility, simplification and improvement of the models. In reality, the heaters in these houses are activated when individuals feel cold, which is not generally at an 18° C inside temperature. The restrictions of human comfort depend on more than basically the dry bulb temperature in the house and are related to humidity, exterior temperature, and other climate conditions. In any case, since the literature demonstrates that this temperature is satisfactory for indoor comfort, the thermostat setpoint utilised was 18° C. Houses of this sort in South Africa do not have an operating cooling system, so a mechanical cooling system was not characterised in the models. The thermostat cooling setpoint was consequently set to an extremely high estimation of 60° C, which guaranteed that the model requires cooling consistently throughout the year. This step was only needed in EnergyPlus since the heating system is attached to a double setpoint thermostat, which requires an input for cooling setpoints.

3.8 Model Setup for EnergyPlus Simulations

Each house was simulated independently with the geometry being produced in Trimble Sketchup utilising the OpenStudio module, accessible from the EERE. The geometry was adopted from the CAD plans, Appendix 1. Each zone was modelled utilising the inside measurements to have exact volumes and envelope surface area. For the internal walls, half of the thickness of every inside wall was utilised as part of the zone.

Each house geometry was transferred into the OpenStudio (version 0.10) application once all zones were finished with all surfaces and openings as characterised in the plans. The OpenStudio application allocates default schedules, constructions, and internal loads, which were all modified or erased to improve the model and to represent the structures more accurately. In the OpenStudio application, the normal simulation parameters were applied to each house model. For this investigation, all internal loads were given the same value. A common parameter library was created to effectively enter the ideal setup for the OpenStudio model. One issue that OpenStudio has is the absence of an electric convective/radiation heating system. Accordingly, each model was given a temporary heat pump system with the heating and cooling COP set to 1.0 and all electrical and motor efficiencies set to 100%. This created a comparable system to an electric heater system, which was utilised while debugging the remainder of the model. Notwithstanding, this couldn't be utilised for similar purposes to a model with an appliance space heater, since the heat pump system has no radiation part and uses forced air to keep all surfaces at a uniform temperature. The heating system was varied utilising a text editor or the EnergyPlus IDF editor to enter more precisely the heating system parameters using the Electric Baseboard: Convection/Radiation object class, which isn’t accessible for use in OpenStudio.

For the parametric investigation, just the reasonable heating energy supply was required for each zone, with the output at the end of the yearly modelling trial period. This output depicts the absolute heating energy needed by the heating system for each zone for the whole year. This output unit for each room is in joules, which was changed over to add up to total house kilowatt-hours in the output spreadsheet. For debugging purposes, other dependent and independent variables were depicted, such as internal temperatures, surface temperatures, and inner loads. These outputs are significant for figuring out the model and guaranteeing that all practices directed by the simulation program make physical sense.

On completion of the working model produced in OpenStudio, the IDF file was exported and finalised. By including all materials and constructions that were utilised for all the situations in the model library, the parametric changes during automated runs did not make an error when another material or construction was not found in the input file. It is crucial to note that OpenStudio will copy, rename, and reconnect components that are imported in a typical library if another part in the model has that component's name, so reviewing all components before, during, and after import and export is vital for proper model inputs for computerised simulations. Before the model was concluded for parametric differences, some reformatting and altering were needed to make the IDF file concise and usable. The EnergyPlus IDF editor is an excellent instrument for achieving this assignment. By utilising IDF Editor, the language structure was put in the IDF file without the requirement for formatting, but all features accessible in EnergyPlus were used. Once all constant components across building models were set up correctly in IDF Editor, the input code was inserted utilising a text editor, but the first iteration was completed in IDF Editor to guarantee correct syntax and connections between components, as well as to have a layer of automated error checking in the model by the program itself.

As stated previously, OpenStudio adds numerous components to the IDF file by default, and many are not required or can be replaced with simplified versions that are simpler to edit and debug. The explanation behind this is a direct result of OpenStudio's emphasis on bigger structure with more intricate space conditioning systems and internal loads. A lot of this complexity is required for building accreditation purposes, but for these houses. it was not required, so a lot of the default setups was deleted. Without altering geometry and zone data, the following objects could be erased from the file:

- Outdoor air, blenders, and node list objects – outside air comes exclusively from infiltration in the houses, so mechanical ventilation is absent.
- Zone air dissemination – the space heating originates from appliance heaters, which utilise no distribution system to circulate air.
- Sizing parameters – the heating system has a fixed limit which is entered manually. Estimating boundaries are possibly required if the program is to compute the required size of a system dependent on heating loads.

- Extra thermostats – The main indoor regulators required for the models are one for daytime heating and one for night time heating. OpenStudio assigns numerous thermostats for each zone when in reality the thermostats can be shared between zones, so many can be deleted.
- The heat pump systems needed for use in the OpenStudio program can be erased. This incorporates not only the actual heat pump objects, but all fans, coils, performance curves, and schedules that accompany the system.

For any normal components that were duplicated from one file to the next, the connections should have been changed, since each house had an alternate number of zones and surfaces. Thus, a conventional space type which contained the break-down of all interior loads and schedules that were applied to each zone in the house model was developed. This template cut down on potential data entry mistakes by limiting the quantity of data to enter for every exceptional situation in the model. It additionally fundamentally decreased the size of the input data files. The erasure of invaluable items decreased the input file size by roughly 75%. This decrease additionally made debugging and coding a much simpler assignment, since there were not any more unnecessary items in the files to create confusion. The entirety of the models had normal constructions and internal loads, which could be saved to the template. For this study, a template called "SA Home Low" was utilised to generally apply similar constructions and interior loads to each zone of each house.

To model, a more precise and accurate heating system, a typical baseboard heating system was produced in IDF editor, and the code was duplicated into each house record. Every thermal zone required a discrete heater, so the limit of each zone's heater was a portion of the summed heater capacity of 2500 W. As a general rule, each house had just a single heater with a maximum limit of 2500 W, which this design reproduced. This implies that if the house had two rooms that were both heated during the night, each room required a heater with the greatest yield of 1250 W. Since rooms in these houses are of similar size, the loads in each room were set to be equivalent, and thus a similar heating limit was viewed as acceptable. Care should have been taken to divide energy output to zones that shared the heater at night and during the day. The heating system was not utilised in the bedrooms during the day, as it would be carried to the more occupied rooms. This was modelled by having the thermostat turn the heating off in those rooms during the day and having heating only available at night. Hence, the heating limit of each zone was set up as 1/N*2500 W, where N is the number of zones that share the same thermostat schedule, with at least 1250 watts per zone, to represent the larger houses that possibly have more than one heater.

The space heater model has a convective heat transfer component as well as a radiation component. With radiation simulated as 25% of the heat output of the system, singular surfaces were defined in EnergyPlus to receive the radiation from every heater. Three surfaces were characterised for each zone that each received a small amount of the radiant energy. The sum of the fractions equated to one. The final models were saved as IDF files and opened for parametric computerised simulations utilising jEPlus according to the methodology. A technique for modelling the houses utilising TRNSYS was also developed and is described in the following section.

3.9 Model Setup for TRNSYS Simulations

The TRNSYS model starts in Sketchup likewise with EnergyPlus, except the TRNSYS3D module was utilised to produce the thermal zones. While the plugin module saved the data as an IDF file type as in the EnergyPlus model, transferring the file into TRNBuild changed the format where it was configured for use with a TRNSYS input document. The building materials were designed utilising the layers and properties given in Table 3.7. In TRNSYS, the convection coefficients for all heat transfer surfaces was characterised. As opposed to EnergyPlus, the values must be physically entered. For internal surfaces, the convection coefficient was assessed either as a vertical surface, a roof surface, or a floor surface. The external coefficient was entered as a constant to obtain assembly thermal conductivity. For this research project, a correlation was done to obtain the more probable convection coefficients and the simulation program with a more appropriate algorithm that provided values transferred to the other required program. The underside of the slab component, which contacts the ground and thus has no convective component on the external layer, has a convection coefficient of zero.

An adjustment that was made for all thermal zones developed in the TRSNYS3D module had to do with air pressures. The zones were produced before the weather data file was accessed by the model, so the default values were utilised for the properties of air. The default properties relate with air at sea level. The height of the topography where these houses are situated is at 1400 m, where the air has varying properties.

Atmospheric pressure is about 80 kPa rather than 101.2 kPa at sea level; therefore, the density of the air is around 1 kg/m^3, instead of approximately 1.22 kg/m^3 at sea level. TRNSYS determined the air capacitance, which is the heat capacity of the air in a thermal zone (found by increasing density, volume, and specific heat capacity together), for each zone utilising these values, so the air capacitance should have been amended for each zone in each house. The air capacitance directs how much energy is needed to change the temperature of the room air by one degree, so this value should have been remedied to get an exact portrayal of each zone. Without changing this value, the heat needed to change the room air temperature would have been roughly 20% higher since that is the difference in air density at the correct elevation versus sea level. The windows were chosen from the inherent library dependent on construction and U- value. The chosen models for this study were Types 1001, 1002, and 2001 for the low, middle, and high levels, respectively. A summarised list of the window properties is depicted in Table 3.15.

Table 3.15 Window Parameters

Window Grade	**Construction (Glass/Air/Glass)**	**U value (W/m^2)**	**SHGC**
Type 1001	4 mm/0 mm/0 mm	5.69	0.856
Type 1002	4 mm/16 mm/4 mm	2.82	0.754
Type 2001	4 mm/16 mm/4 mm	1.39	0.600

Adapted from TRNSYS Component Library

The heating system was characterised as a focal unit with capacity limited to 2500 W (9000 kJ/hour) and was shared between thermal zones automatically at whatever point there was a heating demand. Heating demand times were administered by the heating accessibility schedule. This followed the same day-or-night heating schedule as in the

EnergyPlus model. The irradiated segment of the heat output was set to 25% with no latent heat yield to re-enact a convective-radiation space heater. TRNSYS compiles the construction data for each envelope component at the start of a simulation and computes heat transfer coefficients for the components.

The calculation utilised sequential time steps to focus on a solution for these coefficients, which are then utilised in heat transfer estimations. By default, the number of time steps, referred to in the program as the time base, was set to one. This implies that in the event that the simulation time step is 60 minutes, at that point the time base is one hour, and the program utilises up to 20 time steps to attempt to converge on a solution. At the point when convergence was not found within 20 cycles, the program returned an error. When there are layers in the constructions that have extreme varying densities and heat capacities, there can be some difficulty converging on an answer to develop these coefficients. To account for the contrasts between the brick and air layers in the walls, as well as between the metal and insulation layers in the roof, the time base should have been expanded to three time steps. This took into consideration the thermal storage properties of the heavy wall components to play out in the cycles over 60 hours rather than 20 hours. All simulations utilised a similar time base of three time steps for consistency.

3.10 Batch Parametric Simulation Setup in jEPlus

The EnergyPlus and TRNSYS simulations each needed a different jEPlus file for right syntax and search strings, however, the purpose of the two jEPlus files achieved a similar task in the same order. For EnergyPlus, an. rvi file was required, which arranges the outputs from each EP simulation for output to a.csv file utilising the embedded EnergyPlus feature ReadVarsESO. For simplicity, the file for this task just changed over the EnergyPlus output file, eplusout.eso, to a comma-separated file that could be compiled when performing batch runs. At the point when the ideal output was yearly heating energy usage, the jEPlus program compiled all yearly heating energy usage data into a single file with each line representing one simulation, containing the yearly energy use of each zone. This was added per line to get the final house energy usage for heating for the year. If desired, the inside temperatures can also be recorded on an hourly basis, despite the fact that while computing all combinations of parameters, it is not prescribed to have an hourly-recorded item, since the data may become overwhelming to assess.

A parametric tree was produced using four levels: ceiling/roof properties, slab properties, wall properties and window properties. Each level was compared to a parameter that was varied, and thus had three possible values, based on the trial run setup. Every parameter was changed utilising a string search, where the program scanned the input files for a specific string and replaced that string with the parameter's current value. For instance, when the wall insulation was set to be an air-gap, the program scanned the input files for the text string "@@WallIns@@" and replaced it with the text "SA Airgap40". The program did this for every one of the four parameter branches toward the start of every simulation to set the correct values, then saved the input files and executed EnergyPlus with that IDF, or TRNSYS with the DCK and B17 files.

The way that the parameters were entered relied upon what parameter should have been changed. At the point when a layer of an envelope component should have been swapped out for another, then the name of the material layer in the construction was the parameter being changed. On account of the wall component, the layer between the two layers of brick was swapped, so the values in the parameter tree are the names of the various layers that was utilised to insert into the mid-wall gap. For a parameter change which relates to changing just a single material property, and not changing a whole layer, the parameter to be changed was a mathematical range corresponding to the three levels of insulation.

For instance, the slab insulation parameter varies the thickness of insulation underneath the concrete slab. The least value is set to one millimetre and is basically an insignificant measure of thermal insulation. The greatest value aligns to a thick layer of similar insulation. Only the thickness value of the insulation is varied, and all material properties of the insulation remain constant.

The central issue is that every IDF file requires a material library which contains the materials that were utilised for all simulations, not just the materials utilised for that specific simulation. This is on the grounds that the main changes made to the IDF file are the strings altered by the parameter tree; consequently, all building components require to be set up before the parametric variations are run. If not, EnergyPlus will not be able to obtain certain materials in the library when the values are altered at the construction level. With the parameters characterised and the right strings placed in the IDFfile, the project file was executed to automate the simulation of all parameter variations. All 81 simulations for the investigation were run in sequence and an output file was produced for every trial. An organised results file was produced when all simulations were finished, thereafter, the outputs were simultaneously extracted utilising the ReadVarsESO program and arranged into a single file. This file contained outputs from every simulation and was arranged for the examination of impacts of envelope component variation on heating energy use.

3.11 Model for Embodied Energy of Construction Materials

The embodied energy and construction costs were estimated for one storey houses of varying plinth area. Analyses for selected building materials were performed and compared. The embodied energy was calculated using input-output tables. A step-wise calculation method was followed from Holm (2000). The bill of quantities (Appendix 2) for these houses was prepared as per the actual construction and current market rate. Values of the embodied energy used in the calculation are given in Table 3.16 and taken from a previous study (Irurah, 2000).

Table 3.16 Energy intensities for various materials

Material/Components	Total Embodiment (MJ/kg)
Cement	9.35
Aggregate (sand, crushed stone)	0.37
Steel reinforcement	26.75
Brick (average)	3.38
Timber	35.65
Iron sheets	85.09
Asbestos sheets	21.91
Gypsum boards	8.38
Flushdoor (average)	2300.28
Glass	99.67
Paint (average)	182.86
Pipes (plastic, average)	226.63
Hollow Block	0.41
Solid Block	0.48

The quantity and type of construction materials and the factors affecting their embodied energy intensity are required to quantify the total embodied energy content of a given building design/element. The amount of the materials required is assessed from the architectural plans and calculated engineering specifications, (Appendix 1), of the existing or proposed building to be evaluated. The initial embodied energy content is estimated using the following model:

$E_{emb,\ initial,i} = E_{extraction,\ I} + E_{manufacture,\ I}$ (1)

$E_{emb,\ initial,i} = \sum_{1}^{i} 1(\alpha_i m_i)$ (2)

where:

$E_{emb,initial,i}$ is the initial embodied energy of the ith type of building material (in MJ)

$E_{emb,initial}$ is the initial embodied energy of the entire structure (in MJ)

a_i is the embodied energy intensity factor for the i^{th} type of building material (MJ/kg)

m_i is the mass of the i^{th} type of building material (in kg)

m_i should include both the quantities of material in-place and also the wastages incurred during construction.

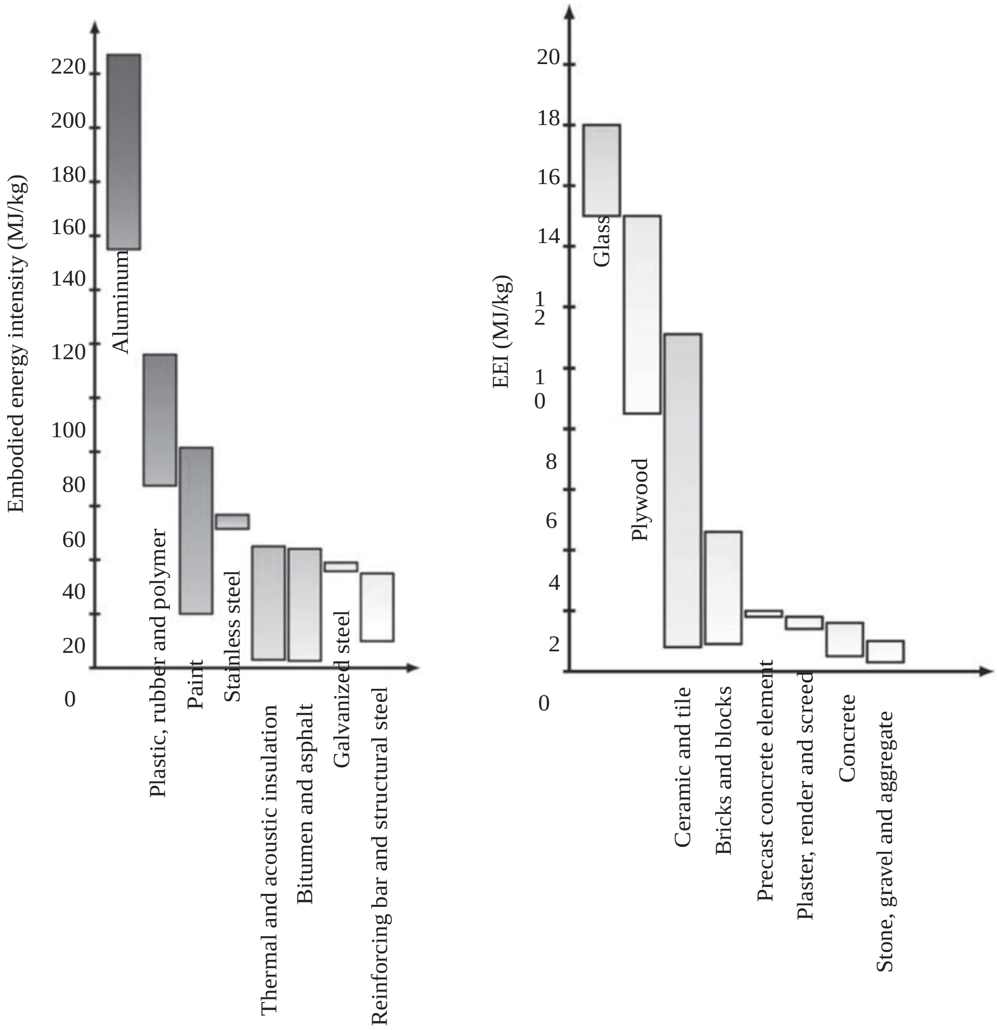

Figure 3.4 Embodied energy intensities for different types of building materials. (From Atmaca, A., and Atmaca, N., *Energ. Build.*, 102, 417–431, 2015; Baird, G. et al., *IPENZ Trans.*, 24, 46–54, 1997; Hammond, G.J.C., Inventory of Carbon and Energy (ICE) Version 2.0, *Bath DoMEUo*, Circular Ecology and University of Bath, UK, 2011; Huberman, N., and Pearlmutter, D., *Energ. Build.*, 40, 837–848, 2008; Kofoworola, O.F., and Gheewala, S.H., *Energ. Build.*, 41, 1076–1083, 2009.)

Table 3.17 Embodied Energy Intensities for Common Building Materials

Material Intensity	**Energy Intensity**	**Material**	**Energy**
Aggregate	0.10	Insulation	
Virgin rock	0.04	Cellulose	3.30
River	0.02	Fiberglass	30.30
Aluminium	191.00	Polyester	53.70
	236.8	Glass wool	14.00
Aluminium	8.10		
Steel	42.0		
Steel, Virgin	32	Gravel	0.2
Asphalt	3.40	Paint	90.40
			93.3 (New Zealand)
Cement	7.80		90.4 (China)
	5.85	Solvent based	98.10
	6.15		
Cement	2.00	Lime	5.63
Water	0.00814	Water based	76.00
		Aggregate	0.124
Ceramic		Plasterboard	6.10
Brick and tile	2.50	Plastics	
Brick (glazed)	7.20	PVC	70.00
Clay tile	5.47	Polyethylene	87.00
Concrete		Polystyrene	105.00
Block	0.94		117 (New Zealand)
Brick	0.97		105 (China)
Paver	1.20	Sealants and adhesives	
Precast	2.00	Phenol formaldehyde	87.00
Ready mix,	1.00	Urea formaldehyde	78.20
30 MPa	1.30	Steel (recycled)	10.10
	1.08	Reinforcing, section	8.90
Roofing tile	0.81	Reinforcement	8.08
Glass	25.8	Steel (virgin, general)	32.00
Float	15.90	Galvanized	34.80
Toughened	26.2 (New Zealand)	Stainless	11.00
	26.4 (China)	Timber (softwood)	
Laminated	16.30	Plywood	10.4 (New Zealand)
Gypsum	8.64		18.9 (China)
		Rough saw	5.18

(From Chen, T. Y., Burnett, Chau, C.K. 2001. Analysis of embodied energy use in the residential building sector of Hong Kong. Energy, 26(2001) 323-340; Goggins J, Keane T, Kelly A. The assessment of embodied energy in typical reinforced concrete building structures in Ireland. *Energ. Build*. 2010;42:735–744; Jiao Y, Lloyd CR, Wakes SJ. The relationship between total embodied energy and cost of commercial buildings. *Energ. Build*. 2012;52:20–27; Ramesh, T., Prakash, R. & Shukla, K. K. 2010. Life cycle energy analysis of buildings: An overview. *Energ. Build*. 42: 1592–1600.)

The data of embodied energy intensities used in the calculation are not known precisely for each location/country in public domain. Therefore, the embodied energy intensities values for the selected materials used in this study is based on the literature as shown in Figure 3.4 and Table 3.17.

The replacement factor for such components/materials can be calculated using the following formula:

Replacement factor = Life span of building/Average life span of component (3)

The following revised mathematical formula can be used to estimate the total embodied energy of buildings, more precisely and accurately by including transporting, installing, and finishing the construction materials and components during initial construction as well as renovations of the structure (Chen, Burnett & Chau, 2001).

$$E_{\text{emb},i} = E_{\text{emb,initial},i} + E_{\text{transport},i} + E_{\text{installing},i} + E_{\text{finishing},i} \quad (4)$$

The calculation of the embodied energy and costs were done separately for each of the components (i.e. walls, roof, foundation etc.). Labour costs were also included on a nominal sub-contract price basis. The municipal costs for water and electricity supply as well as professional fees which amounts to approximately R43 626 (Forty-Three Thousand Rand), excluding value-added tax (VAT), were not included in the calculation for total construction costs since these are indirect costs and are covered by the municipality for the government housing programme. Since the RDP house was compared to the conventional house, these costs were excluded from both.

The operating energy is the energy used in the operation of a building, for example, energy consumed in cooling, heating, lighting, ventilation and to operate appliances. Out of all these operations, it should be noted that energy for cooling and heating has the highest share and depends on the heat gain or loss of the structure. Both operational and LCE can be minimised by minimising the building envelope’s heat loss/heat gain through the appropriate selection of construction materials used in different layers. The low thermal conductivity and considerable heat capacity at the parity of all other conditions are basically needed to keep heat loss/heat gain. Moreover, the LCE can be reduced further if the embodied energy of such materials is low. The LCE of the building is assessed based on the following derived formula:

$$LCE = \sum m_i e_i + E_C + \sum m_i e_i [\{(L_b/L_{mi}) - 1] + E_o A L_b + E_D + E_T \quad (5)$$

The first term in the right-hand side of the above equation represents building embodied energy, which includes E_c, the energy used at the site for erection/construction of the building. The second term is used for recurring embodied energy and includes embodied energy for replacement construction and finishing materials to rehabilitate the building and energy used in regular annual maintenance. The terms L_b and L_{mi} represent life span of the building and life span of the material (1), respectively. The third term in the above equation represents the operational energy, which is required for maintaining comfort conditions and day-to-day maintenance of the buildings. The thermal comforts are maintained by using heating, ventilation, and air-conditioning (HVAC) and day-to-day requirements, such as domestic hot water, lighting, and operating appliances. The operational energy varies generally depending on the level of the required thermal comfort, climatic conditions, and operating schedules. At the end of the service life of buildings, the buildings are demolished, and waste materials are required to be transported to the landfill site. Some energy is used in demolishing and waste transportation. The last two terms in the above equation are used for energy used in demolishing and transportation. In some cases, the energy used for on-site construction and demolition at the end of its service life is considered negligible as its contribution to LCE is small (almost 1%).

3.12 Methods of Data Collection

To assess various parameters of a building and their effects on the system energy utilisation, a wide range of parametric variation analyses have been developed. While the particular methodology differs depending on the purpose of the study, the general methodology remains the same. Tian (2013) gives a review of the sensitivity analysis procedure as shown in Figure 3.5. A selection from Tian’s outline depicts various techniques to approach the creation of a building energy model:

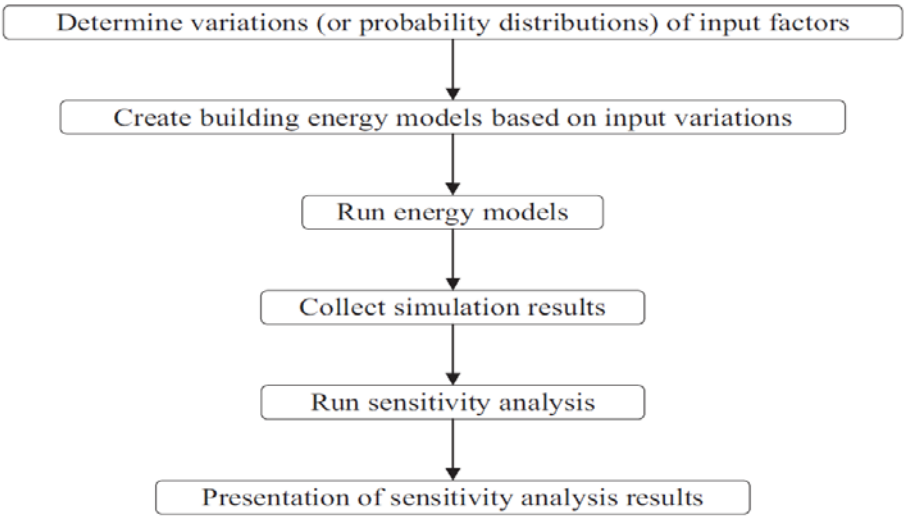

Figure 3.5 Typical process flow diagram for performing sensitivity analyses (Tian, 2013).

The two normal decisions are to utilise either a full building simulation program, such as EnergyPlus, ESP-r, TRNSYS, and/or DOE-2, or to create a simplified calculation model usually based on ISO13790:2008 (Thermal Performance of Buildings – Calculation of Energy Use for Space Heating and Cooling), or similar techniques. The building simulation programs can be utilised to enter detailed parameters and complete simulations on an hourly basis. The programs listed above have text-based input files and these are easily edited. The simplified calculation method is computationally more affordable and offers simple admittance to variable inputs.

Mechri et al. (2010) utilised an ANOVA process to assess the sensitivity of an office building's energy usage to numerous parameters such as external shading, glazing area and orientation. The investigation utilised arbitrary sampling of parameter values based on both Latin Hypercube Sampling (LHS) and Fourier Amplitude of Sensitivity Technique (FAST) methods. A simplified thermal simulation was performed on month-to-month time steps, permitting an assessment where building-level factors could be quickly changed in subsequent simulations and large sample quantities could be used. The study found that the largest contributor to building energy use fluctuation, of those variables tested, was the percentage of glass to total envelope area. Thermal mass location and building shape were the next largest benefactors at approximately one-third the contribution of glazing. The huge contribution of glazing percentage is likely because of the range used in the study, which spanned from 20% to 90%. Interaction effects were low at a maximum of 3% contribution to energy change. With a simulation model that describes thermal mass affected by direct solar gain, the interaction between glazing area and thermal mass location may have more significance, yet the Mechri's et al. (2010) simplified model does exclude such considerations. This study will draw upon Mechri's et al. process but will institute a more complex modelling simulation using full hourly weather data. Instead of utilising arbitrarily chosen values, the different parameters will be varied between discrete levels according to local, national and international building standards and construction practices. O'Neill et al. (2011) used sensitivity studies when calibrating an energy model with the physical manifestation of the building. To identify parameters within the energy model which need to be precisely adjusted, O'Neill and associates performed a sensitivity study which changed over 1000 parameters of an EnergyPlus model by ±20% of their nominal value. After the runs were completed and the outcomes viewed, those parameters which created the greatest variance in energy use were recorded. An on-location climate station and energy management program were used to determine actual energy use and enter recorded weather data for the correlation time frame. After calibration of the sensitive parameters, the subsequent model energy use corresponded with the recorded data to within 4%. The investigation highlights how an energy model can be analysed for drivers of uncertainty in results by systematically changing parameters which influence the output.

TRNSYS has the ability within the Type 56 model to calculate simplified convective heat transfer coefficients on inside faces, and only constant values can be utilised for outside faces. EnergyPlus has several methods for calculating the convective heat transfer coefficients. The Thermal Analysis Research Program (TARP) used in EnergyPlus utilises surface and air properties at each time step to calculate convection coefficients. Due to the more detailed computations utilised in EnergyPlus (see Figure 2.5), the subsequent calculated convective heat transfer coefficients may closely represent the actual conditions. The coefficients from the EnergyPlus simulations were used in TRNSYS for both internal and external faces, in any case, since the inputs to TRNSYS can only be constant values in the Type 56 model, the yearly average was utilised for the interior and exterior coefficients divided into the wall, roof, and floor components.

3.13 Data Analysis

In order to perform the sensitivity study, an analysis of variance (ANOVA) was performed. By linking to each simulation result the values of parameters used to accomplish that result, the impacts of specific parameters were extracted and assessed. The Minitab Statistical Software was utilised to perform this extraction and representation of data. The arranged output from the parametric assessment of each house was imported to Minitab. The result of each simulation was put into a single column as kilowatt-hours per square metre (kWh/m^2) floor area. Five parametric sections were made to show parameter values for each data point. Notwithstanding the four construction parameters outlined above, the fifth parameter was house geometry since the energy use was standardised to floor area. Once the data was entered and composed, the ANOVA analysis was run, and results were viewed in two different ways. The main effects plot indicated how the change of a single parameter influenced the energy use with all the other parameters kept constant. The interactions plot indicated a variety of all the parameter interactions with one another to aid in the assessment of parameter dependence on each other. For explicit examinations and more detailed investigation of situations, the data was adjusted in Microsoft Excel, which permitted more focused perspectives of connections between parameters. The data output from the simulations was labelled with the estimation of every insulation value for every parameter so that an analysis of the effects could be obtained. A column was made for each parameter except the heating energy use value for every simulation, which contained that parameter's value for that trial run. The heating energy use was also divided by the total floor area for each house model to convert the units for energy usage from kWh/year to $KWh/m^2/year$.

For this study, it is ideal to use the EnergyPlus results which give us a closer representation to these simulations. This whole building simulation software, EnergyPlus, has received a more extensive acceptance in the building energy analysis community and is promoted by the Building and Technology Program of Energy Efficiency and Renewable Energy Office (Anon, 2013). The tool calculates the energy demand in an integrating manner considering the impact of cooling, heating, lighting, and many other building integrated sustainable energy systems (Bojie et al., 2012).

3.14 Chapter Summary

The following conclusions can be drawn from this study:

- A mathematical model was developed and validated with measured data for different buildings.
- Empirical correlation were established to calculate the optimum energy intervention for the maximum annual thermal performance of the buildings.

CHAPTER FOUR: RESULTS

4.1 Energy Simulation

Energy modelling was performed for each of the four houses for all variations of the four parameters, namely, (wall, window, ceiling, and slab). Every parameter had three values: RDP construction, SANS 10400-XA building code requirements, and IECC 2012 construction standard prerequisites. Simulations were performed using two energy simulation programs, EnergyPlus and TRNSYS.

The modelling was conducted consecutively with no randomisation. Levels one, two, and three correspond to the parameter boundary value arranged by increased insulation value. The results were analysed in various ways during the debugging and simulation process and are introduced utilising accumulated averages per boundary value, while all other analysed parameters were varied, otherwise known as a “main effects” investigation. The results are shown as heating energy, kilowatt-hours per square metre per year. An examination of the interactions was also performed and will be discussed. The following sections review the results using EnergyPlus first, followed by the TRNSYS results, and then a correlation of the two programs with a discussion on potential sources of variation between the EnergyPlus and TRNSYS modelling programs. The simulation software is used to compare the different variations of the four parameters and make inferences on energy reduction on each.

4.2 Energy Performance Simulation Results using EnergyPlus

The results from the main effects analysis of the EnergyPlus simulations is illustrated in Figure 4.1, with a detailed examination of the results below. The different graphs show the main effects plot for EnergyPlus annual heating for different factors and components of the modelled building, namely geometry, wall, window, ceiling, and slab. The geometry measures the mean annual heating for the different houses. 1-J, 2-S, 3-V and 4-A with plinth area of 42 m^2, 62 m^2, 84 m^2 and 105 m^2, respectively. The standard RDP construction, (Level 1) is compared to Level 2-SA min and Level 3-IECC criteria.

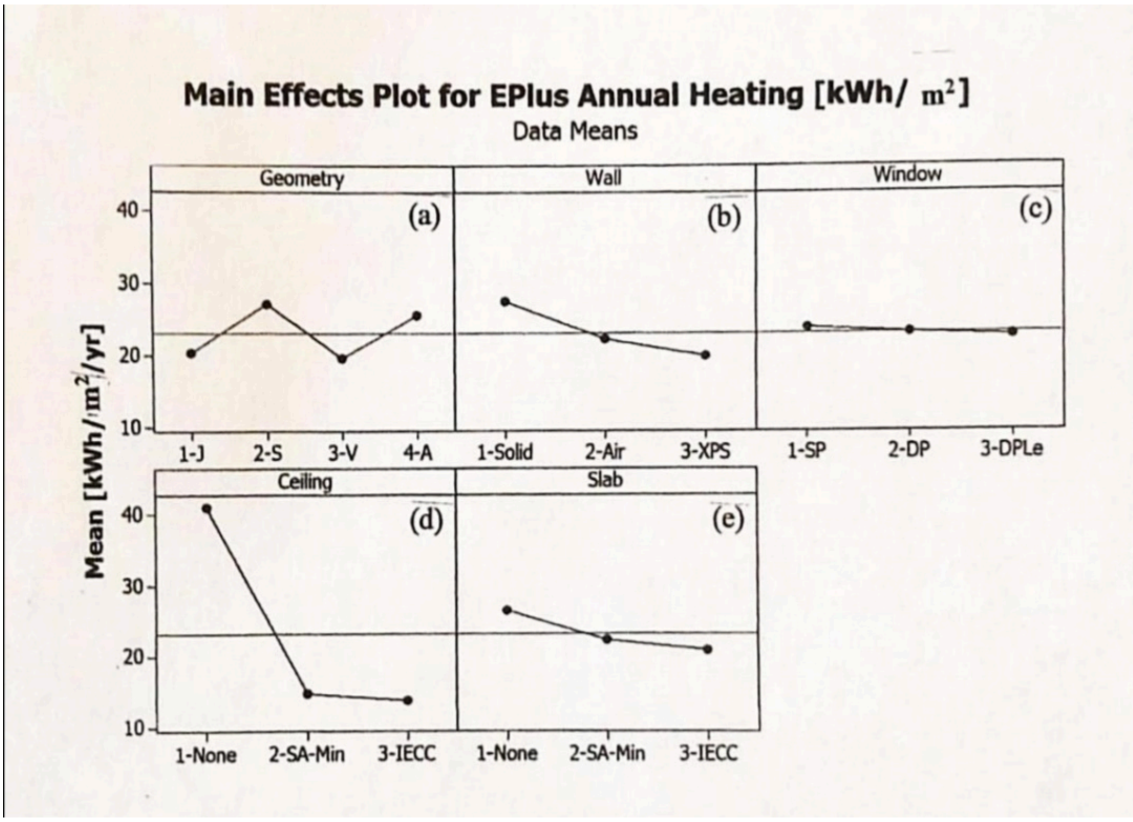

Figure 4.1 Main effects from the EnergyPlus simulations results.

4.2.1 Main effects of wall insulation in EnergyPlus.

Figure 4.1 (b) shows the effect of increased wall insulation on the energy output for a solid brick wall without an air-gap (1-Solid), a wall with an air-gap (2-Air), and a cavity wall with 40 mm extruded polystyrene (3-XPS). In the case of the two layers of solid brick, (1-Solid) on the graph, a consistent reduction in heating energy usage is observed. For Level 2, which is the SANS 10400XA, South African Minimum Standard (2-SA-Min) of wall insulation where an air-gap, (2-Air) is utilised, the properties of the air-gap incorporated implies that the gap is wide enough for some convective flow, which raises the conductivity value of the air layer. Nonetheless, the general impact is still an increase in insulation as well as a thermal break between the two layers of brick. The average annual value of heating energy decreases from 27 kWh/m^2 for Level 1-Solid to 22 kWh/m^2 for Level 2-Air and 20 kWh/m^2 for Level 3-XPS which the international building code standard is (3-IECC 2012) with the minimum requirement of a 40 mm extruded polystyrene cavity wall. While including the air-gap, the normal decrease is 20%. Given that this energy efficiency measure adds no expense to the structure, it is a practical measure to add in the model. Table 4.1

shows the relative energy decreases for the various houses of different plinth area simulated in EnergyPlus. The variations are due to geometric contrasts in the houses considering relative wall areas to other envelope components. House 1-J/CH 42 has more wall area as a percentage of total envelope area than House 4-A/CH 105, which clarifies why more savings are conceivable in House 1-J. The characteristics of House CH 42 are generally like the RDP house size and shape.

Table 4.1. Mean wall insulation effects of the different houses in EnergyPlus

Percentage Decrease in Energy Use	**1-J/ CH 42**	**2-S/ CH 62**	**3-V/ CH 84**	**4-A/ CH 105**
Level 2 -Wall w/ Air Gap - (2-Air)	24%	18%	21%	12%
Level 3 -Wall w/EPS - (3-XPS)	34%	28%	31%	19%

A transition from the air-gap insulation, Level 2-SA min code, to the Level 3-IECC 2012 minimum requirement of a layer of polystyrene insulation brings more energy savings. The mean energy utilisation is decreased by 27% averaged across all models, down to 20 kWh/m^2. This shows that the walls can benefit from an increase in insulation at either level. Indeed, the moderately linear decrease in energy use over the three levels implies that there are probably further savings that can be accomplished with extra insulation. The energy savings curve has not yet approached the asymptote of the curve.

4.2.2 Main effects of window types in EnergyPlus

In Figure 4.1 (c), the effect of various window types on the mean energy output is shown. The Level 1 window (1-SP) is a single-pane steel-framed window, with the Level 2, SA min code and Level 3, international IECC requirement being increasingly better-insulated low-end (2-DP), and mid-range double-pane windows (3-DPLe), respectively. There is a minimal decrease in energy use when changing the window type. The minimal reduction in energy is due because of the generally small window areas and the low insulation values of the other parts.

Table 4.2. Mean window insulation effects of the different house in EnergyPlus

Percentage Decrease in Energy Use	**1-J/ CH 42**	**2-S/ CH 62**	**3-V/ CH 84**	**4-A/ CH 105**
Window Level 2 - (2-DP)	2.1%	1.9%	4.2%	2.7%
Window Level 3 - (3-DPLe)	3.8%	3.6%	7.7%	5.0%

Table 4.2 depicts a minimum decrease in energy use when Level 2 and Level 3 windows are utilised in all the other houses, except for 3-V/CH 84 where it shows a 3.5% reduction. The low decrease is because of the heat retention from the increase in thermal resistance of the heavier windows is likely cancelled by the lower solar heat gain coefficient, which means less solar gain during the day that helps balance heating demand. Due to the orientation and the size of the glazing being close to 20% of the floor area for the 3-V/CH 84 house, the 'solar collection' provides the most favourable thermal efficiency, thereby a larger difference between levels.

4.2.3 Main effects of ceiling insulation in EnergyPlus

Figure 4.1 (d) shows the EnergyPlus simulations for all the houses roof-ceiling insulation, namely roof only-no ceiling (1-None), roof with 18 cm batt insulation (2-SA-Min) and roof with 33 cm batt insulation (3-IECC). The graph shows the mean annual heating and the effect of adding roof insulation. The RDP construction method, (1-None), utilises a single layer of corrugated metal sheet for the roof with no ceiling or insulation underneath. Therefore, the conductivity value of the roof component is extremely high. The largest insulator of the roof system is the inside surface air film. The inside surface convective heat transfer coefficient is the primary contributor to overall insulation since the air inside the house is not mechanically circulated during these simulations, decreasing the free convection component, and eliminating the forced convection component.

When using Level 2, the South Africa code minimum, the mean annual value of heating energy changes from 42 kWh/m^2 to 14 kWh/m^2 thereby resulting in a 63% average decrease in annual heating energy. In the IECC, Level 3, the mean annual value of heating energy drastically changes from 42 kWh/m^2 to 12 kWh/m^2 thereby resulting in a 67% average decrease in annual heating energy.

Table 4.3. Mean roof insulation effect of the different houses in EnergyPlus

Percentage Decrease in Energy Use	**1-J/ CH 42**	**2-S/ CH 62**	**3-V/ CH 84**	**4-A/ CH 105**
Ceiling Level 2 - (2-SA-Min)	65%	67%	54%	67%
Ceiling Level 3 - (3-IECC)	67%	68%	59%	68%

When examining the main effects plot for ceiling insulation in Figure 4.1, as well as the results in Table 4.3, the gradual decrease in energy use from Level 2 to Level 3 is small. Figure 4.1 shows that the decrease in energy use is likely to be close to an asymptote, implying that most of the energy savings achieved at Level 2 could be ascertained with even less insulation. It also implies that the amount of insulation used in Level 3 does not merit the additional material cost, since the Level 3 insulation has almost double the amount of added material and insulation value than Level 2.

4.2.4 Main effects of slab insulation in EnergyPlus

Figure 4.1 (e) shows the EnergyPlus results for the different houses for the slab insulation. The graph measures the mean annual heating for different slab insulation. The 1-None is 80 mm slab with no insulation while the SA-min is an insulated slab and IECC criteria for slab insulation layer represents both perimeter insulation and under-slab insulation in one layer. This is accomplished by adding a layer of soil over the slab layer. Here we expect only the surface to contact the ground and not the surrounding air directly. For the RDP house which has brick walls, the difference in conductivity between the wall and the slab is generally small, so the thermal bridging from the slab contacting the air is represented by the base of the wall contacting the air. The mean annual value of heating energy reduces from 27 kWh/m^2 for Level 1-None to 23 kWh/m^2 for Level 2-SA min and 21 kWh/m^2 for Level 3-IECC. This gives an average 16% energy reduction from Level 1 to Level 2 and a 21% energy reduction from Level 1 to Level 3.

Table 4.4 Mean slab insulation effects of the different houses in EnergyPlus

Percentage Decrease in Energy Use	**1-J/ CH 42**	**2-S/ CH 62**	**3-V/ CH 84**	**4-A/ CH 105**
Slab Insulation Level 2 – (2-SA-Min)	15%	15%	17%	16%
Slab Insulation Level 3 – (3-IECC)	20%	21%	22%	23%

The outcomes from the EnergyPlus modelling show a moderate yet significant reduction in energy use when including an insulating layer to the slab. The cold winter ground temperature is disconnected from the house with an increase in insulation, and the energy savings reflect that there is value to the extra insulation. The linear relationship shown in Figure 4.1, as well as the tabulated data shown in Table 4.4, demonstrates that there are extra savings available even at the IECC2012 level of insulation over the SANS level.

4.2.5 Interaction effects using EnergyPlus

The different parameter interactions are illustrated in Figure 4.2. If two parameters acting together create an impact which neither would create separately, it is depicted on the graphs as deviations between the sequences of lines, which would effectively result in a deviation of the gradient of the graphs.

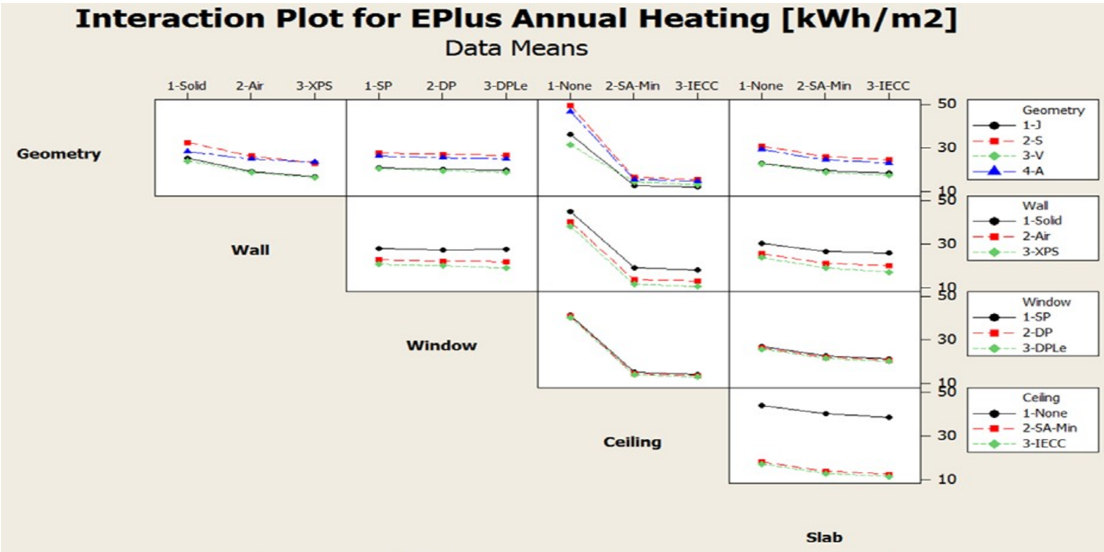

Figure 4.2 Interaction effects from the EnergyPlus simulation

In the Geometry-Wall plot at the upper-left corner of Figure 4.2, the mix of geometric layout design and wall insulation level create visible contrasts in energy utilisation decreases of the various house models. Data is standardised with plinth area, hence the general areas of envelope surface components are included in the “Geometry” boundary. At the point when the various geometries are joined with the varying wall insulation levels, heat gains and losses change only one envelope part, creating varying trends in energy utilisation. House 4-A seems to follow a different trend from the rest of the houses. This house has the largest plinth area and an extremely level rooftop. This house geometry has a lower percentage of wall area to overall envelope area, clarifying why the decreases in energy use are not as great.

The other deviation is observed in geometry and ceiling/roof insulation when looking at the gradient of energy use reduction in the appropriate graph (third from left, top row). The varying values of insulation under the roof influence the energy utilisation of each house differently dependent on the geometry. House 3-V has a large roof area however, it is considerably more steeply pitched than every other house. Houses 2-S and 4-A have low and almost level rooftops and are more affected by the changing insulation values. These varying geometries result in House 3-V having more interior volume per square metre of plinth area than Houses 4-A and 2-S. This may make House 3-V less sensitive to envelope changes, as the capacitance of the house is greater due to the additional mass of air. Relative to the main effects of each parameter variation, interaction effects are small, and due to geometric contrasts in the models than to the actual parameters being investigated since the study focused more on envelope components than on house design.

4.3 Energy Performance Simulation Results using TRNSYS

The results from the main effects analysis of the TRNSYS simulations is depicted in Figure 4.3, with a detailed analysis of the results below. The different graphs show the main effects plot for TRNSYS annual heating for different factors and components of the modelled building, namely geometry, wall, window, ceiling and slab. The variations due to geometric contrasts in the houses considering relative wall areas to other envelope components are examined. The standard RDP construction, (Level 1) is compared to Level 2-SA min and Level 3-IECC criteria.

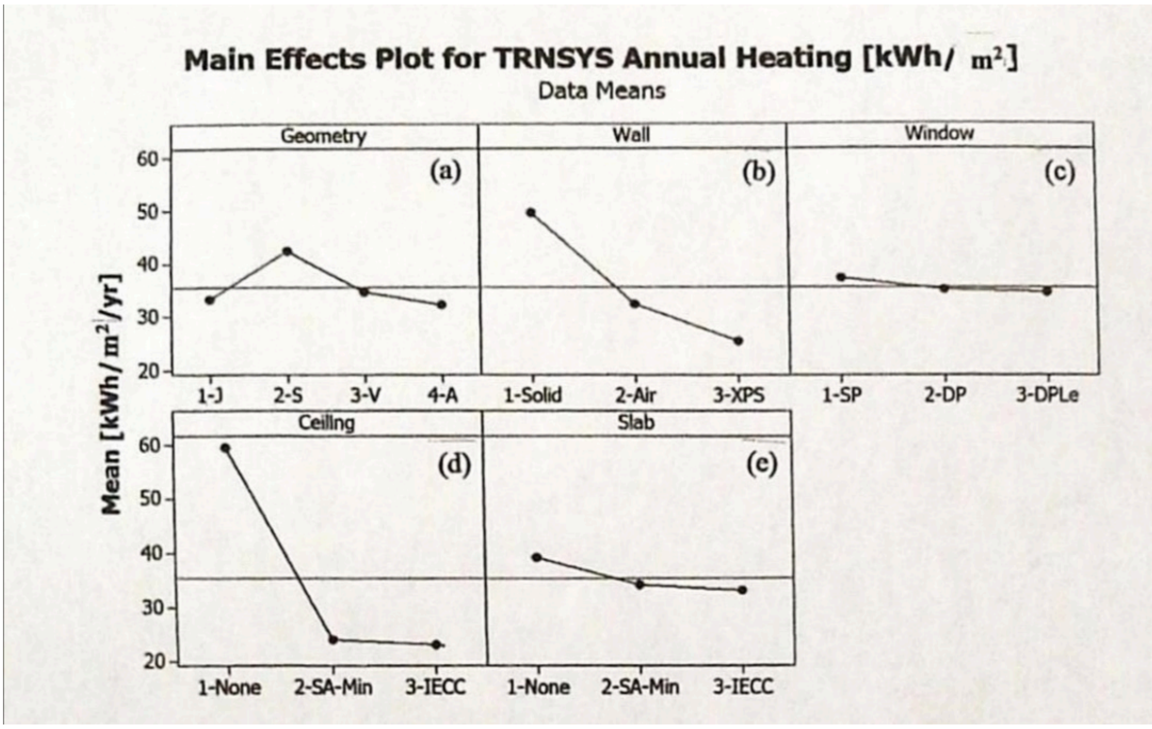

Figure 4.3 Main effects from the TRNSYS simulations results.

4.3.1 Main effects of wall insulation in TRNSYS

Figure 4.3 (b) shows the TRNSYS simulation and the effect of increased wall insulation. The graph measures the mean annual heating for the wall insulation that complies with different standards. Level 1 comprises of two layers of solid brick (1-Solid), for Level 2, (SANS 10400XA), of wall insulation, an air-gap, (2-Air) was utilised and for Level 3, the IECC 2012 building code with the minimum requirement of a 40 mm extruded polystyrene cavity wall is utilised. Utilising TRNSYS, the trend in energy use reduction by including wall insulation is similar to the EnergyPlus results in that there is a considerable decrease in energy usage. The results are summarised as percentage average decreases from the present construction case in Table 4.5.

Table 4.5 Mean wall insulation effects of the different houses in TRNSYS

Percentage Decrease in Energy Use	**1-J/ CH 42**	**2-S/ CH 62**	**3-V/ CH 84**	**4-A/ CH 105**
Level 2 -Wall w/ Air Gap - (2-Air)	42%	35%	34%	35%
Level 3 -Wall w/EPS - (3-XPS)	55%	49%	46%	48%

The mean annual value of heating energy reduces from 50 kWh/m^2 for Level 1-Solid to 32 kWh/m^2 for Level 2-Air and 26 kWh/m^2 for Level 3-XPS which is the IECC 2012 building code with the minimum requirement of a 40 mm extruded polystyrene cavity wall. There is an average reduction of 37% from Level 1 to Level 2 and 50% from Level 1 to Level 3. The decrease in heating energy prerequisites is more prominent in the TRNSYS simulation than in the EnergyPlus simulation. With similar mass and material properties utilised, the impact of including an air-gap between the layers of brick is approximately 1.5 times greater than the decrease in EnergyPlus. This is likely because of the differences in the time scale and computational method of TRSNSYS versus EnergyPlus. The two programs both utilise an algorithm that uses the material properties of the wall design to create a heat conduction transfer function. The coefficients of the transfer function are subject to an iterative cycle of calculations until the convergence limits are deemed to satisfy. TRNSYS limits the algorithm to twenty sequential iterations to converge to a solution, with each iteration taking one-time step. For this simulation, the low mass of the air-gap layer and the high mass of the brick layers caused the algorithm to fail in obtaining a solution under the default settings of the one-time step per calculation iteration.

The program documentation proposes expanding the time step, or "time-base" to take into account the thermal capacitance values present in the high mass walls utilised in this investigation. The shortest time base in which convergence could be accomplished for the wall system was three hours. This time base was used for all scenarios and parameter assessments. In contrast to this, the time step utilised in EnergyPlus was kept at the default setting of six time steps per hour, and no convergence issues emerged utilising these settings. While this may have contributed to the contrasts between the results, in the scenarios where convergence could be achieved in TRNSYS with the default time setting of one hour, the results did not vary by greater than 5% from the simulations utilising a time setting of three hours. Another probable reason for the distinction between the simulation results is because of the computation of convective heat transfer coefficients.

As examined in Chapter Two, the average values computed in EnergyPlus are lower than the TRNSYS coefficients for the internal faces. For the external faces, which are exposed to the wind, the coefficients determined in EnergyPlus average 35 W/m^2, or two times more than those in TRNSYS, which defaults to 17 W/m^2. By utilising the EnergyPlus values for exterior convection heat transfer coefficients, the roof components and conductivity of the wall is increased consistently. The key difference is that while the yearly averages are equivalent, EnergyPlus has the coefficients changing at every time step, and TRNSYS utilises the same value throughout the simulation. The wind speed and temperature change between the surrounding air and the surface implies that, at some points in the modelling, EnergyPlus will have fluctuating heat transfer rates through the building envelope than TRNSYS. An examination of the overall impact of this difference was not performed.

4.3.2 Main effects of window types in TRNSYS

Figure 4.3 (c), results show the effect of various window types on the mean energy output. The Level 1 window (1-SP) is a single-pane steel-framed window, with Level 2 being an increasingly better-insulated low-end (2-DP) and Level 3 being mid-range double-pane windows (3-DPLe), respectively. There is certainly not an enormous decrease in energy use while changing window type. The impact of including better quality double-pane windows to the TRNSYS-modelled houses are small relative to the other component variations; however, the results show a bigger decrease in energy utilisation compared to the EnergyPlus simulation. To include an inferior-quality double-pane window depicted as Window Level 2 in Table 4.6 results in a 4% to 8% decrease, while the superior-quality double-pane window depicted as Window Level 3 creates a 6% to 10% decrease and a 1% to 2% incremental decrease over Window Level 2.

This could be because of the more complex window model utilised in TRNSYS, which calculates heat transfer based not just on a single conductivity value and solar heat gain coefficient, but also utilises the assembly material properties such as reflectivity and transmittance to obtain differing heat gains and losses based on solar incidence angles. In EnergyPlus, the actual parameter that changed was the conductivity of the window, though, in TRNSYS, the complete window model changed, incorporating all the varying properties of the glass and air layers.

Table 4.6 Mean window insulation effect of the different house in TRNSYS

Percentage Decrease in Energy Use	**1-J/ CH 42**	**2-S/ CH 62**	**3-V/ CH 84**	**4-A/ CH 105**
Window Level 2 - (2-DP)	4%	5%	8%	6%
Window Level 3 - (3-DPLe)	6%	6%	10%	7%

4.3.3 Main effects of ceiling insulation in TRNSYS

Figure 4.3 (d) depicts the TRNSYS simulations, for all the houses roof insulation, namely, a roof with ceiling. The graph shows the mean annual heating and the effect of adding roof insulation. The RDP construction is in the category Level 1-None while Level 2- SA min is the national criteria and Level 3-IECC is the international building regulation for a ceiling. As with the EnergyPlus simulations, the house models are very sensitive to the roof insulation component in TRNSYS. From the base model roof with no insulation to Level 2 and Level 3, the percentage decrease in energy utilisation, averaged over all boundary variations, as depicted in Table 4.7.

Table 4.7 Mean roof insulation effect of the different houses in TRNSYS

Percentage Decrease in Energy Use	**1-J/ CH 42**	**2-S/ CH 62**	**3-V/ CH 84**	**4-A/ CH 105**
Ceiling Level 2 - (2-SA-Min)	65%	57%	56%	60%
Ceiling Level 3 - (3-IECC)	66%	58%	58%	61%

The annual value of heating energy reduces on average from 58 kWh/m^2 for Level 1-None to 23 kWh/m^{2}for Level 2-SA min and 22 kWh/m^2 for Level 3-IECC. This gives an average 60% energy reduction from Level 1 to Level 2 and a 61% energy reduction from Level 1 to Level 3. Similarly, as with the EnergyPlus simulation, the energy decrease when including insulation to the bare metal rooftop is extremely huge. This, again, is because of the high conductivity value of the metal roof, which provides minimal insulation from the outside temperature. The heat transfer across the roof component is a lot higher than any other component in the model, particularly considering the generally low mass and thermal capacitance of the metal roof compared to the walls and floor.

For the simulation to converge in order to find the conduction heat transfer coefficients, the thin metal roof required unique modelling considerations. With the high mass walls and floor contrasted to the low-mass metal roof at the RDP-equivalent first parameter level, the simulation could not reach convergence for the roof when the time limit was set to three hours. Since the three-hour time limit was insufficient to reach convergence in the wall system, the roof was simulated as a massless system. Modelling the roof as a massless component implies that the normal material properties of conductivity, specific heat, and density are substituted with a solitary thermal resistance value. This creates a less complex model so that the algorithm will converge. The resistance values were calculated manually based on the metal and insulation material properties. While this method does deviate from an exact physical representation, the moderately low mass and thermal capacity of the metal roof and insulation compared to the wall and floor systems make this a minor change in the general behaviour of the model. The percentage energy decrease when including more insulation to reach the IECC2012 criteria is minimal, demonstrating again in this model that most of the savings are in the initial step from no insulation to moderate insulation. In TRNSYS, the overall decrease from the second to the third level, which represents including about four more inches of fiberglass insulation, is a difference in energy utilisation of only one percent. This implies that the heat transfer through the roof has already been reduced by the second level scenario to the point where including more insulation is not necessary and would not be a cost-effective investment.

4.3.4 Main effects of slab insulation in TRNSYS

Figure 4.3 (e) shows the TRNSYS results for the different houses for the slab insulation. The graph depicts the mean annual heating for the different levels. Level 1-None is the RDP construction of an 80 mm slab with no insulation, Level 2-SA min is an insulated slab which is the national code and Level 3-IECC, insulated slab and perimeter is the international criteria. The slab model in TRNSYS was designed to be identical to the one used in EnergyPlus, and the trends of the results were similar. The average decrease for the different houses is shown in Table 4.8, with the overall trend depicted in Figure 4.2 (e). The mean annual value of heating energy reduces from 40 kWh/m^2 for Level 1-None to 34 kWh/m^2 for Level 2-SA min and 33 kWh/m^2 for Level 3-IECC. This gives an average 12% energy reduction from Level 1 to Level 2 and 16% energy reduction from Level 1 to Level 3, as illustrated in Table 4.8.

Table 4.8 Mean slab insulation effect for the different houses in TRNSYS

Percentage Decrease in Energy Use	**1-J/ CH 42**	**2-S/ CH 62**	**3-V/ CH 84**	**4-A/ CH 105**
Slab Insulation Level 2 - (2-SA-Min)	14%	13%	8%	13%
Slab Insulation Level 3 - (3-IECC)	17%	16%	10%	16%

The results show that an increase in energy savings can be obtained from the second level and third level insulation values. These results are marginally lower than the EnergyPlus results, and this might be mostly because of the various techniques for ground temperature input between the two programs. With EnergyPlus, there are two approaches to ground temperature input. The first uses a pre-processing program to perform a finite element analysis on the ground beneath the model. By utilising primary known data on the model internal temperatures and given deep ground temperatures in the region, the temperature at the bottom surface of the floor system is calculated on a grid across the floor. While this can be a truly precise technique for figuring the ground temperatures, it was not practical to pre-process every situation before starting each parametric run. It would also have required a further examination on soil properties and training on the pre-processing program. Instead, an estimate was utilised, which took the surrounding temperature and utilised a cosine wave variation to simulate the changing ground temperature throughout the year. To incorporate some soil variation, a layer of soil material was added in the floor assembly for all scenarios. The exact cosine wave was utilised in both programs; however, EnergyPlus only considers a monthly ground temperature, so each month of the year has a constant ground temperature. TRNSYS, on the other hand, has an input for the ground temperature at each time step, so at an hourly time interval, the cosine wave is input to the building model. This difference between the energy simulation modelling programs may clarify the difference in heat flux through the slab during times of heating in the colder months of the year.

4.3.5 Interaction effects using TRNSYS

The effect of interactions of the different parameters (geometry, wall, windows, ceiling and slab) from the TRNSYS simulations is shown in Figure 4.4. The geometry of the building is also shown as the fifth parameter for comparison, as depicted in the EnergyPlus results displayed in Figure 4.1. Although there is little interaction between the four insulation parameters of wall, window, ceiling and slab, it is observed that there is some interaction between the geometry type and the energy use of different levels of wall and ceiling insulation which results in the deviation of the slope of the respective graphs. The results from both EnergyPlus and TRNSYS show small interaction effects of the four parameters.

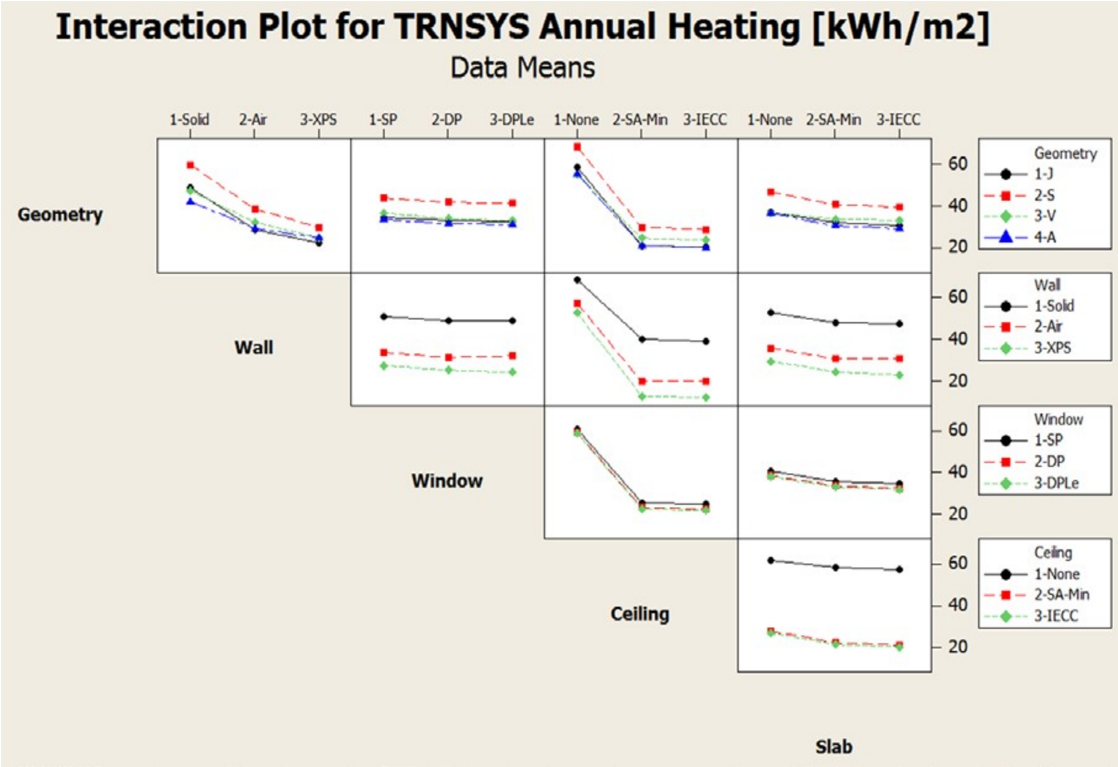

Figure 4.4 Interaction effects from the TRNSYS simulation.

One area where there might be interaction effects is between the window type and slab insulation. Theoretically, the concrete slab, which is uncovered as the finished surface in all models, can absorb the solar gain through the window. With more insulation under the slab and a higher solar heat gain coefficient in the windows, the passive solar gains of the house should be higher than if the slab were less insulated and if the windows had a lower solar heat gain coefficient, as in the second and third level window types. However, this does not seem to be present from the simulation results. This is because there is no ray tracing beyond the zone envelope for either EnergyPlus or TRNSYS. At the point when irradiance is calculated to strike the window, a certain amount of heat enters the zone based on the solar heat gain coefficient and conductivity of the window assembly, but the radiation stops at the external layer. This implies that the concrete slab floor does not receive the solar gain directly. Instead, the slab gains heat from the zone air and interior radiation sources such as the heaters. A confirmation of this behaviour can be observed in the Geometry-Slab interaction plot. House 3-V/CH 84 has more northerly-directed glazing than the other houses. Following passive solar design principles, this should prompt increased thermal heat storage to the slab, and the better insulation under the slab should enable increased heating energy reduction. Comparing House 3-V/CH 84 to the remainder of the houses in the Geometry-Slab plot, the trend of energy use reduction with increasing slab insulation illustrates a diminished heating reduction than the other houses. Although House 1-J/CH 42 has no northerly-directed glazing, and almost nothing toward the east or west, but shows more energy saving than House 3-V/CH 84.

4.4 Comparison of Heating Energy Use between EnergyPlus and TRNSYS

Despite the common components between the two energy models, EnergyPlus and TRNSYS determined recognisably unique energy utilisation amounts for each scenario. EnergyPlus consistently calculated energy utilisation at 30% to 40% less than TRNSYS given the same input parameters. The results from the EnergyPlus and TRNSYS simulations for the base-model with RDP-representative construction are illustrated alongside each of the four parameter's highest insulation value in Figure 4.5. The solid lines indicate the EnergyPlus results, while the dotted lines indicate the TRNSYS results. The difference between the results of the two programs may emanate from the varying techniques for computing convection coefficients. Another possibility could be from the varying ways that the two programs represent thermal mass storage in envelope components such as the massive walls.

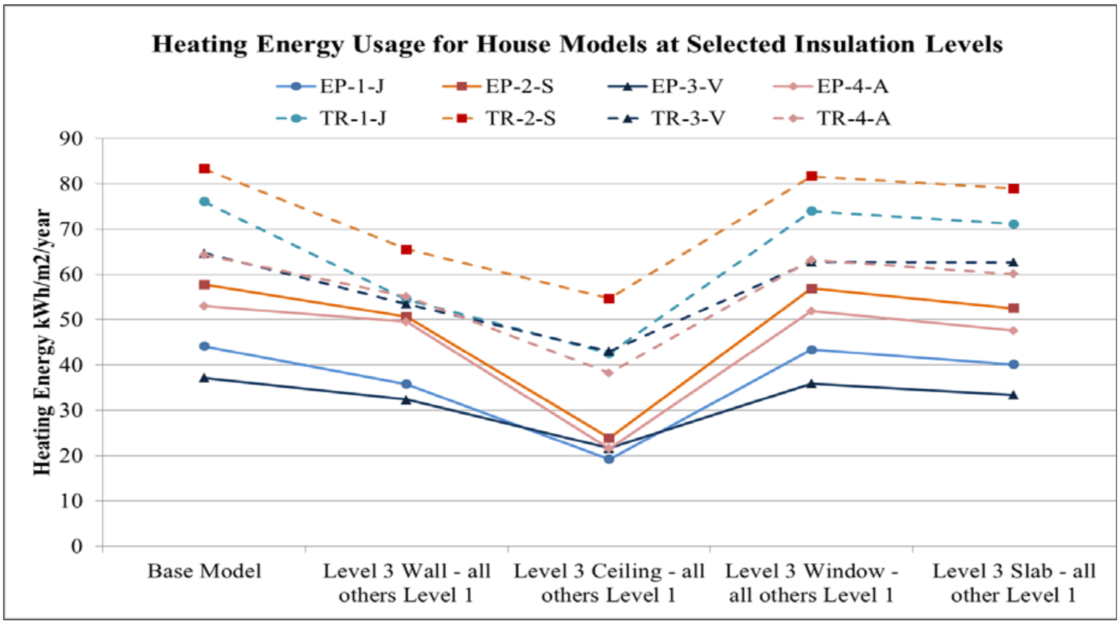

Figure 4.5 Comparison of total calculated heating energy usage between EnergyPlus and TRNSYS.

While the absolute numbers are distinctive between the two modelling programs, the trends in reduction are to a great extent the equivalent. The sensitivity of both models to the varying parameters is fundamentally the same, with the exception of the extra wall insulation being more effective in the TRNSYS simulation. To show the energy decrease if each component was added separately to the base model, the results for each of the four parameters in both simulation programs are shown in Figure 4.6. Each data point represents a single simulation where the labelled component was set to the Level 3 properties while all other components were maintained at the baseline.

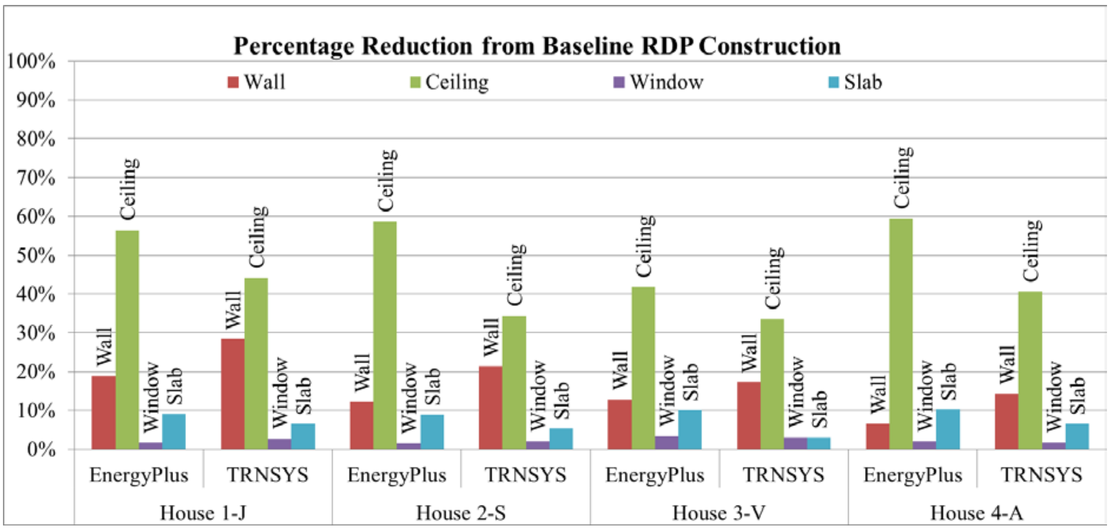

Figure 4.6 Energy reduction for each parameter varied separately.

Both EnergyPlus and TRNSYS simulations show that the effect of the window is almost negligible and the least energy decrease while including insulation under the roof is the most crucial factor for energy decrease. Figure 4.7 shows the graph of the interior temperature versus exterior temperature for the RDP house construction while Figure 4.8 is a similar plot with the exception that a ceiling is installed in the RDP house. The graphs illustrate the two temperature distributions. The data points for the "recorded" lines are from experimental temperature measurements taken using temperature detectors on actual RDP houses. In Table 4.7, the three lines for each data set represent the mean +/- one standard deviation of the data at each exterior temperature reading. The recorded data for Figure 4.7 is for the actual counterpart to House 1-J/CH 42. The close relationship between the two sets of data, simulated and recorded, shows that the EnergyPlus model is accurate and precise in representing the balance between internal loads and solar gains and the envelope components because the simulated data shows a very close temperature change to the actual data across a significant part of the temperature range.

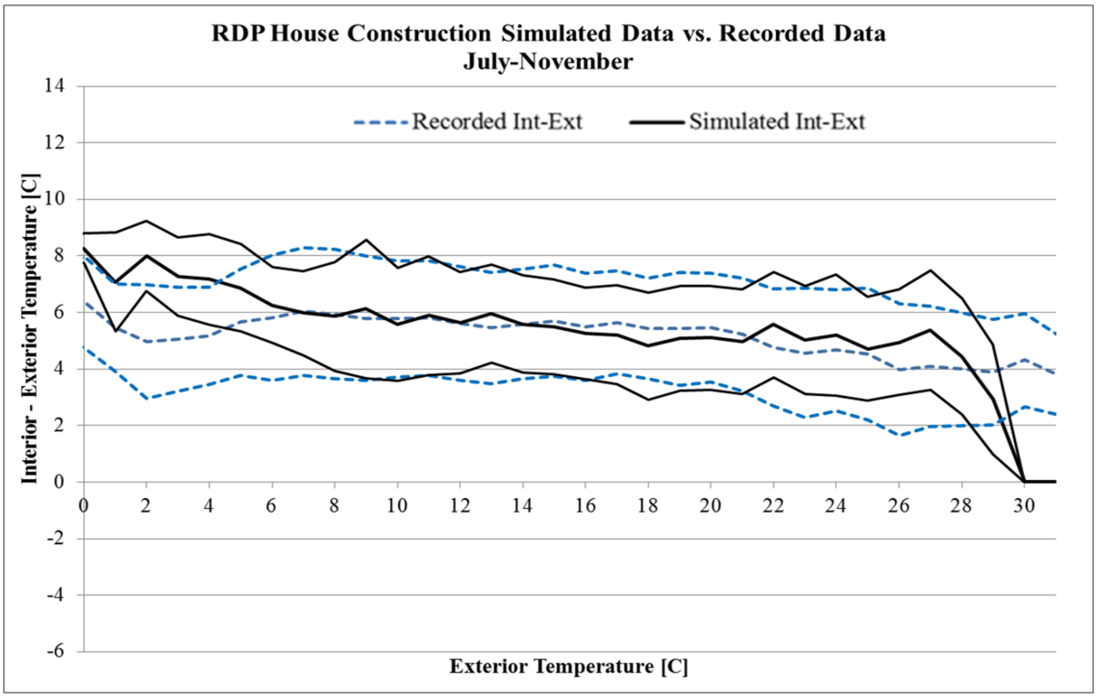

Figure 4.7. Interior temperatures versus exterior temperatures for the RDP house.

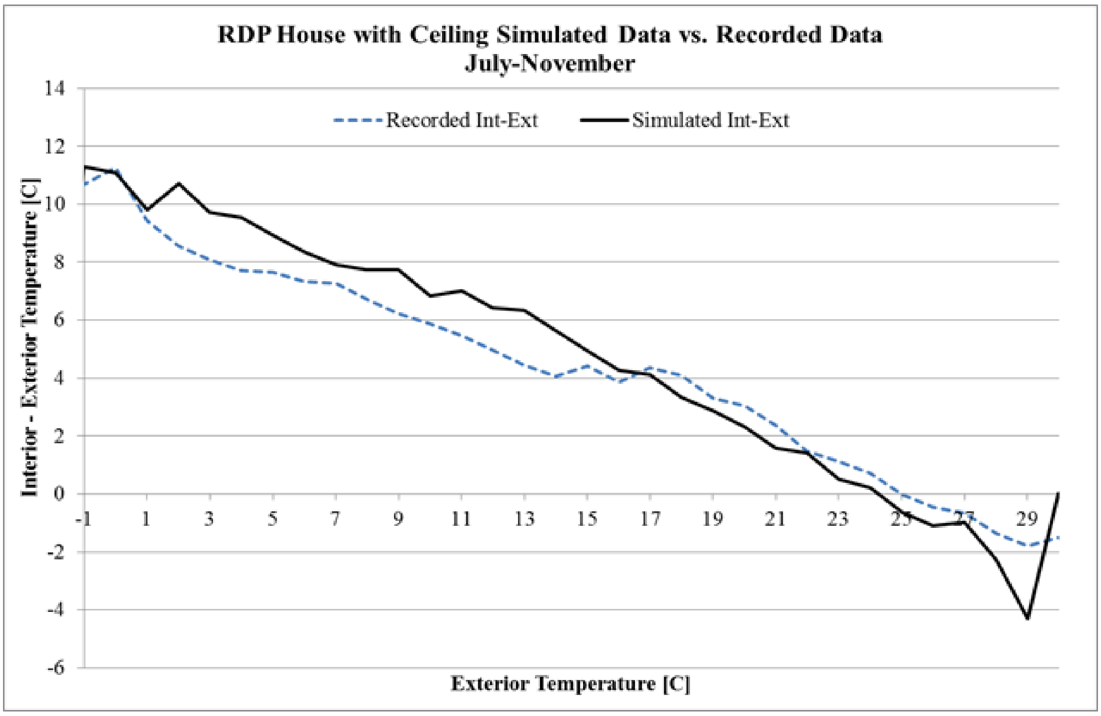

Figure 4.8 Interior temperatures versus exterior temperatures for RDP house with ceiling insulation

Conversely, the TRNSYS simulation resulted in a lower difference in interior and exterior temperatures and simulated a greater annual heating energy usage. This is due to differences in certain input parameter default setting. Figure 4.8 represents the interior versus exterior temperatures for the physical counterpart to the RDP constructed house with a ceiling, which is situated across the road from the RDP house without a ceiling. The houses are almost indistinguishable except that the counterpart RDP house has a ceiling with some insulation retrofitted to it. By changing only one parameter, the insulation levels under the roof, the behaviour of the house internal temperatures changes significantly. With lower outside temperatures, a larger interior temperature differential is maintained, implying that the inside of the house is kept closer to the comfort zone. At the point when the outside temperatures become hotter, the temperature differential drops. Eventually, it is cooler inside at exterior temperatures above 25° C. This result also shows that including insulation under the roof, as was done in the simulations, has a similar impact as adding a ceiling with insulation above it. The amount of insulation present in the actual RDP counterpart house with ceiling is unknown, yet the impact is clear: including either an insulated ceiling or insulation under the roof will shift the interior temperatures to such an extent that it will be warmer in the colder times of the year and cooler in the hotter months.

4.5 Embodied Energy and Construction Cost Analysis

With reference to Table 2.9 and from Figure 4.9, which depicts the variation in the embodied energy, the lowest and highest total embodied energy were estimated for case A/B and case F respectively regardless of the plinth area. Moreover, the total embodied energy for RDP construction estimated even less than that of the case A/B in CH category. In case F, the main reason for the higher embodied energy is wall construction, which could be larger in this case due to the higher number of bedrooms and other utility spaces. The embodied energy follows a similar trend, namely, the walls represent the largest components of the embodied energy, ranging between 800 MJ/m^2 to 1100 MJ/m^2 averaging to above 40%. The highest embodied energy for wall constriction was estimated for case C as the result of extra insulation. The second influential component estimated is the roof ranging from 360 MJ/m^2 to 630 MJ/m^2 with an embodied energy share between 20% and 35% in the CH category. In the case of RDP houses, the embodied energy for the roof was estimated to be 260 MJ/m^2 which is below 20%. The embodied energy values for the floor, foundation and fenestration are similar for the different plinth areas of the conventional house (CH) with exception of Case E where a double pane window was utilised.

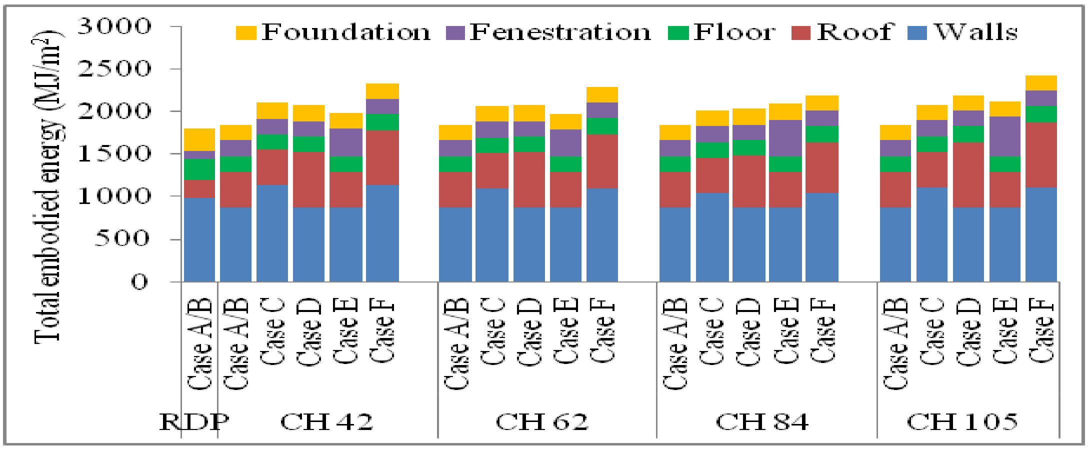

Figure. 4.9 Variation of embodied energy values of houses with different plinth area

Except case E, the embodied energy was estimated to be below 10% for fenestration, floor and foundation. The embodied energy for fenestration in case E was estimated between 320 MJ/m^2 to 440 MJ/m^2 amounting to 16% and 22% based on floor area. For the roof, the embodied energy was estimated highest (between 20% and 35%) for case D because it includes a ceiling and tiled roof. The roof in RDP houses, which has a corrugated iron roof with no ceilings, show comparatively lower embodied energy. From Figure 4.10 which depicts construction costs for different cases shows a variation of between R1945/m^2 (for RDP) and R5492/m^2 (for case E of 105 m^2 in CH category). The cost of construction in every aspect was estimated lowest for RDP. In the CH category, the construction cost was lowest in case A/B and highest for case E regardless of the plinth area.

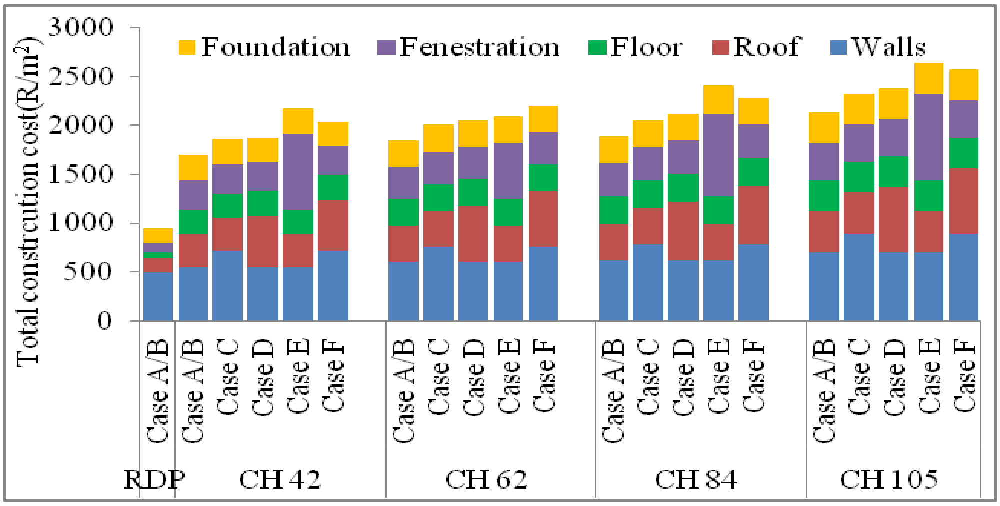

Figure 4.10 Variation in cost of construction for the different cases

It can also be observed from Figure 4.9 and Figure 4.10 that both embodied energy and cost of construction were lowest for case A/B, however, for all other cases a significant difference can be seen. It is also possible that case A/B which is similar to the RDP house and has the lowest construction cost and lowest embodied energy may lack in thermal comfort.

Table 4.9 depicts that the build-up of initial and recurring embodied energy follows a similar pattern, namely, the sub-structure and the super-structure represents the greatest towards the initial embodied energy, 31% to 42%; and 44% to 49% respectively, but do not have an effect on recurring embodied energy. The contrast is applicable for finishes since it contributes the least (9% to 25%) of the initial embodied energy but is the fundamental cause of recurring embodied energy due to replacement factor and required maintenance ranging from 26% to 46%.

Table 4.9 Sub-systems contribution to embodied energy

Sub-system	Contribution to initial embodied				Contribution to total embodied			
	CH (MJ)	%	RDP	%	CH (MJ)	%	RDP	%
Sub-	19 808	30	29 130	43	19 808	21	29 130	35
Super-	29 135	45	31 780	48	29 135	33	31 780	39
Finishes	15 915	25	5669	9	42 760	46	21 735	26
Totals	64 858	100	66 579	100	92 220	100	82 635	100

When comparing the life cycle energy performance of both houses, the CH is potentially better than the RDP. The initial embodied energy of CH (64 858MJ) is lower than that of RDP (66 579MJ). There is a saving of 1 721MJ which is adequate to supply about 10 low-income houses with free basic electricity at the rate of 50 kWh per month. The thermal performance measurements show that the internal environment of CH is cooler in summer and warmer in winter, thus the operational energy demand and by implication, the heating requirements of CH in winter will be lower than that of the RDP house, (Haripersad et al., 2016). Over the entire life cycle, the sum of the embodied energy of the sub and superstructure of CH (48 943MJ) is significantly lower than that of the RDP (60 910MJ).

However, towards the end of the DSL, the position of the compared dwellings is reversed, that is, the total embodied energy of the CH (92 220MJ) is greater than that of the RDP house (82 635MJ). This is due to the substantial difference between the initial embodied energy of CH finishes (15 915 MJ) as compared to that of RDP finishes (5 669 MJ), namely, 281%. As an experimental project, it is concluded that the embodied energy of CH was effectively optimised in relation to the sub-structure and super-structure. The outlined finishes for CH however constitute a “hotspot” which can be resolved by changing to a more durable outer wall finish.

4.6 Life Cycle Energy Cost Analysis for Selected Scenarios

A thirty-year life cycle cost analysis and cash flow model was created for House 1-J/CH 42, which represents a typical RDP house construction. The EnergyPlus simulation results from the study were utilised since it represented the actual house behaviour more closely than TRNSYS. The building material costs were priced and estimated using 2018 market values, as well as building loans interest rates of 8.75%

for the mortgage term of twenty years and annual electricity rates from the national power utility (Eskom) that utilises a tiered pricing system averaging R1 5161/kWh. The home loan lending rate reflects normal bond rates from South African banks in 2018. Electricity rates inflate at the 20-year average rate of 8.35%. The results of the cash flow analysis are shown in Table 4.10.

The geometry for the house is unaltered, as are material types and insulation enhancements. In EnergyPlus and TRNSYS the heating system had a defined maximum limit. Yearly heating energy utilisation for House 1-J with current building materials in EnergyPlus simulation resulted in a heating energy usage of 1 854 kWh per year. The large variation in energy usage diminishes the absolute energy savings by including insulation materials in EnergyPlus, as the energy utilisation for the base model was much lower already. The EnergyPlus model has a more representative heating system because an electric heater does not have boundless ability to keep the inside temperatures at a setpoint, as shown in the correlation of simulated versus actual temperatures in Figure 4.7. Consequently, utilising the EnergyPlus simulation data and the results from the life cycle cost analysis is a more representative model of the savings that can be expected by implementing energy efficiency measures to the RDP houses.

Table 4.10 Life Cycle Energy Cost Analysis of House 1-J/CH 42 with EnergyPlus Results

House CH 42 Excluding Embodied Energy	**Added Cost**	**30-year Cost**	**Energy Savings [kWh]**	**Cost Cumulative Savings**	**Monthly Mortgage Addition**	**Break Even Year**
Base Model	R134 928	R532 737	0	R -	R -	1
Cavity Wall	R -	R 495,684	6076	R 37,053	R -	1
EPS Wall	R 7,944	R 495,363	8599	R 37,374	R 57	21
Code Ceiling	R 8,970	R 398,923	24744	R 133,814	R 64	4
DP Window	R 11,126	R 549,384	713	R (16,647)	R 79	30+ years
EPS Wall + Ceiling	R 16,914	R 367,122	32436	R 165,615	R 119	8

Table 4.11. Life Cycle Energy Cost Analysis of House 1-J/CH 42 including Embodied Energy

House CH 42 Total Energy	Initial Cost	30-yr Cost	Energy Savings [kWh]	Cost Cumulative Savings	Monthly Mortgage Addition	Break Even Year
Base Model	R 134,928	R 798,227	0	R -	R -	1
Cavity Wall	R -	R 744,164	8863	R 54,063	R -	1
EPS Wall	R 7,944	R 715,718	16000	R 82,509	R 57	7
Code Ceiling	R 8,970	R 778,453	6034	R 19,774	R 64	24
DP Window	R 11,126	R 784,633	5699	R 13,594	R 79	25
EPS Wall + Ceiling	R 16,914	R 664,918	27398	R 133,309	R 119	11

The Net Present Value (NPV) and yearly internal rate of return (IRR) are important financial indicators within the life-cycle energy analysis. Table 4.10 further shows that the inclusion of a ceiling with insulation under the metal roof is a financially worthwhile alternative to save significant energy - 24,744 kWh per house over 30 years and has a positive NPV after four years and adding up to R 16,457 over 30 years utilising an 8.75% yearly discount rate. The IRR for the case with a South African code ceiling is 41.26%. For the case of including both the ceiling and wall insulation, the IRR is 25.58% per year, and the NPV is R 25,418. Since the NPV is greater than the initial capital cost of R16,914 for the enhancements, it ought to be viewed as a sound investment when constructing the house. These results also imply that the NPV of the insulation under the roof, R 16,457, is nearly double the cost of installing the insulation, demonstrating a worthwhile investment.

From Table 4.11, when the embodied energy is included, we note that there is a cumulative saving especially the double pane (DP) window that moves from a deficit of R 17,552 to a surplus of R14,333. The cavity wall and extruded polystyrene (EPS) wall also have significant increased cumulative savings over the thirty-year period. The code ceiling and the EPS Wall/Ceiling combination shows a drastic decline in the savings over the life cycle of the building.

4.7 Chapter Summary

In order to reduce energy consumption in different buildings, passive energy interventions were considered. The thermal performance of the considered building was optimized and compared with actual data from existing building. The mathematical model developed was in good agreement with actual experimental data within the error range of ±1.74% and therefore can be used for other buildings situated or to be built in other climatic zones.

The life-cycle analysis was done for the RDP building and the CH42 house. The conventional house shows better thermal performance then the RDP building due to the energy-efficient interventions. The recommended temperature of 18^0C to maintain thermal comfort can help in huge energy reduction. In the selected surveyed buildings, energy reduction is observed just by adding walls with air-gap in the building without any extra investment. The initial embodied energy in the CH building is lower than that of the RDP house, but over the entire life-cycle, this position is reversed due to drastically larger embodied energy associated to finishes in the conventional house.

CHAPTER 5

Summary of Findings, Conclusions and Recommendations

This chapter presents deductions and recommendations based on the analysis of data from this study, so that the gained results can be used for further project development in South Africa. The approach and methodology used to achieve this objective followed a quantitative process enabling a holistic review and analysis of the interventions applied, its measurable and perceived effects and acceptance among researchers and prospective users. The benefit of this approach is that an assessment of the simulated impact attained through the interventions were validated with data measurements in an experimental environment.

Based on the objectives of this thesis study, the mathematical modelling was completed successfully for the different buildings with single or a mix of energy-efficient materials. The theoretical, as well as experimental study, was conducted in order to analyse the thermal performance of the different buildings. The experimental work was conducted on an RDP building during different months and collected data were used to validate the model. The thesis concentrated on energy impact on the life-cycle of residential building through optimisation of different passive/hybrid interventions.

The aim of the study was to assess the impact of selected construction materials on the life cycle energy and thermal comfort on different residential buildings in South Africa, which poses two questions, namely:

- How effective are energy-efficient building methods when incorporated into the design of low-income, masonry-based houses in optimising life-cycle energy, considering both energy and construction costs, utilising the energy simulation programs EnergyPlus and TRNSYS?
- What is the impact of the embodied energy on the life cycle energy (LCE) of the buildings been addressed?

5.1 Findings and Conclusions for Energy Performance from Modelling Software Programs

Based on the objectives of the study, the energy performance and the temperature was selected for analysing the impact of selected construction material on the life-cycle energy of the building. EnergyPlus and TRNSYS simulation software programs were utilised for energy modelling of the typical houses constructed in central South Africa. By using common parameters shared between the models and investigating methods for different heat transfer principles between them, a comparison was made between the energy calculation techniques for both EnergyPlus and TRNSYS. Creating a model, together with an in-depth analysis of calculation procedures using the simulation software gives an accurate representation of such. From the results of the study, the subsequent findings can be made pertaining to the energy modelling programs. EnergyPlus was found to have a more itemised technique for ascertaining certain components of the model, for example, convective/radiative space heaters and convection heat transfer coefficients. Despite these differences between the two simulation software, the trends of parameter effects on energy usage were similar. Both programs demonstrated critical decreases in energy usage when the walls and roof insulation were added. We concluded that for EnergyPlus, the mean energy usage is reduced between 20% and 27% for the wall insulation averaged across all models, while in TRNSYS the energy reduction ranges between 37% and 50%. For the roof insulation, the mean energy usage is reduced between 63% and 66% in EnergyPlus, across all models, while in TRNSYS the energy reduction ranges between 60% and 61%.

The insulation under the concrete slab had only an incrementally small effect and depended more on the geometry of the buildings in terms of floor area to envelope area. Upgrades to the windows produced negligible energy savings to all cases, which is likely because of the small window areas and the poor envelope components around them. Despite the fact that the houses had small plinth areas, with various kinds of materials being utilised, the results of the EnergyPlus simulation corresponded well with temperature estimations taken on the actual houses, showing an exact and representative energy model. For the structural types modelled in this study, with the two different software programs, EnergyPlus simulations represented the actual houses more accurately. It can be concluded that knowing what assumptions can be made, creates the most representative model in the software that should closely represent the actual structure. Also, the orientation, size and type of structure integrating passive energy interventions can play an important role to design an energy efficient building.

Further, from the energy model developed, it is concluded that the thermal performance of buildings can be optimized using passive interventions that have minimum or no additional costs. The study has demonstrated the impact of the selected construction materials by showing significant energy reduction due to the different interventions in the buildings, thus improving thermal comfort. Results are however very dependent on the location and climatic conditions.

5.2 Embodied Energy, Construction Costs and Thermal Comfort Findings and Conclusions

The literature review advocated that embodied energy plays a vital role in the LCEA of a building. The goal of the study was to measure the life cycle energy of low-cost houses of a specific topology, with various building materials, to understand the variation in the embodied energy (EBE) and the impact of various construction materials as well as the construction cost of the structure. The structures' embodied energy, which is a result of construction material consumption in the construction of buildings, is an important aspect that helps in sustainable building development. This study explores the estimation processes of embodied energy and LCE assessment and how these methods can be used to benefit sustainable building development. Hence, the variation in the embodied energy shares clearly indicates that the selection of building materials and accurate and detailed assessment of embodied energy and LCE are crucial, and adequate attention has to be given at the planning, designing, and construction stages of buildings. The construction costs and embodied energy for the buildings were estimated for CH and RDP houses constructed for low-income earners. CH were constructed with two, three and four bedrooms as per their plinth areas. Analyses were conducted for different construction materials and compared. Based on the research findings, the cost of construction was also estimated and found to be lowest for case A/B which has no ceiling or insulation. Regardless of plinth area, construction costs range between R 1945/m^2 (for RDP type) and R 5492/m^2 (for case E of 105 m^2 in the CH category). Also, case A/B was found to be most energy-efficient and cost-effective option in the

CH category. For other cases, a significant difference was observed. The embodied energy values for the individual cases range from 1500 MJ/m^2 to 2600 MJ/m^2 for selected building materials and is found to be lowest in case A/B. The component wise breakup and variation of materials and the EBE per m^2 of floor area was calculated and in accordance with the EBE values obtained by other analysts. Based on the outcomes from the research, it can be concluded that the construction cost may not necessarily be minimised with the materials that have lower embodied energy. It implies that no linear relationship exists between the embodied energy and the cost of construction per m^2 floor area, which is purely market-driven.

The utilisation of cost effective construction materials with low embodied energy, in the building industry, can drastically lessen the total energy consumption, improve the thermal comfort and thus eventually minimise the energy footprint of the building. This study is consistent with other reviewed case studies of residential buildings. It has been observed that shares of embodied energy in the total LCE vary between 9% and 36% for conventional buildings, between 10% and 83% for low-energy buildings like the RDP house. It is also observed that a low-energy building is not more energy-efficient than a passive one. Hence, the study concludes that the variation in the embodied energy shares clearly shows that selection of building materials, and accurate and detailed assessment of embodied energy and LCE are crucial, and adequate attention has to be given at the planning, designing, and construction stages of buildings. Also, it can be concluded that using the mathematical model derived in the study the total energy incorporating embodied and operational energy can be optimized for different types of buildings. The model had lower energy usage in all the passive intervention that were introduced in the buildings and can be used to conduct thermal performance analysis in any climatic zone.

The following outlined the building characteristics for comfort.

- Room temperature maintained as cool as compatible for human comfort.
- Air movement variable, adjusted at approximately 10 m/minute or higher
- Relative humidity set below 70%
- The temperature of internal surfaces equivalent to or below air temperature.
- The air temperature at head level higher than near the floor, but excessive radiant heat should not fall on the heads of the occupants.

A combination of these factors may provide the ideal, if somewhat illusive, feeling of "freshness" that we need to be comfortable and productive. The thermal performance of buildings is very complex and therefore it is difficult to accurately predict their effect because of the varying properties of the materials used and the variations of daily and seasonal conditions and time. Therefore, for the simulations room temperature of 18^{o} C and pressure of 101.3 kPa was used, which is commonly used as a standard condition for testing and documentation of fan capacities, in reducing indoor temperature, energy consumption and demand to ensure that thermal comfort is ascertained.

From the findings of the research, the subsequent conclusions can be made with regard to thermal comfort. The temperatures are a suitable measure for assessing the efficacy of selected construction materials in terms of reducing electric peak loads i.e. electricity demand; and are a good indication for the impact of the technology on HVAC energy consumption. Additionally, exterior and interior temperatures have a clear impact on thermal comfort.

While the principles that describe thermal comfort may be obvious and seem straightforward, the coordinated nature of any design for effective natural ventilation (as an enhancement to HVAC) requires broad knowledge in order to ensure an integrated, optimised and a functional solution. The decision tree introduced in the CIBSE Guide for Natural Ventilation in Non-Domestic Buildings (CIBSE 2005) and the diagram in Figure 2.3, portrays how we should only be implementing conventional mechanical comfort control and ventilation systems in spaces where they are absolutely required. In summary, it can be concluded that there are many passive methods of controlling the internal environment which should be encouraged. For most spaces and a large portion of the year in South Africa, the opportunity exists to review the IEQ prerequisites in terms of the adaptive models of comfort identified above, and design for a blended mode comfort control system, accordingly.

5.3 Findings and Conclusions for Life Cycle Energy Cost Analysis

The selection of energy interventions and costs was analysed through a life-cycle model. From the analysis, the wall and ceiling insulation improvements are most valuable since there are large savings in energy costs than the initial capital expense of including additional material. One specific improvement worth examining with physical experimentation is the implementation of an air-gap between the two layers of brick in the walls. The cost to implement the improvement requires minimum additional material, yet the heating energy savings can be significant. This building practice is presently used along the coastal regions of South Africa where cooling is essential, so the required experience should be accessible for this kind of construction.

Based on the outcomes from the research, the succeeding conclusions can be made in relation to “life-cycle energy cost analysis”. As indicated by these simulations, the most effective measure for decreasing heating energy use in the RDP houses is to include a ceiling or insulation under the roof. This energy intervention greatly decreases the required energy to keep the building at a comfortable temperature, mitigates the danger of freezing inside the dwelling throughout the colder time of year, and minimises extremely high temperatures during the hotter months. The energy savings within the initial few years of occupancy is balanced by the extra cost of the insulation during construction and saves an abundance of energy and money for the owners of the house. The peak demand and total energy demand are lowered, creating less strain on the electricity grid in South Africa, which is an expanding issue due to better standards of living. Enhancements in the standard building design, through the addition of energy efficiency measures such as wall and roof insulation featured in this study, can save the homeowner energy costs and the government infrastructure costs in the long term. Real benefits will be accomplished on a large scale by perceiving the housing scenario in South Africa as an opportunity to develop a more sustainable housing environment for all citizens of the country.

5.4 Recommendations

The recommendations for this study emanate mainly from the validation of the model conclusions and future social and environmental impact.

- This study should serve as a basic initial step to convince the people of South Africa that an energy-efficient house, despite the marginally higher capital expenses, can be more affordable and comfortable in the long term.

- It is recommended that the energy specialists and housing departments work together to create a design for housing and communities that transform the backlog of housing into an opportunity for improving the living standards further.
- It is also recommended that barriers for the mainstreaming of energy-efficient housing, DoH, (2002 b), needs to be eradicated by the government. This can be achieved by the implementation of an Energy Efficiency programme.
- The findings show that for energy conservation in buildings, energy- efficient materials may be used and is beneficial to decrease the energy consumption in all types of buildings and recommended that other similar studies be conducted in different climatic regions in the residential, commercial and industrial sector.
- To explore this impact of wall insulation from this study further, the temperature effect inside the baseline RDP construction house, House 1-J/CH 42, can be investigated through the span of the year. The temperatures can be compared to the same house with insulation added under the roof.
- The mathematical model developed from the study given as:
  $LCE = \sum m_i e_i + E_C + \sum m_i e_i\ [\{(L_b/L_{mi}) - 1] + E_o A L_b + E_D + E_T$
  is recommended for use by local and national government in the implementation and roll-out of future development in the Human Settlements and Public Works Departments.
- A continuation of this research could be to construct a sample of houses that actualise the energy efficiency measures featured in this study and perform an experimental investigation to assess their performance over a longer duration of time. By developing various houses with different insulation values, the true contrast in energy use and thermal comfort can be analysed more closely. Future studies should concentrate on the impact of other types of material/buildings and their effect on potential energy savings. The impact on the citizens and their perceptions on thermal comfort should also be analysed.

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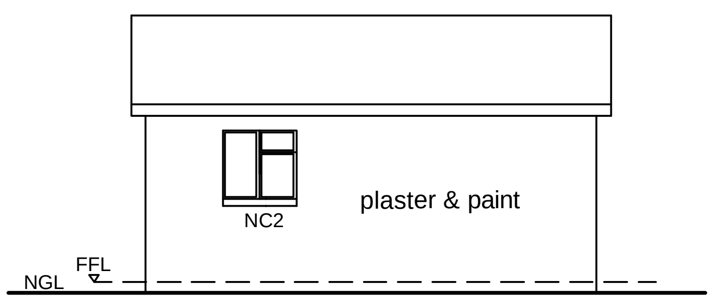
PROJECT:

RDP - BUILDING

SUBJECT:

SCALE:

APPENDIX 1: ARCHITECTURAL PLANS, ENGINEERING DESIGN AND CALCULATIONS



ELEVATION 2

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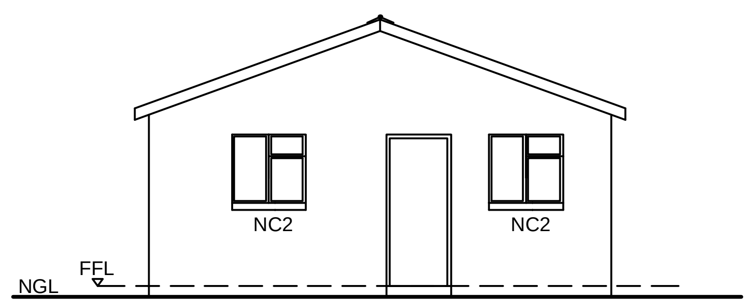

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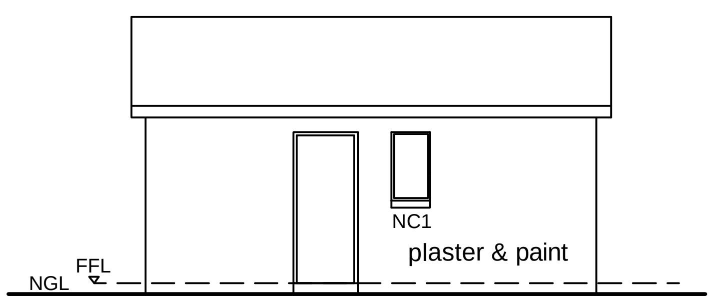

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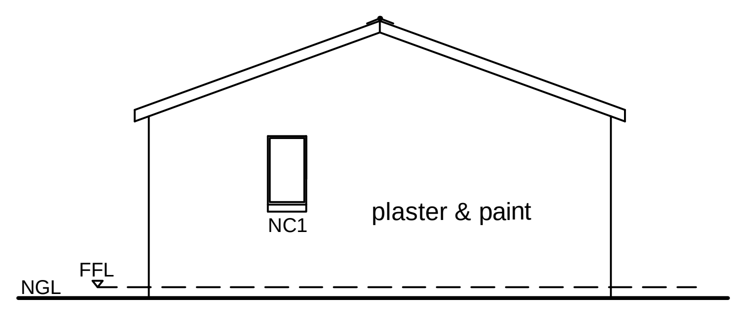

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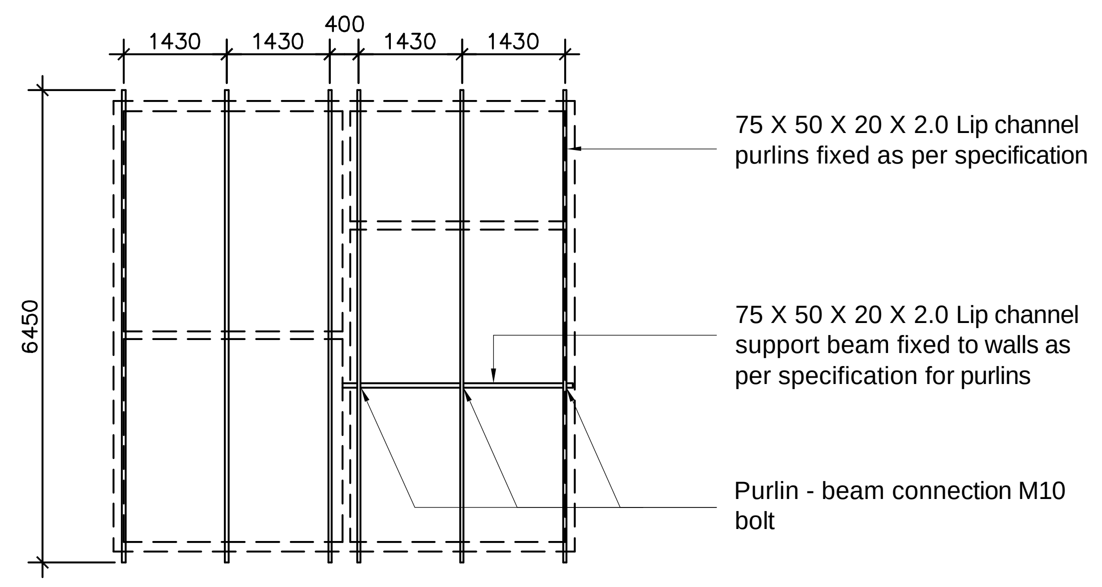

PURLIN LAYOUT

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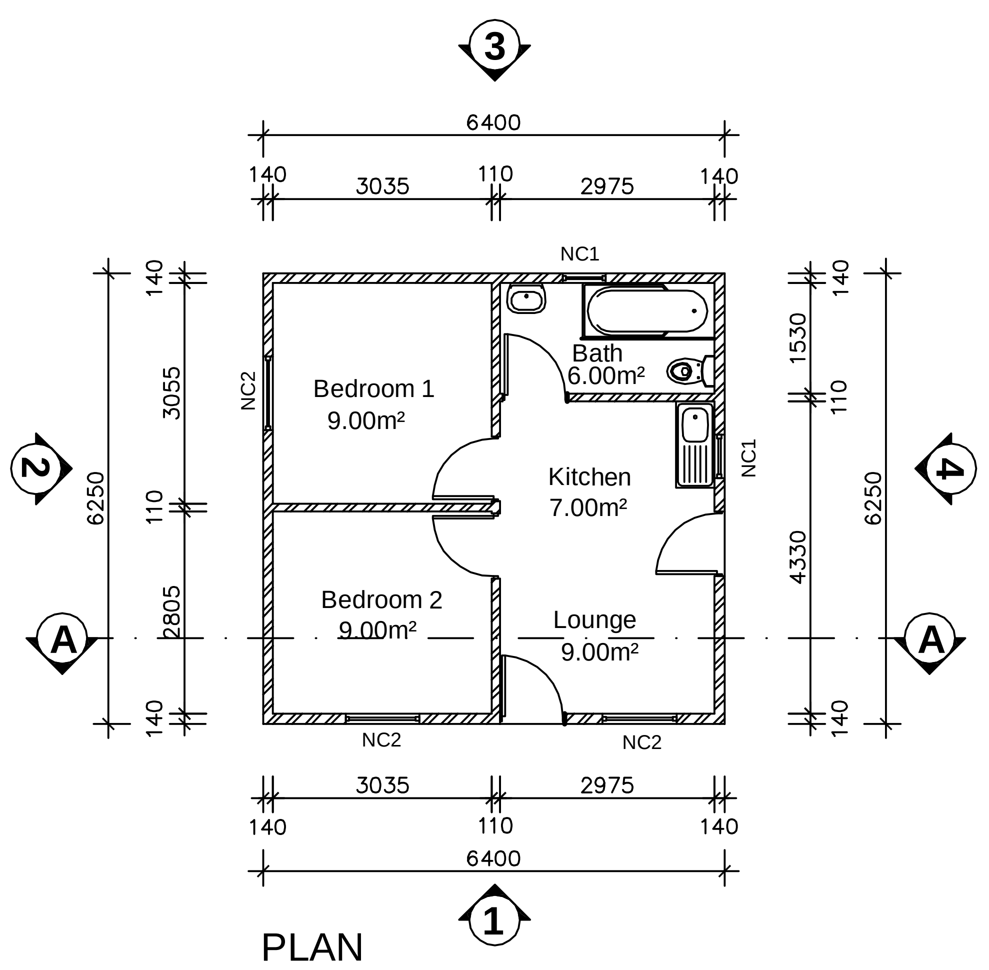
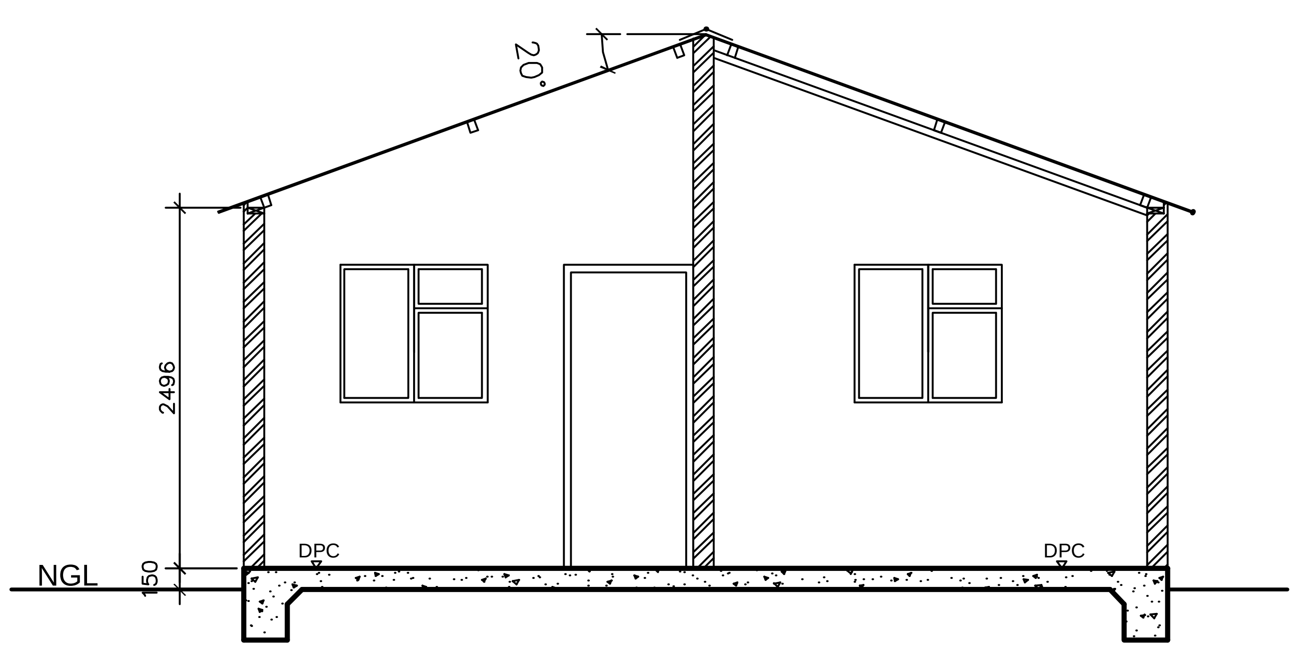


PLAN

SCALE 1: 100



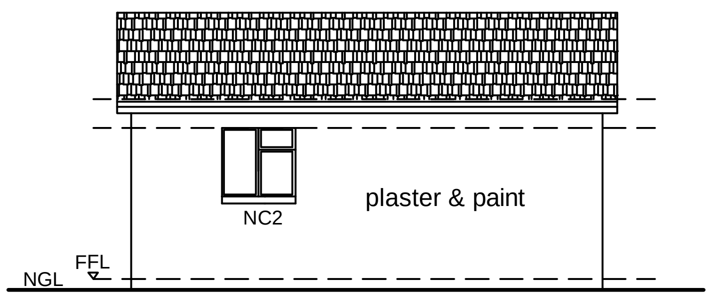
SECTION A - A

SCALE 1: 50

PROJECT:
1 - J / CH : 42

SUBJECT:

SCALE:



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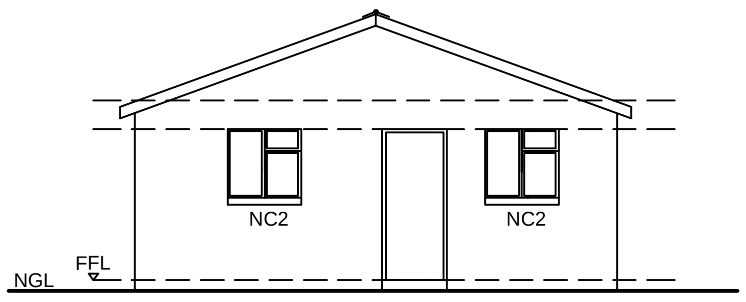
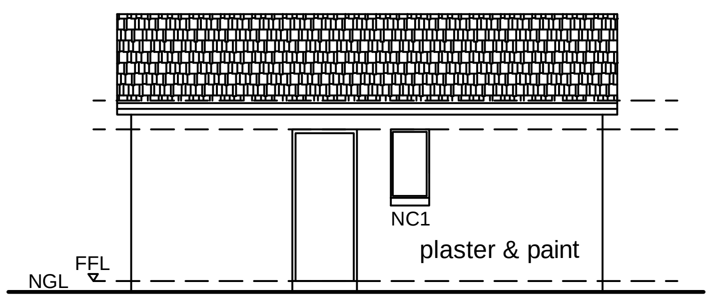
SCALE 1: 100



ELEVATION 1

SCALE 1: 100



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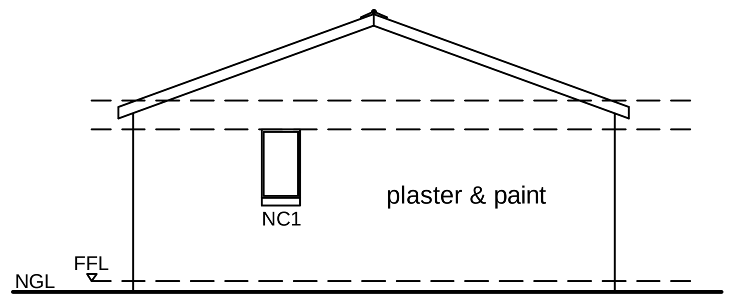
SCALE 1: 100



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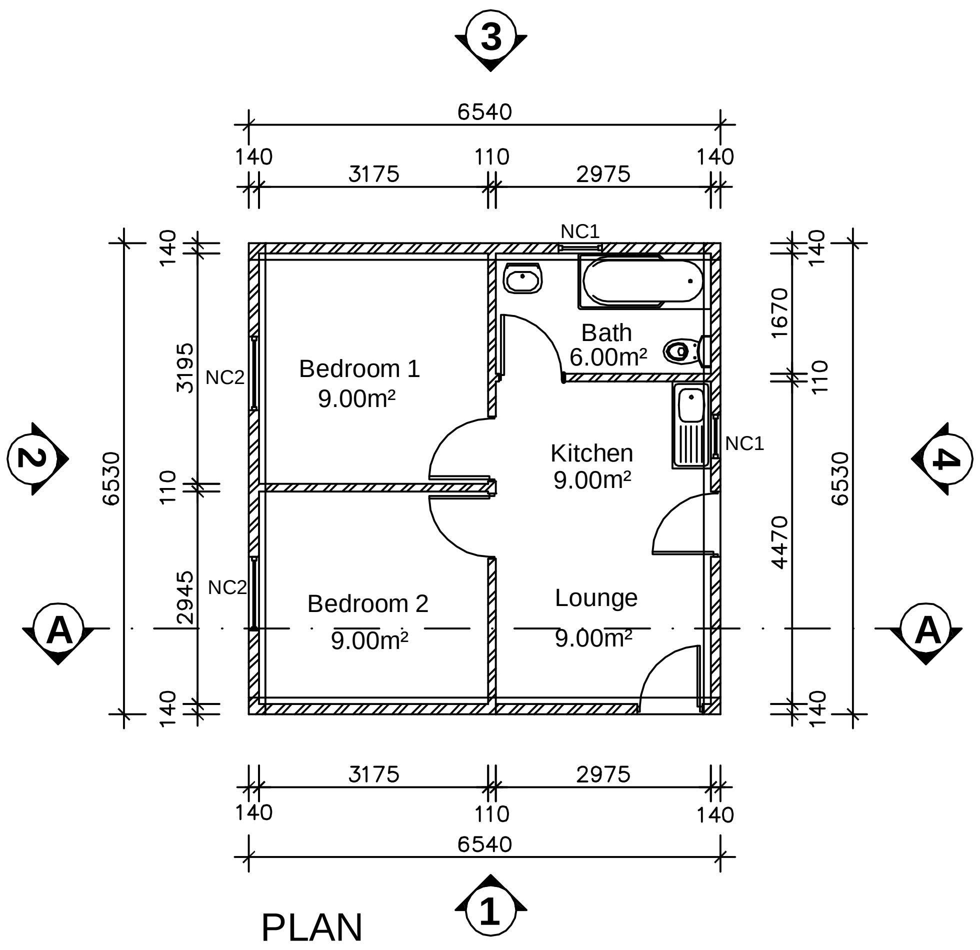
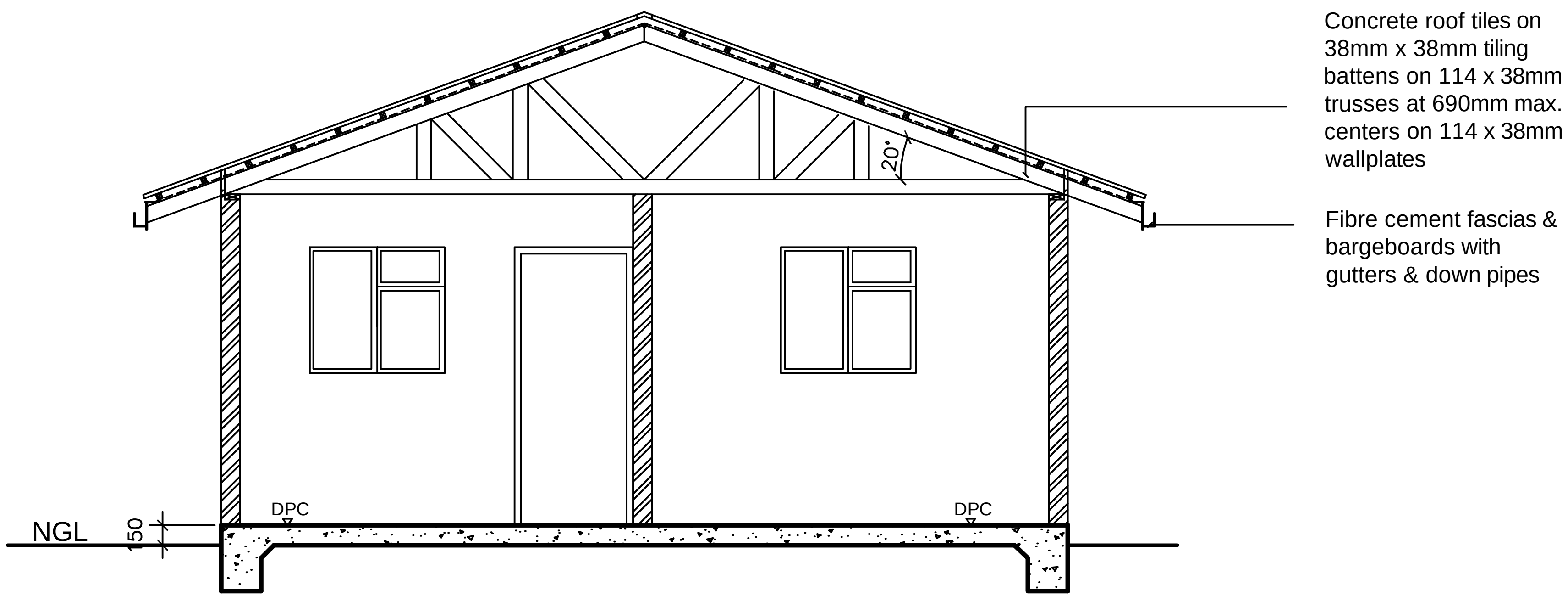


PLAN

SCALE 1: 100



SECTION A - A

SCALE 1: 50

PROJECT:

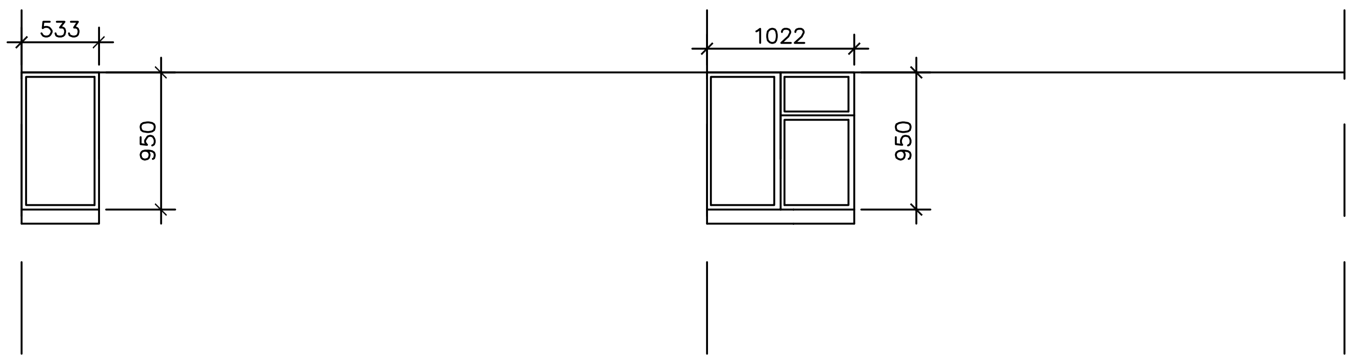
1 - J / CH : 42

SUBJECT:

SCALE:

CASE & CONSTRUCTION PATTERN:

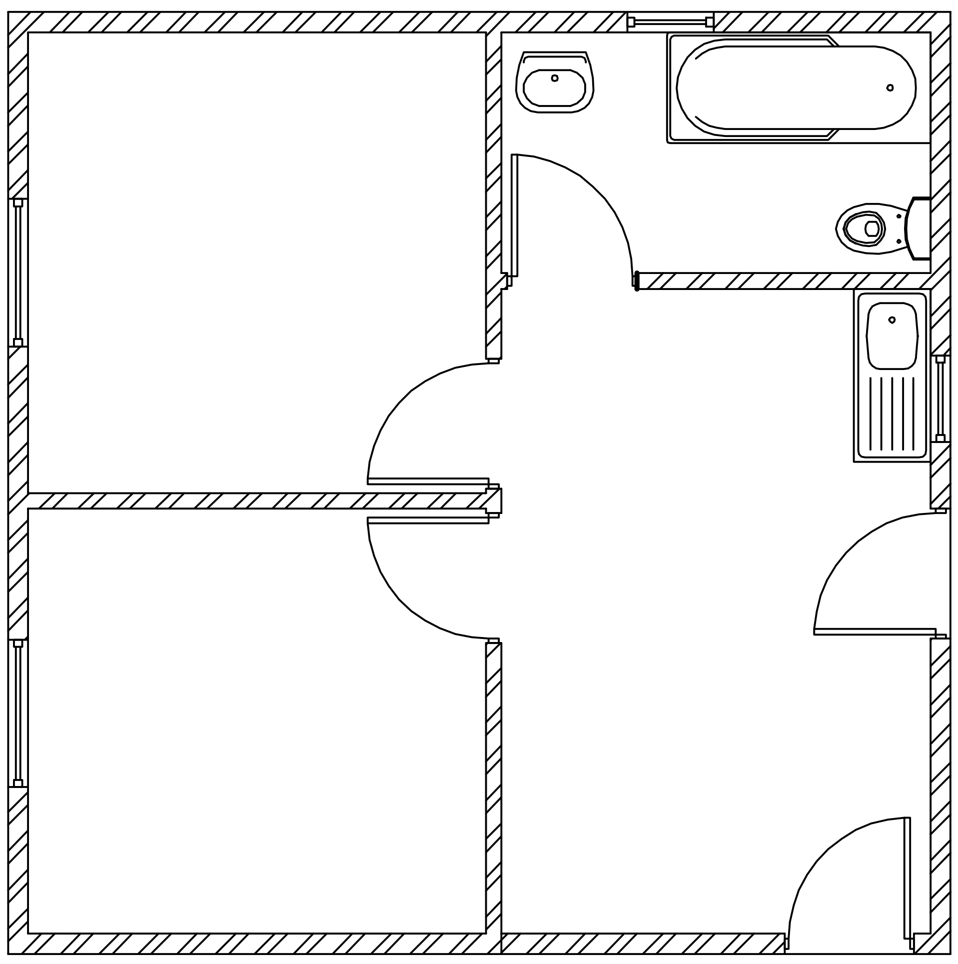
CASE - A	Base Case - No ceiling or Insulation double brick wall without cavity
CASE - B	Cavity wall - 40mm
CASE - C	Cavity wall w/40mm Extruded Polystrene
CASE - D	Gypsum Ceiling w/Blown Cellulose
CASE - E	Double pane windows w/Wood frame
CASE - F	C and D combined

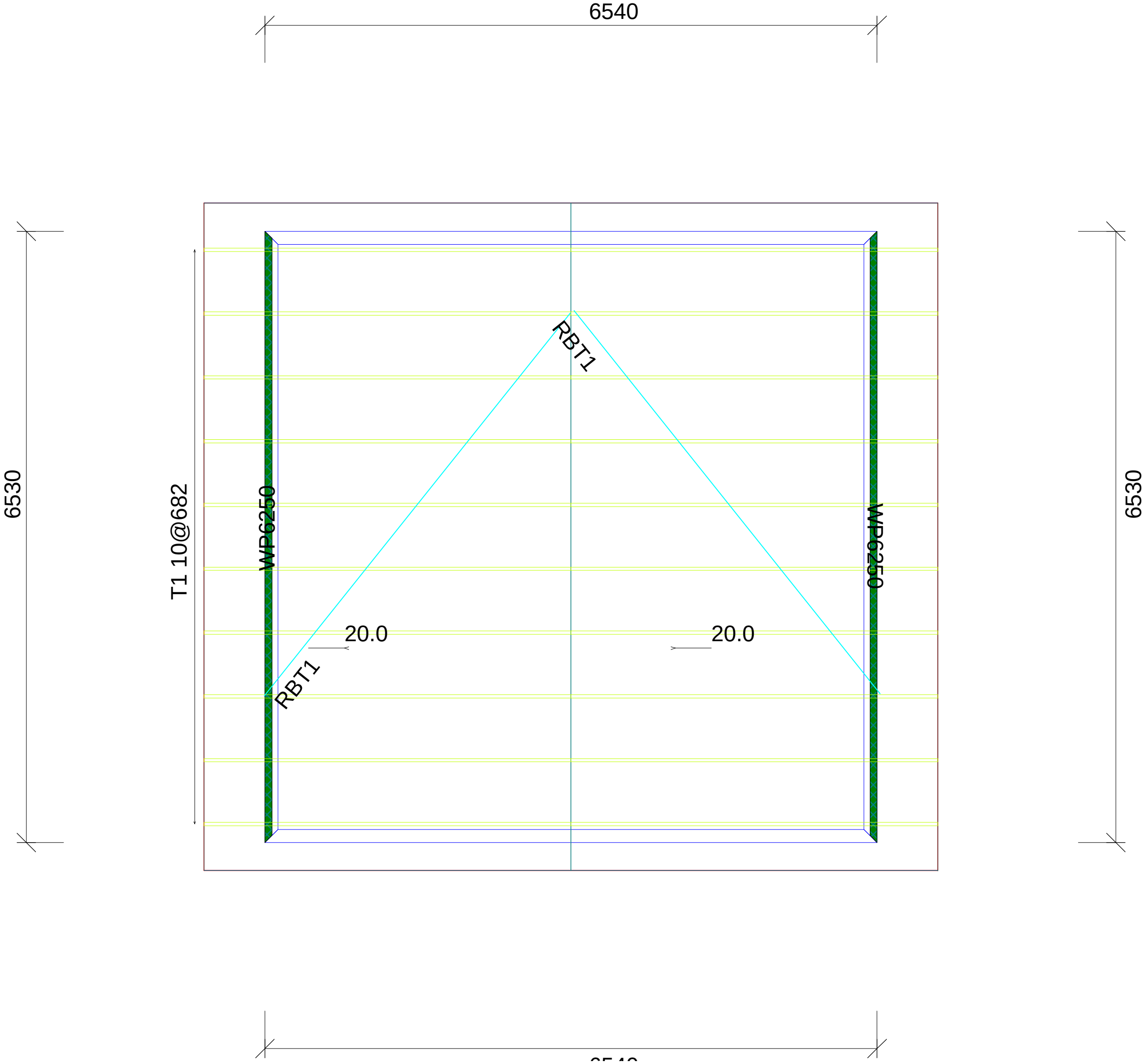


	AREA 1.80m²	AREA 2.16m²
WINDOW NO.	W1	W2
FRAME	Timber	Timber
GLAZING	5mm clear	5mm clear
	monolithic glass	monolithic glass
LOCATION		
NO. REQUIRED	2 off	2 off

WINDOW SCHEDULE

SCALE 1: 100





Loading:

TCDL:	0.49kN/m²
BCDL:	0.14kN/m²
Truss CC:	760mm
Purl/Batt CC:	320mm
Overhang:	650 mm

MiTek 2020
v6.2.137.0

10163 LSD

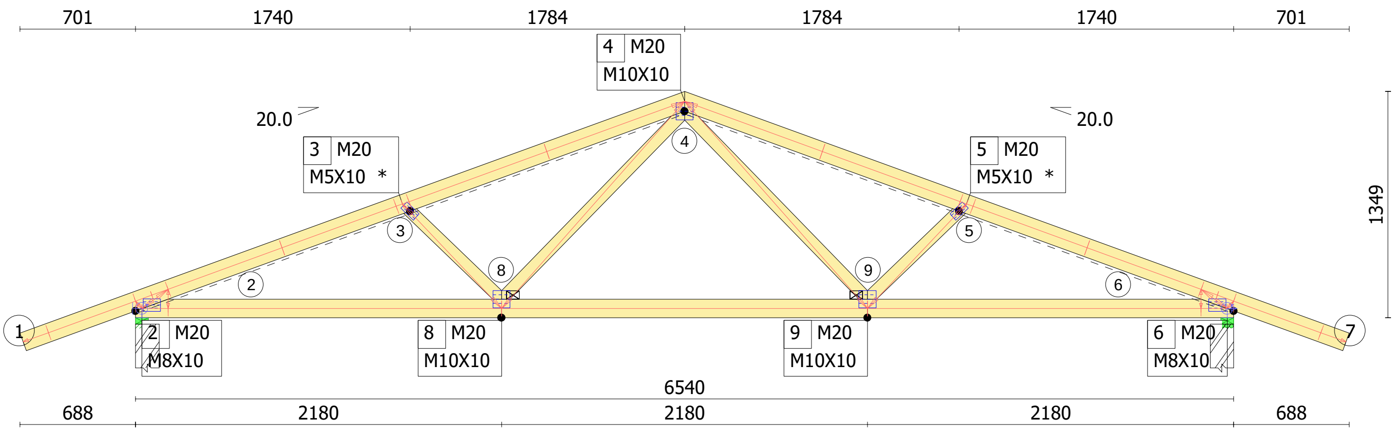
Roof Area: 59.49 m²
Floor Area: 42.71 m²

Truss: T1

MiTek SA (PTY) Ltd.
MiTek 2020 6.2.1

Grade Stresses SANS10163: 2011 "The Structural use of Timber - Limit-states design"
General Loading SANS 10160: 2009 "The General Procedures and Loadings to be adopted in the Design of Buildings"
Plate values used are given in the CSIR contract reports C/WOOD 49 for M20 plates and FOR-C 60 for Gryptite plates.

10 x T1 @ 681.6 320 Batten CC
MEMBER 2-6 @ 2600 CC <10-10>



Scale 1:45

Truss Input Parameters:	**General Loading:**		**General Design Info:**	
Ref: T1	Top Chord Dead	0.490 kN/m²	Top Chord CAMRI	0.790
Quantity: 10	Live Load	0.500 kN/m²	Bottom Chord CAMRI	0.559
Ply: 1	Bottom Chord Dead	0.140 kN/m²	Web CAMRI	0.124
Span: 6540	TC Man Load	1.000 kN	BC Deflection	4.550 mm
Truss C/C: 682	BC Man Load	0.000 kN	Max Allowed BC Def	25.856
TC Restraints: (Default: 320)	Floor Imposed	0.000 kNm²	Truss Weight	33.877 Kg
BC Restraints: 2600 (B1),	Floor Dead	0.000 kNm²		
	Basic Wind Speed	28 m/s		
	Peak Wind Pressure	0.545 kN/m²		

CAMRI = Combined Axial and Moment Resistance Index   SRI = Shear Resistance Index

Maximum Factored Reactions (kN) and Minimum Bearings (mm)

Joint	Max Reaction (LC)	Max Uplift (LC)	Max H Reaction (LC)	Bearings Required / Designed	Bearing type
2	4.244 (2)			25 / 76	Pinned
6	4.244 (2)			25 / 76	H-Roller

Design Results (Member):

Member	Type	Material	CAMRI	LC	SRI	LC	Length	& Angle	Buck Length IP	OP	Maximum F (kN)	M(kNm)	V(kN)	Start F(kN)	M(kNm)	End F(kN)	M(kNm)
1-2	TC	36x111 S5	0.605 IP	8	0.186	8	712	20	1424	545	0.010	0.001	1.036	0.010	-0.001	0.377	-0.516
2-3	TC	36x111 S5	0.578 IP	2	0.201	17	1446	20	848	545	-7.269	0.285	0.983	-7.269	-0.285	-6.821	-0.137
3-4	TC	36x111 S5	0.790 IP	18	0.254	18	1747	20	1542	545	-5.935	0.686	1.241	-5.935	-0.246	-5.159	0.160
4-5	TC	36x111 S5	0.790 IP	19	0.254	19	1747	-20	1542	545	-5.159	0.686	1.241	-5.159	0.160	-5.935	-0.246
5-6	TC	36x111 S5	0.578 IP	2	0.201	20	1446	-20	848	545	-6.821	0.137	0.983	-6.821	-0.137	-7.269	-0.285
6-7	TC	36x111 S5	0.605 IP	22	0.186	22	712	-20	1424	545	0.377	0.516	1.036	0.377	-0.516	0.010	-0.001
2-8	BC	36x111 S5	0.559 IP	2	0.040	2	1986	0	1986	2600	6.585	0.169	0.225	6.585	-0.169	6.585	0.015
8-9	BC	36x111 S5	0.338 IP	2	0.055	1	2180	0	2180	2600	4.390	0.089	0.165	4.390	0.037	4.390	0.037
9-6	BC	36x111 S5	0.559 IP	2	0.040	2	1986	0	1986	2600	6.585	0.169	0.225	6.585	0.015	6.585	-0.169
3-8	WB	36x73 S5	0.079 OP	2	0.000	1	858	-47	772	858	-1.522	0.000	0.000	-1.522	0.000	-1.522	0.000
8-4	WB	36x73 S5	0.124 IP	2	0.000	1	1647	49	1482	1647	1.736	0.000	0.000	1.736	0.000	1.736	0.000
4-9	WB	36x73 S5	0.124 IP	2	0.000	1	1647	-49	1482	1647	1.736	0.000	0.000	1.736	0.000	1.736	0.000

Truss: T1

Design Results (Member):

Member	Type	Material	CAMRI	LC	SRI	LC	Length & Angle		Buck Length IP	OP	Maximum F (kN)	M(kNm)	V(kN)	Start F(kN)	M(kNm)	End F(kN)	M(kNm)
9-5	WB	36x73 S5	0.079	OP 2	0.000	1	858	47	772	858	-1.522	0.000	0.000	-1.522	0.000	-1.522	0.000

Loadcase 2 SA: 1.2Dead Load + 1.6Live Load

(1/Ym1)	(1/Ym2)	(1/Ym3)	(1/Ym4)	(1/Ym5)	d1	d2
1.14	1.00	1.04	1.00	1.00	1.29	1.00

Members	Shear (kN)	SRI	Maximum Axial Force (kN)	Maximum Moment (kNm)	Axial Force (kN)	Axial Stress (MPa)	Axial Perm. (MPa)	Moment (kNm)	Bending Stress (MPa)	Bending Perm. (MPa)	CAMRI	T/C +/-
T1 1-11	0.606	0.107	0.221	-0.216	0.221	0.000	5.333	-0.216	2.918	9.154	0.329	T
T1 11-10	0.426	0.100	0.420	-0.285	0.420	0.089	4.521	-0.285	3.860	9.154	0.441	T
T1 10-19	0.718	0.151	-7.269	-0.285	-7.269	-1.819	-11.644	-0.285	3.860	9.154	0.578	C
T1 19-3	0.547	0.000	-6.821	-0.159	-6.808	-1.707	-11.735	-0.158	2.135	9.154	0.379	C
T1 3-18	0.849	0.000	-6.203	-0.159	-6.203	-1.552	-11.714	-0.159	2.145	9.154	0.367	C
T1 18-4	0.815	0.240	-6.191	0.265	-5.894	-1.549	-12.230	0.265	3.588	9.154	0.519	C
T2 4-20	0.815	0.240	-6.191	0.265	-5.894	-1.414	-11.161	0.265	3.588	9.154	0.519	C
T2 20-5	0.849	0.000	-6.203	-0.159	-6.203	-1.549	-11.690	-0.158	2.135	9.154	0.366	C
T2 5-21	0.547	0.000	-6.821	-0.159	-6.808	-1.704	-11.714	-0.159	2.145	9.154	0.380	C
T2 21-14	0.718	0.151	-7.269	-0.285	-7.269	-1.707	-10.927	-0.285	3.860	9.154	0.578	C
T2 14-15	0.426	0.100	0.420	-0.285	0.420	0.105	5.333	-0.285	3.860	9.154	0.441	T
T2 15-7	0.606	0.107	0.221	-0.216	0.221	0.055	5.333	-0.216	2.918	9.154	0.329	T
B3 13-2	0.005	0.000	0.000	0.000	0.000	0.000	11.644	0.000	0.001	9.154	0.000	T
B3 2-12	1.097	0.000	6.585	-0.169	6.585	1.648	5.333	-0.169	2.290	9.154	0.559	T
B3 12-8	0.225	0.040	6.585	-0.169	6.585	1.648	5.333	-0.169	2.290	9.154	0.559	T
B3 8-9	0.149	0.044	4.390	0.089	4.390	1.099	5.333	0.089	1.207	9.154	0.338	T
B3 9-16	0.225	0.040	6.585	-0.169	6.585	1.648	5.333	-0.169	2.290	9.154	0.559	T
B3 16-6	1.097	0.000	6.585	-0.169	6.585	1.648	5.333	-0.169	2.290	9.154	0.559	T
B3 6-17	0.005	0.000	0.000	0.000	0.000	0.000	11.644	0.000	0.001	9.154	0.000	T
W4 3-8	0.000	0.000	-1.522	0.000	-1.522	-0.579	-7.368	0.000	0.000	9.154	0.079	C
W5 8-4	0.000	0.000	1.736	0.000	1.736	0.660	5.333	0.000	0.000	9.154	0.124	T
W6 4-9	0.000	0.000	1.736	0.000	1.736	0.660	5.333	0.000	0.000	9.154	0.124	T
W7 9-5	0.000	0.000	-1.522	0.000	-1.522	-0.579	-7.368	0.000	0.000	9.154	0.079	C

Loadcases Considered (LC Number, LC Name):

1 , SA: 1.35Dead Load Only
2 , SA: 1.2Dead Load + 1.6Live Load
8 , SA: 1.2Dead Load + 1.6Man TC
9 , SA: 1.2Dead Load + 1.6Man BC
12 , Serviceability State (1.1Dead Only)
15 , Serviceability State (1.0Dead + 1.0Man load)
16 , SA: 1.2Dead Load + 1.6Man TC (1)
17 , SA: 1.2Dead Load + 1.6Man TC (2)
18 , SA: 1.2Dead Load + 1.6Man TC (3)
19 , SA: 1.2Dead Load + 1.6Man TC (4)
20 , SA: 1.2Dead Load + 1.6Man TC (5)
21 , SA: 1.2Dead Load + 1.6Man TC (6)
22 , SA: 1.2Dead Load + 1.6Man TC (7)
23 , Serviceability State (1.0Dead + 1.0Man load)
24 , Serviceability State (1.0Dead + 1.0Man load) (2)
25 , Serviceability State (1.0Dead + 1.0Man load)
26 , Serviceability State (1.0Dead + 1.0Man load) (4)
27 , Serviceability State (1.0Dead + 1.0Man load)
28 , Serviceability State (1.0Dead + 1.0Man load) (6)
29 , Serviceability State (1.0Dead + 1.0Man load)

Loading Data: **SA: 1.2Dead Load + 1.6Live Load**

Chord	Type	Distribution	Direction	Projected	Begin	Val1	End	Val2	Panel
Top	Dead	Uniform	Down	No	-669	0.024	7209	0.024	Filter
Top	Dead	Uniform	Down	No	-669	0.401	3270	0.401	
Top	Dead	Uniform	Down	No	3270	0.401	7209	0.401	
Top	Live	Uniform	Down	Yes	-669	0.512	3270	0.512	
Top	Live	Uniform	Down	Yes	3270	0.512	7209	0.512	
Bottom	Dead	Uniform	Down	No	0	0.022	6540	0.022	Filter
Bottom	Dead	Uniform	Down	No	0	0.115	6540	0.115	

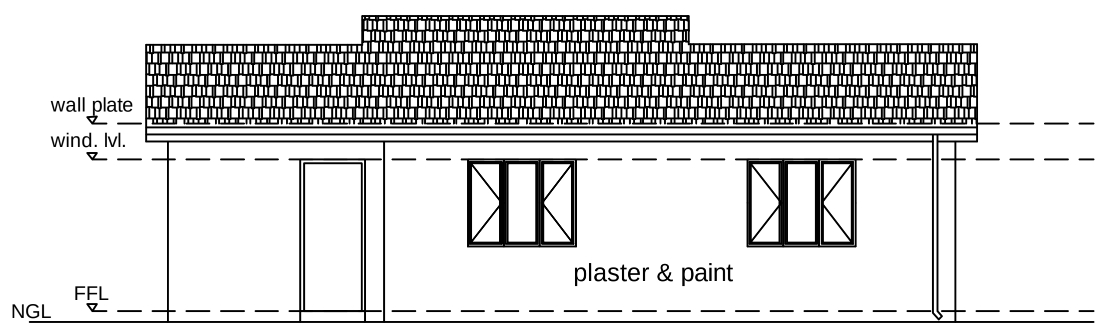
Reactions for Loadcase 2:

Joint:	Vertical Reaction:	Horizontal Reaction:
2	**4.244**	
6	**4.244**	

PROJECT:
2 - S / CH : 62

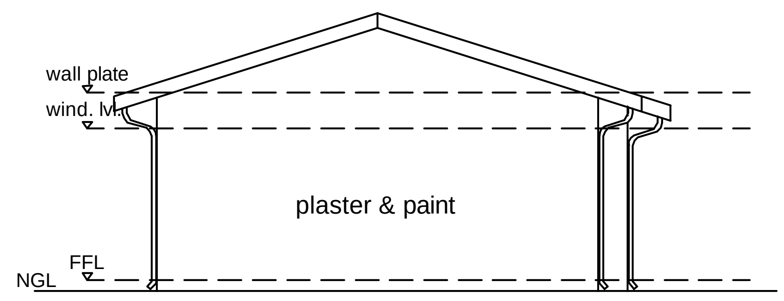
SUBJECT:

SCALE:



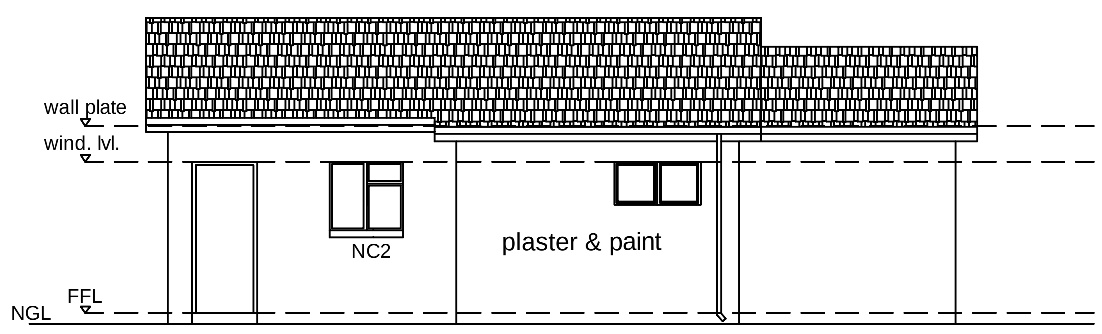
ELEVATION 2

SCALE 1: 100



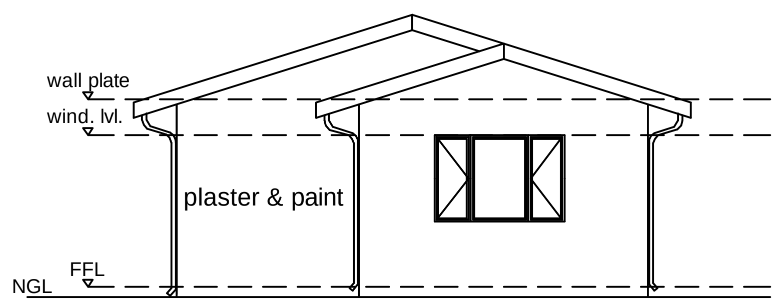
ELEVATION 1

SCALE 1: 100



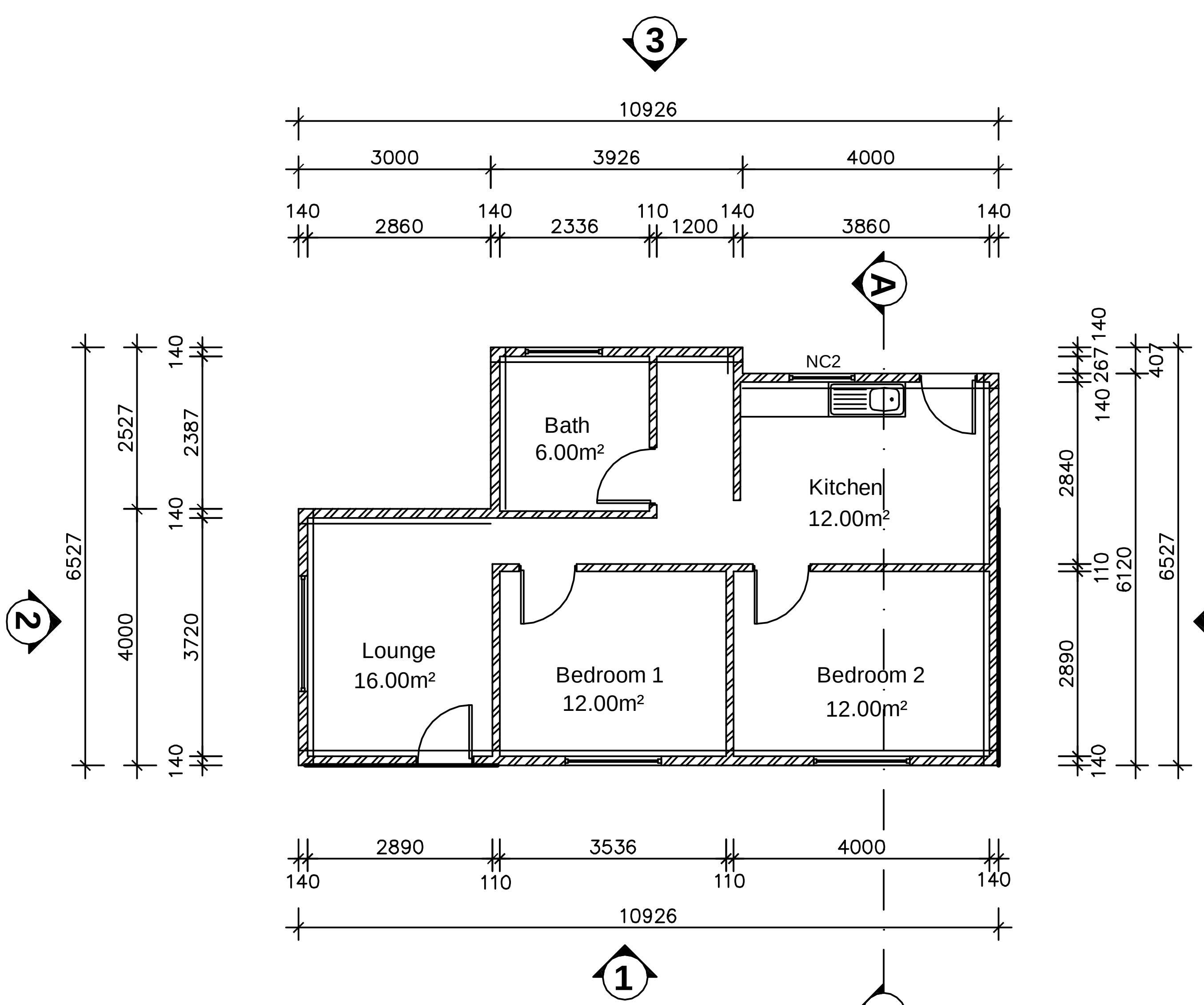
ELEVATION 4

SCALE 1: 100



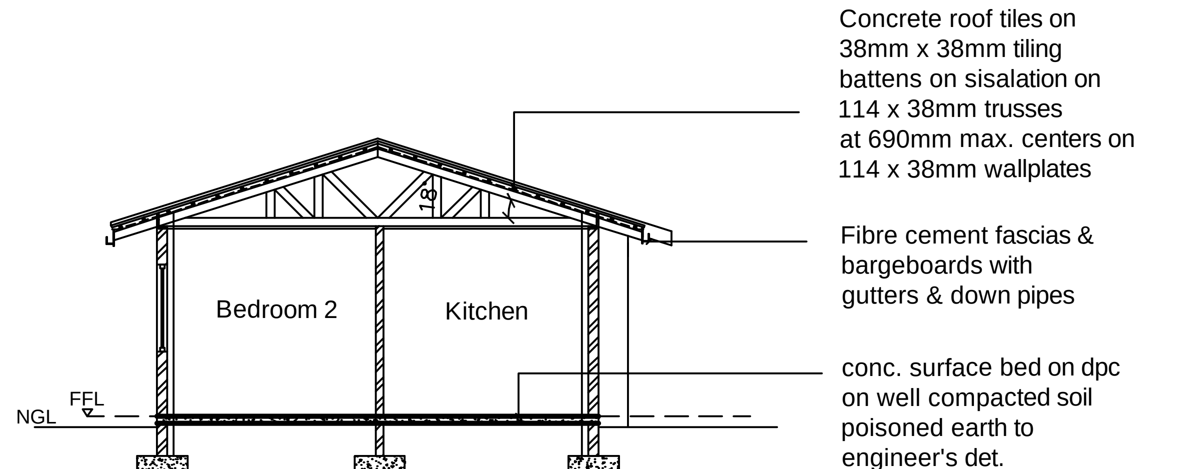
ELEVATION 3

SCALE 1: 100



PLAN

SCALE 1: 100



SECTION A - A

SCALE 1: 100

PROJECT:
2 - S / CH : 62

SUBJECT:

SCALE:

CASE & CONSTRUCTION PATTERN:

CASE - A Base Case - No ceiling or Insulation double brick wall without cavity

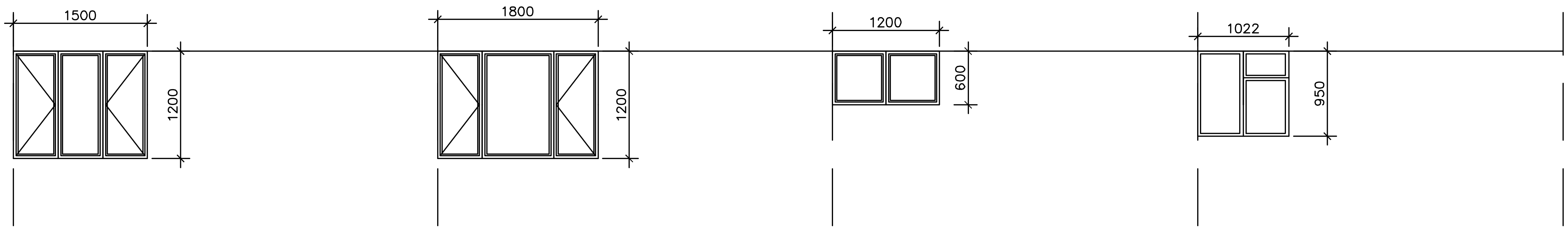
CASE - B Cavity wall - 40mm

CASE - C Cavity wall w/40mm Extruded Polystrene

CASE - D Gypsum Ceiling w/Blown Cellulose

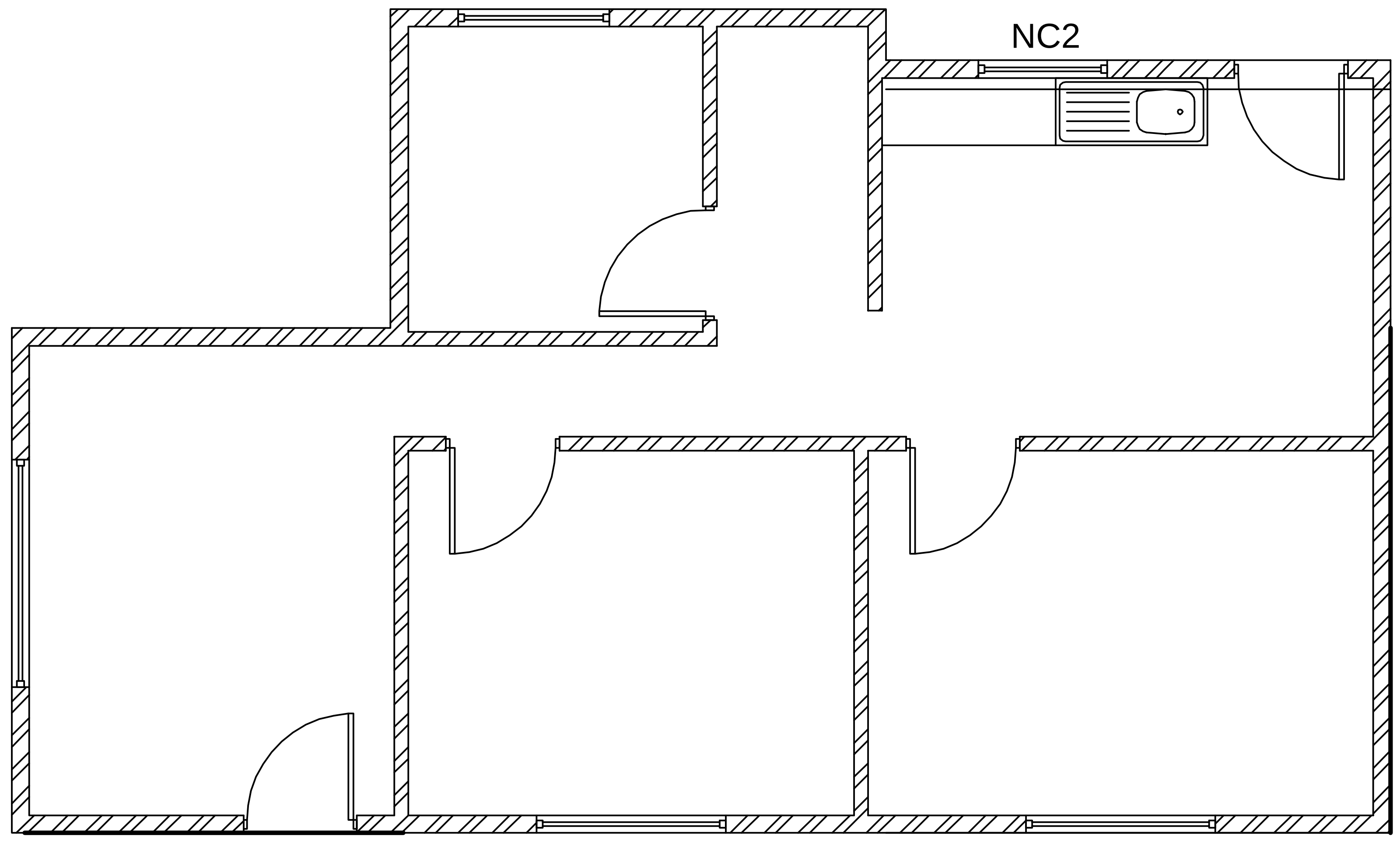
CASE - E Double pane windows w/Wood frame

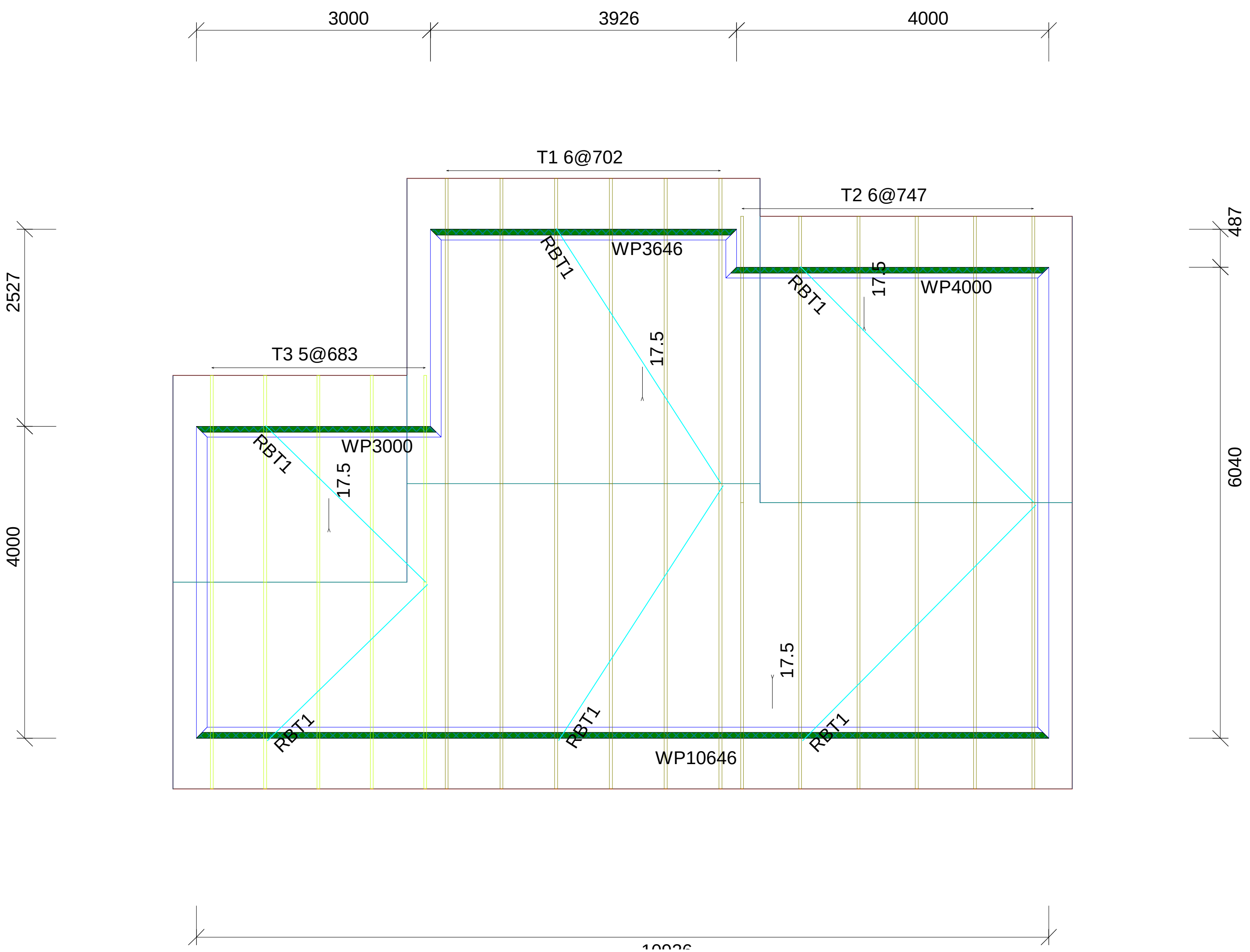
CASE - F C and D combined



	AREA 1.80m^2	AREA 2.16m^2	AREA 0.36m^2	AREA 1.44m^2
WINDOW NO.	W1	W2	W3	W4
FRAME	Timber	Timber	Timber	Timber
GLAZING	5mm clear	5mm clear	5mm obscure	5mm clear
	monolithic glass	monolithic glass	toughened safety glass	monolithic glass
LOCATION			W.C	
NO. REQUIRED	3 off	1 off	1 off	1 off

WINDOW SCHEDULE
SCALE 1: 100





Loading:

TCDL:	0.49kN/m²
BCDL:	0.14kN/m²
Truss CC:	760mm
Purl/Batt CC:	320mm
Overhang:	650 mm

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10163 LSD

Roof Area: 84.60 m²
Floor Area: 62.31 m²

Truss: T1

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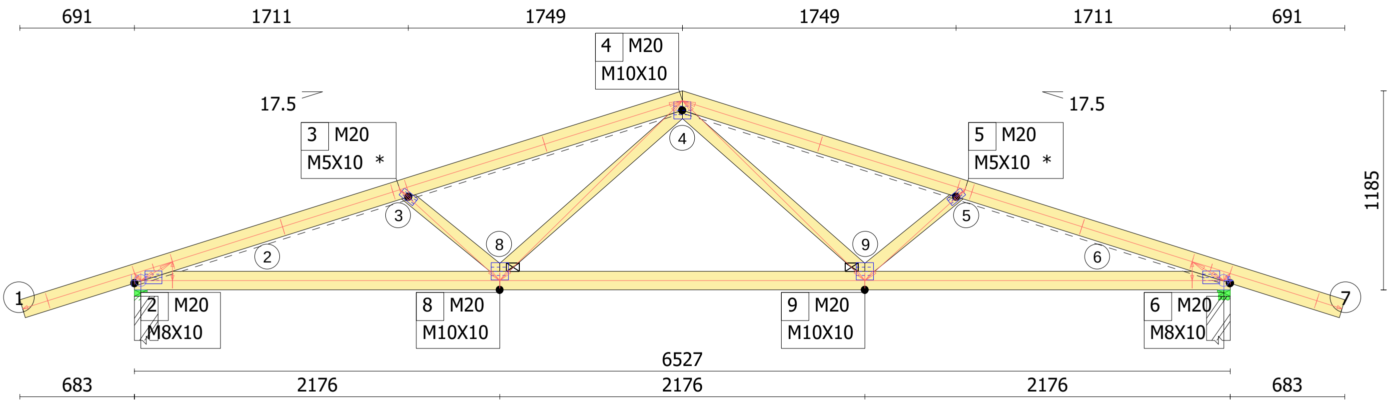
Grade Stresses SANS10163: 2011 "The Structural use of Timber - Limit-states design"
General Loading SANS 10160: 2009 "The General Procedures and Loadings to be adopted in the Design of Buildings"
Plate values used are given in the CSIR contract reports C/WOOD 49 for M20 plates and FOR-C 60 for Gryptite plates.

6 x T1 @ 702 320 Batten CC
MEMBER 2-6 @ 2600 CC <10-10>



Scale 1:45

Truss Input Parameters:

Ref: T1
Quantity: 6
Ply: 1
Span: 6527
Truss C/C: 702
TC Restraints: (Default: 320)
BC Restraints: 2600 (B1),

General Loading:

Top Chord Dead	0.490 kN/m²
Live Load	0.500 kN/m²
Bottom Chord Dead	0.140 kN/m²
TC Man Load	1.000 kN
BC Man Load	0.000 kN
Floor Imposed	0.000 kNm²
Floor Dead	0.000 kNm²
Basic Wind Speed	28 m/s
Peak Wind Pressure	0.000 kN/m²

General Design Info:

Top Chord CAMRI	0.811
Bottom Chord CAMRI	0.602
Web CAMRI	0.130
BC Deflection	5.492 mm
Max Allowed BC Def	25.804
Truss Weight	33.177 Kg

CAMRI = Combined Axial and Moment Resistance Index   SRI = Shear Resistance Index

Maximum Factored Reactions (kN) and Minimum Bearings (mm)

Joint	Max Reaction (LC)	Max Uplift (LC)	Max H Reaction (LC)	Bearings Required / Designed	Bearing type
2	4.315 (2)			26 / 76	Pinned
6	4.315 (2)			26 / 76	H-Roller

Design Results (Member):

Member	Type	Material	CAMRI	LC	SRI	LC	Length	& Angle	Buck Length IP	OP	Maximum F (kN)	M(kNm)	V(kN)	Start F(kN)	M(kNm)	End F(kN)	M(kNm)
1-2	TC	36x111 S5	0.599 IP	8	0.188	8	699	18	1398	562	0.009	0.001	1.054	0.009	-0.001	0.332	-0.515
2-3	TC	36x111 S5	0.600 IP	2	0.201	17	1377	18	864	562	-8.233	0.286	0.986	-8.233	-0.286	-7.845	-0.119
3-4	TC	36x111 S5	0.811 IP	18	0.255	18	1721	18	1536	562	-6.603	0.698	1.252	-6.603	-0.225	-5.919	0.163
4-5	TC	36x111 S5	0.811 IP	19	0.255	19	1721	-18	1536	562	-5.919	0.698	1.252	-5.919	0.163	-6.603	-0.225
5-6	TC	36x111 S5	0.600 IP	2	0.201	20	1377	-18	864	562	-7.845	0.119	0.986	-7.845	-0.119	-8.233	-0.286
6-7	TC	36x111 S5	0.599 IP	22	0.188	22	699	-18	1398	562	0.332	0.515	1.054	0.332	-0.515	0.009	-0.001
2-8	BC	36x111 S5	0.602 IP	2	0.042	2	1950	0	1950	2600	7.631	0.166	0.230	7.631	-0.166	7.631	0.022
8-9	BC	36x111 S5	0.385 IP	2	0.057	1	2176	0	2176	2600	5.125	0.099	0.168	5.125	0.045	5.125	0.045
9-6	BC	36x111 S5	0.602 IP	2	0.042	2	1950	0	1950	2600	7.631	0.166	0.230	7.631	0.022	7.631	-0.166
3-8	WB	36x73 S5	0.077 OP	2	0.000	1	804	-42	724	804	-1.622	0.000	0.000	-1.622	0.000	-1.622	0.000
8-4	WB	36x73 S5	0.130 IP	2	0.000	1	1527	45	1374	1527	1.832	0.000	0.000	1.832	0.000	1.832	0.000
4-9	WB	36x73 S5	0.130 IP	2	0.000	1	1527	-45	1374	1527	1.832	0.000	0.000	1.832	0.000	1.832	0.000

Truss: T1

Design Results (Member):

Member	Type	Material	CAMRI	LC	SRI	LC	Length	& Angle	Buck Length IP	OP	Maximum F (kN)	M(kNm)	V(kN)	Start F(kN)	M(kNm)	End F(kN)	M(kNm)
9-5	WB	36x73 S5	0.077	OP 2	0.000	1	804	42	724	804	-1.622	0.000	0.000	-1.622	0.000	-1.622	0.000

Loadcase 2 SA: 1.2Dead Load + 1.6Live Load

(1/Ym1)	(1/Ym2)	(1/Ym3)	(1/Ym4)	(1/Ym5)	d1	d2
1.14	1.00	1.04	1.00	1.00	1.28	1.00

Members	Shear (kN)	SRI	Maximum Axial Force (kN)	Maximum Moment (kNm)	Axial Force (kN)	Axial Stress (MPa)	Axial Perm. (MPa)	Moment (kNm)	Bending Stress (MPa)	Bending Perm. (MPa)	CAMRI	T/C +/-
T1 1-11	0.624	0.113	0.197	-0.218	0.197	0.000	5.351	-0.218	2.951	9.184	0.331	T
T1 11-10	0.390	0.084	0.464	-0.286	0.464	0.100	4.583	-0.286	3.863	9.184	0.442	T
T1 10-19	0.735	0.145	-8.233	-0.286	-8.233	-2.060	-11.462	-0.286	3.863	9.184	0.600	C
T1 19-3	0.533	0.000	-7.845	-0.142	-7.833	-1.963	-11.772	-0.141	1.905	9.184	0.374	C
T1 3-18	0.868	0.000	-7.016	-0.142	-7.016	-1.756	-11.753	-0.142	1.916	9.184	0.358	C
T1 18-4	0.829	0.244	-7.004	0.280	-6.742	-1.753	-11.907	0.280	3.793	9.184	0.560	C
T2 4-20	0.829	0.244	-7.004	0.280	-6.742	-1.631	-11.083	0.280	3.793	9.184	0.560	C
T2 20-5	0.868	0.000	-7.016	-0.142	-7.016	-1.753	-11.732	-0.142	1.916	9.184	0.358	C
T2 5-21	0.533	0.000	-7.845	-0.142	-7.833	-1.960	-11.753	-0.142	1.916	9.184	0.375	C
T2 21-14	0.735	0.145	-8.233	-0.286	-8.233	-1.963	-10.923	-0.286	3.863	9.184	0.600	C
T2 14-15	0.390	0.084	0.464	-0.286	0.464	0.116	5.351	-0.286	3.863	9.184	0.442	T
T2 15-7	0.624	0.113	0.197	-0.218	0.197	0.049	5.351	-0.218	2.951	9.184	0.331	T
B3 13-2	0.005	0.000	0.000	0.000	0.000	0.000	11.462	-0.000	0.001	9.184	0.000	T
B3 2-12	0.898	0.000	7.631	-0.166	7.631	1.910	5.351	-0.166	2.250	9.184	0.602	T
B3 12-8	0.230	0.042	7.631	-0.166	7.631	1.910	5.351	-0.166	2.250	9.184	0.602	T
B3 8-9	0.152	0.045	5.125	0.099	5.125	1.283	5.351	0.099	1.335	9.184	0.385	T
B3 9-16	0.230	0.042	7.631	-0.166	7.631	1.910	5.351	-0.166	2.250	9.184	0.602	T
B3 16-6	0.898	0.000	7.631	-0.166	7.631	1.910	5.351	-0.166	2.250	9.184	0.602	T
B3 6-17	0.005	0.000	0.000	-0.000	0.000	0.000	11.462	-0.000	0.001	9.184	0.000	T
W4 3-8	0.000	0.000	-1.622	0.000	-1.622	-0.617	-8.059	0.000	0.000	9.184	0.077	C
W5 8-4	0.000	0.000	1.832	0.000	1.832	0.697	5.351	0.000	0.000	9.184	0.130	T
W6 4-9	0.000	0.000	1.832	0.000	1.832	0.697	5.351	0.000	0.000	9.184	0.130	T
W7 9-5	0.000	0.000	-1.622	0.000	-1.622	-0.617	-8.059	0.000	0.000	9.184	0.077	C

Loadcases Considered (LC Number, LC Name):

1 , SA: 1.35Dead Load Only
2 , SA: 1.2Dead Load + 1.6Live Load
8 , SA: 1.2Dead Load + 1.6Man TC
9 , SA: 1.2Dead Load + 1.6Man BC
12 , Serviceability State (1.1Dead Only)
15 , Serviceability State (1.0Dead + 1.0Man load)
16 , SA: 1.2Dead Load + 1.6Man TC (1)
17 , SA: 1.2Dead Load + 1.6Man TC (2)
18 , SA: 1.2Dead Load + 1.6Man TC (3)
19 , SA: 1.2Dead Load + 1.6Man TC (4)
20 , SA: 1.2Dead Load + 1.6Man TC (5)
21 , SA: 1.2Dead Load + 1.6Man TC (6)
22 , SA: 1.2Dead Load + 1.6Man TC (7)
23 , Serviceability State (1.0Dead + 1.0Man load)
24 , Serviceability State (1.0Dead + 1.0Man load) (2)
25 , Serviceability State (1.0Dead + 1.0Man load)
26 , Serviceability State (1.0Dead + 1.0Man load) (4)
27 , Serviceability State (1.0Dead + 1.0Man load)
28 , Serviceability State (1.0Dead + 1.0Man load) (6)
29 , Serviceability State (1.0Dead + 1.0Man load)

Loading Data: **SA: 1.2Dead Load + 1.6Live Load**

Chord	Type	Distribution	Direction	Projected	Begin	Val1	End	Val2	Panel
Top	Dead	Uniform	Down	No	-667	0.023	7194	0.023	Filter
Top	Dead	Uniform	Down	No	-667	0.413	3263	0.413	
Top	Dead	Uniform	Down	No	3263	0.413	7194	0.413	
Top	Live	Uniform	Down	Yes	-667	0.525	3263	0.525	
Top	Live	Uniform	Down	Yes	3263	0.525	7194	0.525	
Bottom	Dead	Uniform	Down	No	0	0.022	6527	0.022	Filter
Bottom	Dead	Uniform	Down	No	0	0.118	6527	0.118	

Reactions for Loadcase 2:

Joint:	Vertical Reaction:	Horizontal Reaction:
2	**4.315**	
6	**4.315**	

Truss: T2

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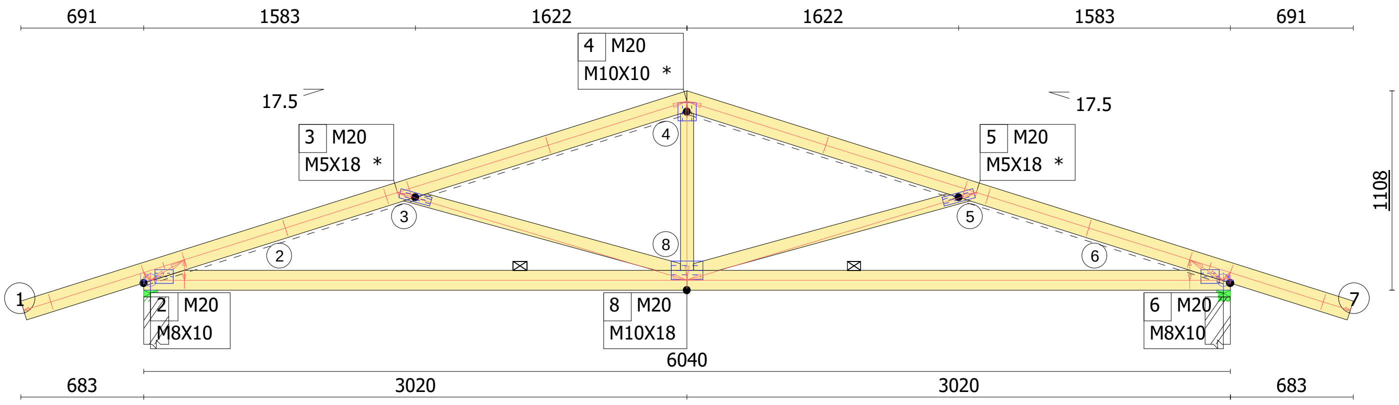
Grade Stresses SANS10163: 2011 "The Structural use of Timber - Limit-states design"
General Loading SANS 10160: 2009 "The General Procedures and Loadings to be adopted in the Design of Buildings"
Plate values used are given in the CSIR contract reports C/WOOD 49 for M20 plates and FOR-C 60 for Gryptite plates.

6 x T2 @ 746.8 320 Batten CC
MEMBER 2-6 @ 2600 CC <10-10>



Scale 1:42

Truss Input Parameters:		**General Loading:**		**General Design Info:**	
Ref: T2		Top Chord Dead	0.490 kN/m²	Top Chord CAMRI	0.761
Quantity: 6		Live Load	0.500 kN/m²	Bottom Chord CAMRI	0.577
Ply: 1		Bottom Chord Dead	0.140 kN/m²	Web CAMRI	0.381
Span: 6040		TC Man Load	1.000 kN	BC Deflection	3.853 mm
Truss C/C: 747		BC Man Load	0.000 kN	Max Allowed BC Def	23.856
TC Restraints: (Default: 320)		Floor Imposed	0.000 kNm²	Truss Weight	30.932 Kg
BC Restraints: 2600 (B1),		Floor Dead	0.000 kNm²		
		Basic Wind Speed	28 m/s		
		Peak Wind Pressure	0.000 kN/m²		

CAMRI = Combined Axial and Moment Resistance Index SRI = Shear Resistance Index

Maximum Factored Reactions (kN) and Minimum Bearings (mm)

Joint	Max Reaction (LC)	Max Uplift (LC)	Max H Reaction (LC)	Bearings Required / Designed	Bearing type
2	4.296 (2)			25 / 76	Pinned
6	4.296 (2)			25 / 76	H-Roller

Design Results (Member):

Member	Type	Material	CAMRI	LC	SRI	LC	Length	& Angle	Buck Length IP	OP	Maximum F (kN)	M(kNm)	V(kN)	Start F(kN)	M(kNm)	End F(kN)	M(kNm)
1-2	TC	36x111 S5	0.593 IP	8	0.185	8	699	18	1398	597	0.010	0.001	1.071	0.010	-0.001	0.338	-0.521
2-3	TC	36x111 S5	0.584 IP	2	0.193	17	1176	18	974	597	-7.895	0.279	0.966	-7.895	-0.279	-7.543	-0.079
3-4	TC	36x111 S5	0.761 IP	18	0.243	18	1619	18	1619	597	-5.102	0.683	1.218	-5.102	-0.159	-4.418	0.158
4-5	TC	36x111 S5	0.761 IP	19	0.243	19	1619	-18	1619	597	-4.418	0.683	1.218	-4.418	0.158	-5.102	-0.159
5-6	TC	36x111 S5	0.584 IP	2	0.193	20	1176	-18	974	597	-7.543	0.079	0.966	-7.543	-0.079	-7.895	-0.279
6-7	TC	36x111 S5	0.593 IP	22	0.185	22	699	-18	1398	597	0.338	0.521	1.071	0.338	-0.521	0.010	-0.001
2-8	BC	36x111 S5	0.577 IP	2	0.070	1	2794	0	1902	2600	7.310	0.165	0.246	7.310	-0.165	7.310	0.026
8-6	BC	36x111 S5	0.577 IP	2	0.070	1	2794	0	1902	2600	7.310	0.165	0.246	7.310	0.026	7.310	-0.165
3-8	WB	36x73 S5	0.381 OP	2	0.000	1	1681	-17	1513	1681	-2.333	0.000	0.000	-2.333	0.000	-2.333	0.000
8-4	WB	36x73 S5	0.116 IP	2	0.000	1	995	90	895	995	1.655	0.000	0.000	1.655	0.000	1.655	0.000
8-5	WB	36x73 S5	0.381 OP	2	0.000	1	1681	17	1513	1681	-2.333	0.000	0.000	-2.333	0.000	-2.333	0.000

Truss: T2

Loadcase 2 SA: 1.2Dead Load + 1.6Live Load

Members	Shear (kN)	SRI	Maximum Axial Force (kN)	Maximum Moment (kNm)	Axial Force (kN) (1/Ym1) 1.15	Axial Stress (MPa) (1/Ym2) 1.00	Axial Perm. (MPa) (1/Ym3) 1.05	Moment (kNm) (1/Ym4) 1.00	Bending Stress (MPa) (1/Ym5) 1.00	Bending Perm. (MPa) d1 1.28	CAMRI d2 1.00	T/C +/-
T1 1-10	0.664	0.119	0.209	-0.232	0.209	0.000	5.422	-0.232	3.140	9.307	0.347	T
T1 10-9	0.311	0.058	0.541	-0.279	0.541	0.118	4.712	-0.279	3.776	9.307	0.431	T
T1 9-18	0.729	0.131	-7.895	-0.279	-7.895	-1.976	-11.110	-0.279	3.776	9.307	0.584	C
T1 18-3	0.452	0.000	-7.543	-0.107	-7.522	-1.888	-11.943	-0.107	1.450	9.307	0.314	C
T1 3-17	0.865	0.000	-5.596	-0.107	-5.596	-1.400	-11.910	-0.107	1.450	9.307	0.273	C
T1 17-4	0.801	0.232	-5.576	0.286	-5.323	-1.395	-11.637	0.286	3.874	9.307	0.536	C
T2 4-19	0.801	0.232	-5.576	0.286	-5.324	-1.274	-10.624	0.286	3.874	9.307	0.536	C
T2 19-5	0.865	0.000	-5.596	-0.107	-5.596	-1.395	-11.867	-0.107	1.450	9.307	0.273	C
T2 5-20	0.452	0.000	-7.543	-0.107	-7.522	-1.883	-11.910	-0.107	1.450	9.307	0.314	C
T2 20-13	0.729	0.131	-7.895	-0.279	-7.895	-1.888	-10.614	-0.279	3.776	9.307	0.584	C
T2 13-14	0.311	0.058	0.541	-0.279	0.541	0.135	5.422	-0.279	3.776	9.307	0.431	T
T2 14-7	0.664	0.119	0.209	-0.232	0.209	0.052	5.422	-0.232	3.140	9.307	0.347	T
B3 12-2	0.006	0.000	0.000	0.000	0.000	0.000	11.110	-0.000	0.001	9.307	0.000	T
B3 2-11	0.892	0.000	7.310	-0.165	7.310	1.829	5.422	-0.165	2.233	9.307	0.577	T
B3 11-8	0.261	0.047	7.310	-0.165	7.310	1.829	5.422	-0.165	2.233	9.307	0.577	T
B3 8-15	0.261	0.047	7.310	-0.165	7.310	1.829	5.422	-0.165	2.233	9.307	0.577	T
B3 15-6	0.892	0.000	7.310	-0.165	7.310	1.829	5.422	-0.165	2.233	9.307	0.577	T
B3 6-16	0.006	0.000	0.000	-0.000	0.000	0.000	11.110	-0.000	0.001	9.307	0.000	T
W4 3-8	0.000	0.000	-2.333	0.000	-2.333	-0.888	-2.332	0.000	0.000	9.307	0.077	C
W5 8-4	0.000	0.000	1.655	0.000	1.655	0.630	5.422	0.000	0.000	9.307	0.130	T
W6 8-5	0.000	0.000	-2.333	0.000	-2.333	-0.888	-2.332	0.000	0.000	9.307	0.381	C

Loadcases Considered (LC Number, LC Name):

1 , SA: 1.35Dead Load Only
2 , SA: 1.2Dead Load + 1.6Live Load
8 , SA: 1.2Dead Load + 1.6Man TC
9 , SA: 1.2Dead Load + 1.6Man BC
12 , Serviceability State (1.1Dead Only)
15 , Serviceability State (1.0Dead + 1.0Man load)
16 , SA: 1.2Dead Load + 1.6Man TC (1)
17 , SA: 1.2Dead Load + 1.6Man TC (2)
18 , SA: 1.2Dead Load + 1.6Man TC (3)
19 , SA: 1.2Dead Load + 1.6Man TC (4)
20 , SA: 1.2Dead Load + 1.6Man TC (5)
21 , SA: 1.2Dead Load + 1.6Man TC (6)
22 , SA: 1.2Dead Load + 1.6Man TC (7)
23 , Serviceability State (1.0Dead + 1.0Man load)
24 , Serviceability State (1.0Dead + 1.0Man load) (2)
25 , Serviceability State (1.0Dead + 1.0Man load)
26 , Serviceability State (1.0Dead + 1.0Man load) (4)
27 , Serviceability State (1.0Dead + 1.0Man load)
28 , Serviceability State (1.0Dead + 1.0Man load) (6)
29 , Serviceability State (1.0Dead + 1.0Man load)

Loading Data: **SA: 1.2Dead Load + 1.6Live Load**

Chord	Type	Distribution	Direction	Projected	Begin	Val1	End	Val2	Panel
Top	Dead	Uniform	Down	No	-667	0.023	6707	0.023	Filter
Top	Dead	Uniform	Down	No	-667	0.439	3020	0.439	
Top	Dead	Uniform	Down	No	3020	0.439	6707	0.439	
Top	Live	Uniform	Down	Yes	-667	0.560	3020	0.560	
Top	Live	Uniform	Down	Yes	3020	0.560	6707	0.560	
Bottom	Dead	Uniform	Down	No	0	0.022	6040	0.022	Filter
Bottom	Dead	Uniform	Down	No	0	0.125	6040	0.125	

Reactions for Loadcase 2:

Joint:	Vertical Reaction:	Horizontal Reaction:
2	**4.296**	
6	**4.296**	

Truss: T3

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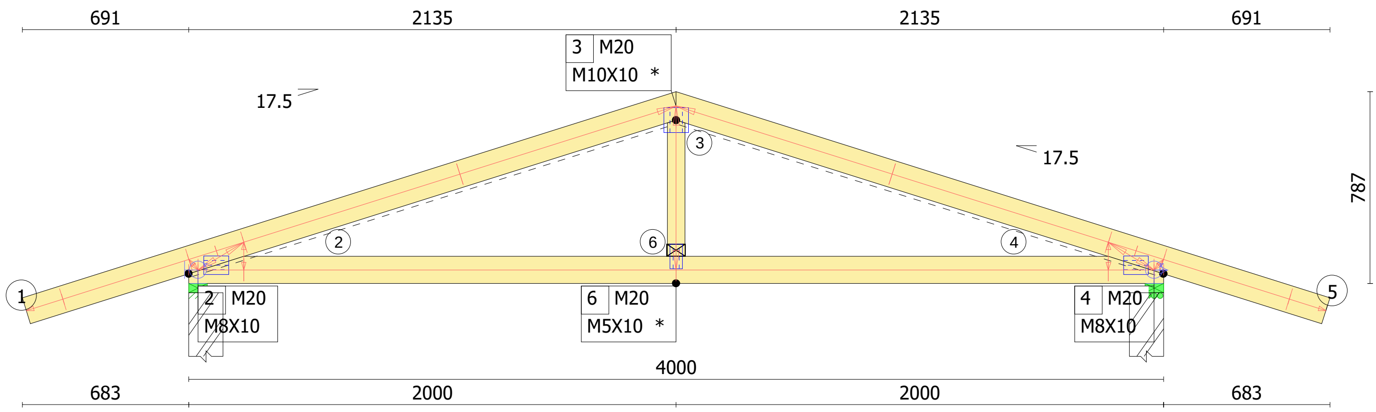
Grade Stresses SANS10163: 2011 "The Structural use of Timber - Limit-states design"
General Loading SANS 10160: 2009 "The General Procedures and Loadings to be adopted in the Design of Buildings"
Plate values used are given in the CSIR contract reports C/WOOD 49 for M20 plates and FOR-C 60 for Gryptite plates.

5 x T3 @ 683.5 320 Batten CC
MEMBER 2-4 @ 2600 CC <10-10>



Scale 1:31

Truss Input Parameters:	General Loading:		General Design Info:	
Ref: T3	Top Chord Dead	0.490 kN/m²	Top Chord CAMRI	0.742
Quantity: 5	Live Load	0.500 kN/m²	Bottom Chord CAMRI	0.393
Ply: 1	Bottom Chord Dead	0.140 kN/m²	Web CAMRI	0.027
Span: 4000	TC Man Load	1.000 kN	BC Deflection	1.077 mm
Truss C/C: 684	BC Man Load	0.000 kN	Max Allowed BC Def	15.696
TC Restraints: (Default: 320)	Floor Imposed	0.000 kNm²	Truss Weight	18.772 Kg
BC Restraints: 2600 (B1),	Floor Dead	0.000 kNm²		
	Basic Wind Speed	28 m/s		
	Peak Wind Pressure	0.000 kN/m²		

CAMRI = Combined Axial and Moment Resistance Index   SRI = Shear Resistance Index

Maximum Factored Reactions (kN) and Minimum Bearings (mm)

Joint	Max Reaction (LC)	Max Uplift (LC)	Max H Reaction (LC)	Bearings Required / Designed	Bearing type
2	3.017 (16)			18 / 76	Pinned
4	3.017 (19)			18 / 76	H-Roller

Design Results (Member):

Member	Type	Material	CAMRI	LC	SRI	LC	Length & Angle		Buck Length IP	Buck Length OP	Maximum F (kN)	Maximum M(kNm)	Maximum V(kN)	Start F(kN)	Start M(kNm)	End F(kN)	End M(kNm)
1-2	TC	36x111 S5	0.567 IP	8	0.179	8	699	18	1398	547	0.009	0.001	1.044	0.009	-0.001	0.329	-0.512
2-3	TC	36x111 S5	0.742 IP	17	0.190	2	1860	18	1594	547	-3.508	0.716	0.700	-3.508	-0.337	-2.814	0.169
3-4	TC	36x111 S5	0.742 IP	18	0.190	2	1860	-18	1594	547	-2.814	0.716	0.700	-2.814	0.169	-3.508	-0.337
4-5	TC	36x111 S5	0.567 IP	20	0.179	20	699	-18	1398	547	0.329	0.512	1.044	0.329	-0.512	0.009	-0.001
2-6	BC	36x111 S5	0.393 IP	17	0.071	17	1774	0	1593	2600	2.950	0.312	0.365	2.950	0.312	2.950	-0.126
6-4	BC	36x111 S5	0.393 IP	18	0.071	18	1774	0	1593	2600	2.950	0.312	0.365	2.950	-0.126	2.950	0.312
6-3	WB	36x73 S5	0.027 IP	1	0.000	1	673	90	606	673	0.359	0.000	0.000	0.359	0.000	0.359	0.000

Loadcase 2 SA: 1.2Dead Load + 1.6Live Load

Members	Shear (kN)	SRI	Maximum Axial Force (kN)	Maximum Moment (kNm)	Axial Force (kN)	Axial Stress (MPa)	Axial Perm. (MPa)		Moment (kNm)	Bending Stress (MPa)	Bending Perm. (MPa)	CAMRI	T/C +/-
					(1/Ym1) 1.16	(1/Ym2) 1.00	(1/Ym3) 1.11	(1/Ym4) 1.00	(1/Ym5) 1.00		d1 1.27	d2 1.00	
T1 1-8	0.629	0.106	0.198	-0.220	0.198	0.000	5.779		-0.220	2.974	9.919	0.308	T

Truss: T3

Loadcase 2 SA: 1.2Dead Load + 1.6Live Load

(1/Ym1)	(1/Ym2)	(1/Ym3)	(1/Ym4)	(1/Ym5)	d1	d2
1.16	1.00	1.11	1.00	1.00	1.27	1.00

Members	Shear (kN)	SRI	Maximum Axial Force (kN)	Maximum Moment (kNm)	Axial Force (kN)	Axial Stress (MPa)	Axial Perm. (MPa)	Moment (kNm)	Bending Stress (MPa)	Bending Perm. (MPa)	CAMRI	T/C +/-
T1 8-7	0.254	0.043	0.531	-0.255	0.531	0.116	5.048	-0.255	3.447	9.919	0.370	T
T1 7-3	0.974	0.190	-3.402	0.272	-3.095	-0.851	-13.845	0.272	3.684	9.919	0.433	C
T2 3-11	0.974	0.190	-3.402	0.272	-3.095	-0.719	-11.697	0.272	3.684	9.919	0.433	C
T2 11-12	0.254	0.043	0.531	-0.255	0.531	0.133	5.779	-0.255	3.447	9.919	0.370	T
T2 12-5	0.629	0.106	0.198	-0.220	0.198	0.050	5.779	-0.220	2.974	9.919	0.308	T
B3 10-2	0.005	0.000	0.000	0.000	0.000	0.000	12.595	0.000	0.001	9.919	0.000	T
B3 2-9	0.372	0.000	2.952	0.067	2.952	0.739	5.779	0.067	0.913	9.919	0.220	T
B3 9-6	0.197	0.053	2.952	0.074	2.952	0.739	5.779	0.074	0.998	9.919	0.228	T
B3 6-13	0.197	0.053	2.952	0.074	2.952	0.739	5.779	0.074	0.998	9.919	0.228	T
B3 13-4	0.372	0.000	2.952	0.067	2.952	0.739	5.779	0.067	0.913	9.919	0.220	T
B3 4-14	0.005	0.000	0.000	0.000	0.000	0.000	12.595	0.000	0.001	9.919	0.000	T
W4 6-3	0.000	0.000	0.393	0.000	0.393	0.150	5.779	0.000	0.000	9.919	0.026	T

Loadcases Considered (LC Number, LC Name):

1 , SA: 1.35Dead Load Only
2 , SA: 1.2Dead Load + 1.6Live Load
8 , SA: 1.2Dead Load + 1.6Man TC
9 , SA: 1.2Dead Load + 1.6Man BC
12 , Serviceability State (1.1Dead Only)
15 , Serviceability State (1.0Dead + 1.0Man load)
16 , SA: 1.2Dead Load + 1.6Man TC (1)
17 , SA: 1.2Dead Load + 1.6Man TC (2)
18 , SA: 1.2Dead Load + 1.6Man TC (3)
19 , SA: 1.2Dead Load + 1.6Man TC (4)
20 , SA: 1.2Dead Load + 1.6Man TC (5)
21 , Serviceability State (1.0Dead + 1.0Man load)
22 , Serviceability State (1.0Dead + 1.0Man load) (2)
23 , Serviceability State (1.0Dead + 1.0Man load)
24 , Serviceability State (1.0Dead + 1.0Man load) (4)
25 , Serviceability State (1.0Dead + 1.0Man load)

Loading Data: **SA: 1.2Dead Load + 1.6Live Load**

Chord	Type	Distribution	Direction	Projected	Begin	Val1	End	Val2	Panel
Top	Dead	Uniform	Down	No	-667	0.020	4667	0.020	Filter
Top	Dead	Uniform	Down	No	-667	0.402	2000	0.402	
Top	Dead	Uniform	Down	No	2000	0.402	4667	0.402	
Top	Live	Uniform	Down	Yes	-667	0.547	2000	0.547	
Top	Live	Uniform	Down	Yes	2000	0.547	4667	0.547	
Bottom	Dead	Uniform	Down	No	0	0.019	4000	0.019	Filter
Bottom	Dead	Uniform	Down	No	0	0.115	4000	0.115	

Reactions for Loadcase 2:

Joint:	Vertical Reaction:	Horizontal Reaction:
2	**2.906**	
4	**2.906**	

Truss: G2

Design Results (Member):

Member	Type	Material	CAMRI	LC	SRI	LC	Length & Angle		Buck Length IP	OP	Maximum F (kN)	M(kNm)	V(kN)	Start F(kN)	M(kNm)	End F(kN)	M(kNm)
7-4	WB	36x73 S5	0.405	OP 2	0.000	1	1238	24	1114	1238	-3.963	0.000	0.000	-3.963	0.000	-3.963	0.000

Loadcase 2 SA: 1.2Dead Load + 1.6Live Load

(1/Ym1)	(1/Ym2)	(1/Ym3)	(1/Ym4)	(1/Ym5)	d1	d2
1.06	1.00	1.03	1.00	1.00	1.37	1.00

Members	Shear (kN)	SRI	Maximum Axial Force (kN)	Maximum Moment (kNm)	Axial Force (kN)	Axial Stress (MPa)	Axial Perm. (MPa)	Moment (kNm)	Bending Stress (MPa)	Bending Perm. (MPa)	CAMRI	T/C +/-
T1 10-9	0.082	0.042	0.109	0.007	0.086	0.013	2.957	0.007	0.092	8.392	0.414	T
T1 9-2	0.287	0.075	-16.027	0.088	-15.908	-4.011	-10.819	0.088	1.184	8.392	0.137	C
T1 2-3	0.347	0.101	-12.091	0.122	-11.984	-3.026	-10.834	0.122	1.656	8.392	0.153	C
T2 3-4	0.354	0.101	-12.088	0.127	-11.984	-2.962	-10.607	0.127	1.720	8.392	0.153	C
T2 4-13	0.320	0.075	-16.047	0.085	-15.914	-3.967	-10.698	0.085	1.149	8.392	0.137	C
T2 13-14	0.138	0.042	0.058	-0.019	0.058	0.014	4.889	-0.019	0.263	8.392	0.414	T
B3 12-1	0.004	0.000	0.000	0.000	0.000	0.000	13.482	0.000	0.000	11.529	0.000	T
B3 1-11	0.876	0.000	14.697	-0.192	14.697	2.740	7.297	-0.192	1.443	11.529	0.174	T
B3 11-6	1.573	0.021	14.697	0.516	14.697	2.740	7.297	0.516	3.876	11.529	0.174	T
B3 6-7	1.500	0.032	14.697	0.556	14.697	2.740	7.297	0.556	4.170	11.529	0.166	T
B3 7-8	1.404	0.032	14.703	0.595	14.703	2.741	7.297	0.595	4.464	11.529	0.166	T
B3 8-15	1.363	0.044	14.703	0.495	14.703	2.741	7.297	0.495	3.714	11.529	0.489	T
B3 15-5	0.981	0.000	14.703	-0.216	14.703	2.741	7.297	-0.216	1.619	11.529	0.174	T
B3 5-16	0.004	0.000	0.000	0.000	0.000	0.000	13.482	0.000	0.001	11.529	0.000	T
W4 6-2	0.000	0.000	2.618	0.000	2.618	0.996	4.889	0.000	0.000	8.392	0.001	T
W6 7-3	0.000	0.000	8.413	0.000	8.413	3.201	4.889	0.000	0.000	8.392	0.061	T
W8 8-4	0.000	0.000	2.666	0.000	2.666	1.014	4.889	0.000	0.000	8.392	0.001	T
W5 2-7	0.000	0.000	-3.957	0.000	-3.957	-1.506	-3.726	0.000	0.000	8.392	0.074	C
W7 7-4	0.000	0.000	-3.963	0.000	-3.963	-1.508	-3.726	0.000	0.000	8.392	0.074	C

Loadcases Considered (LC Number, LC Name):

1 , SA: 1.35Dead Load Only
2 , SA: 1.2Dead Load + 1.6Live Load
3 , SA: 0.9Dead Load + 1.3Wind Along
4 , SA: 1.2Dead Load + 1.3Wind Left(Downward) 1
5 , SA: 0.9Dead Load + 1.3Wind Left(Uplift) 1
6 , SA: 1.2Dead Load + 1.3Wind Right(Downward) 1
7 , SA: 0.9Dead Load + 1.3Wind Right(Uplift) 1
8 , SA: 1.2Dead Load + 1.6Man TC
9 , SA: 1.2Dead Load + 1.6Man BC
12 , Serviceability State (1.1Dead Only)
15 , Serviceability State (1.0Dead + 1.0Man load)
16 , SA: 1.2Dead Load + 1.3Wind Left(Downward) 2
17 , SA: 1.2Dead Load + 1.3Wind Left(Downward) 3
18 , SA: 1.2Dead Load + 1.3Wind Left(Downward) 4
19 , SA: 0.9Dead Load + 1.3Wind Left(Uplift) 2
20 , SA: 0.9Dead Load + 1.3Wind Left(Uplift) 3
21 , SA: 0.9Dead Load + 1.3Wind Left(Uplift) 4
22 , SA: 1.2Dead Load + 1.3Wind Right(Downward) 2
23 , SA: 1.2Dead Load + 1.3Wind Right(Downward) 3
24 , SA: 1.2Dead Load + 1.3Wind Right(Downward) 4
25 , SA: 0.9Dead Load + 1.3Wind Right(Uplift) 2
26 , SA: 0.9Dead Load + 1.3Wind Right(Uplift) 3
27 , SA: 0.9Dead Load + 1.3Wind Right(Uplift) 4
28 , SA: 1.2Dead Load + 1.6Man TC (1)
29 , SA: 1.2Dead Load + 1.6Man TC (2)
30 , SA: 1.2Dead Load + 1.6Man TC (3)
31 , SA: 1.2Dead Load + 1.6Man TC (4)
32 , SA: 1.2Dead Load + 1.6Man TC (5)
33 , Serviceability State (1.0Dead + 1.0Man load) (1)
34 , Serviceability State (1.0Dead + 1.0Man load)
35 , Serviceability State (1.0Dead + 1.0Man load) (3)
36 , Serviceability State (1.0Dead + 1.0Man load)
37 , Serviceability State (1.0Dead + 1.0Man load) (5)

Loading Data: **SA: 1.2Dead Load + 1.6Live Load**

Chord	Type	Distribution	Direction	Projected	Begin	Val1	End	Val2	Panel
Top	Dead	Uniform	Down	No	0	0.223	2268	0.223	
Top	Dead	Uniform	Down	No	2268	0.223	4536	0.223	
Top	Dead	Uniform	Down	No	0	0.028	2268	0.028	
Top	Dead	Uniform	Down	No	2268	0.028	4536	0.028	
Top	Live	Uniform	Down	Yes	0	0.304	2268	0.304	
Top	Live	Uniform	Down	Yes	2268	0.304	4536	0.304	
Bottom	Dead	Force	Down	No	716	1.806			T1
Bottom	Dead	Force	Down	No	1470	1.806			T1
Bottom	Dead	Force	Down	No	2224	1.806			T1
Bottom	Dead	Force	Down	No	2978	1.806			T1
Bottom	Dead	Force	Down	No	3732	1.806			T1
Bottom	Dead	Uniform	Down	No	0	0.064	339	0.064	
Bottom	Dead	Uniform	Down	No	339	0.032	4109	0.032	
Bottom	Dead	Uniform	Down	No	4109	0.064	4536	0.064	
Bottom	Dead	Uniform	Down	No	0	0.039	4536	0.039	
Bottom	Live	Force	Down	No	716	0.821			T1
Bottom	Live	Force	Down	No	1470	0.821			T1
Bottom	Live	Force	Down	No	2224	0.821			T1
Bottom	Live	Force	Down	No	2978	0.821			T1
Bottom	Live	Force	Down	No	3732	0.821			T1

Reactions for Loadcase 2:

Joint:	Vertical Reaction:	Horizontal Reaction:

Truss: G2

Reactions for Loadcase 2:

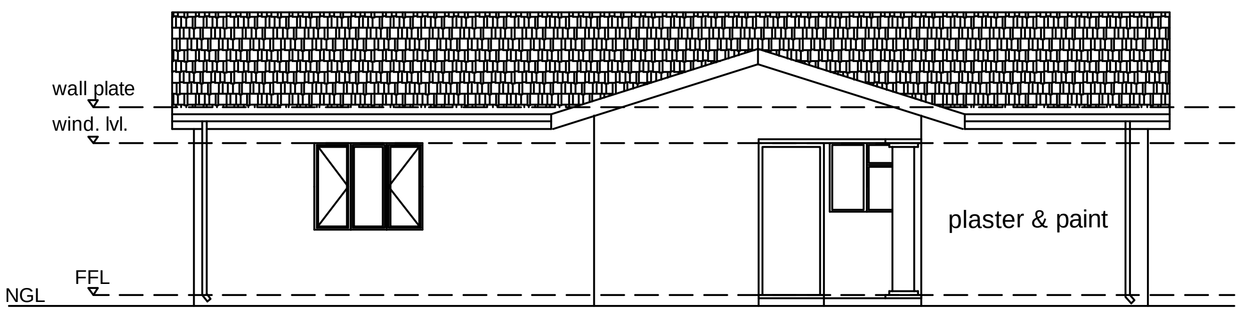
Joint:	Vertical Reaction:	Horizontal Reaction:
1	**8.149**	
5	**7.944**	

PROJECT:

3 - V / CH : 84

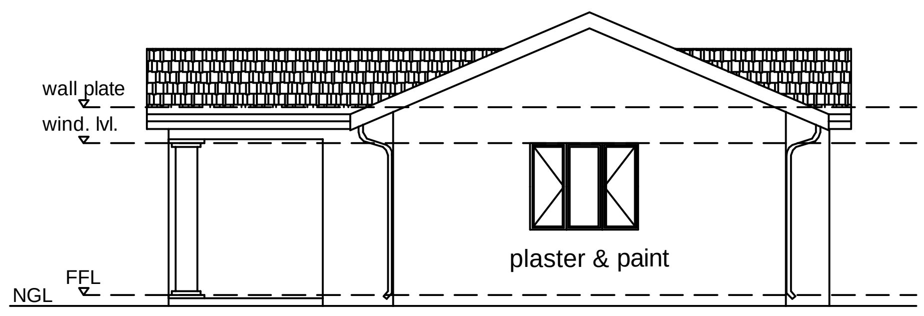
SUBJECT:

SCALE:



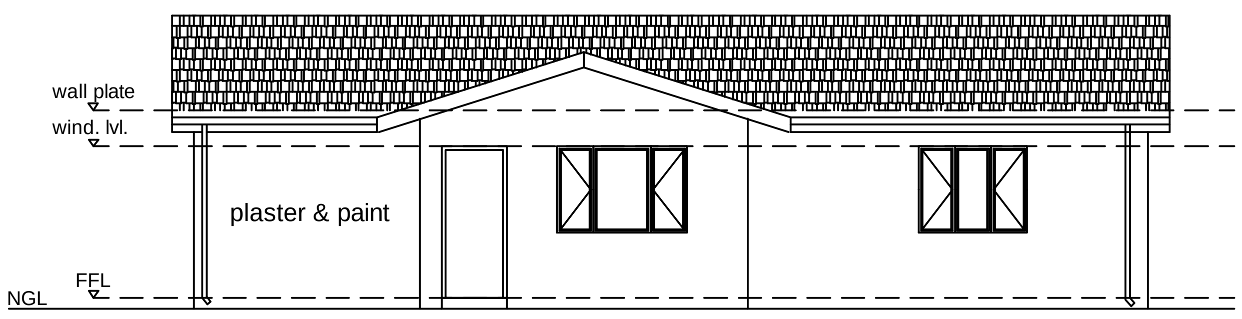
ELEVATION 1

SCALE 1: 100



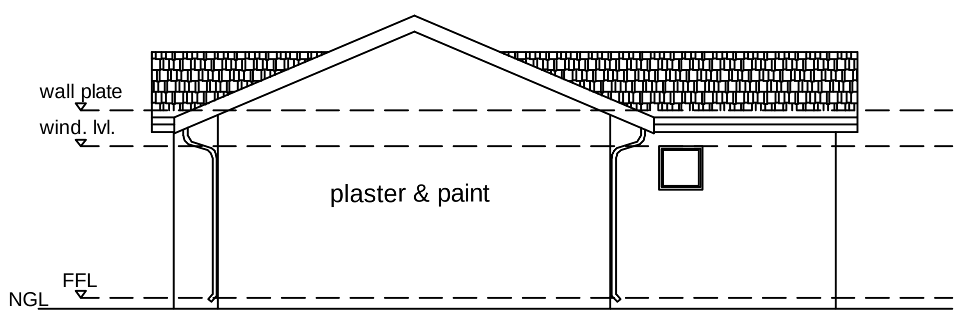
ELEVATION 2

SCALE 1: 100



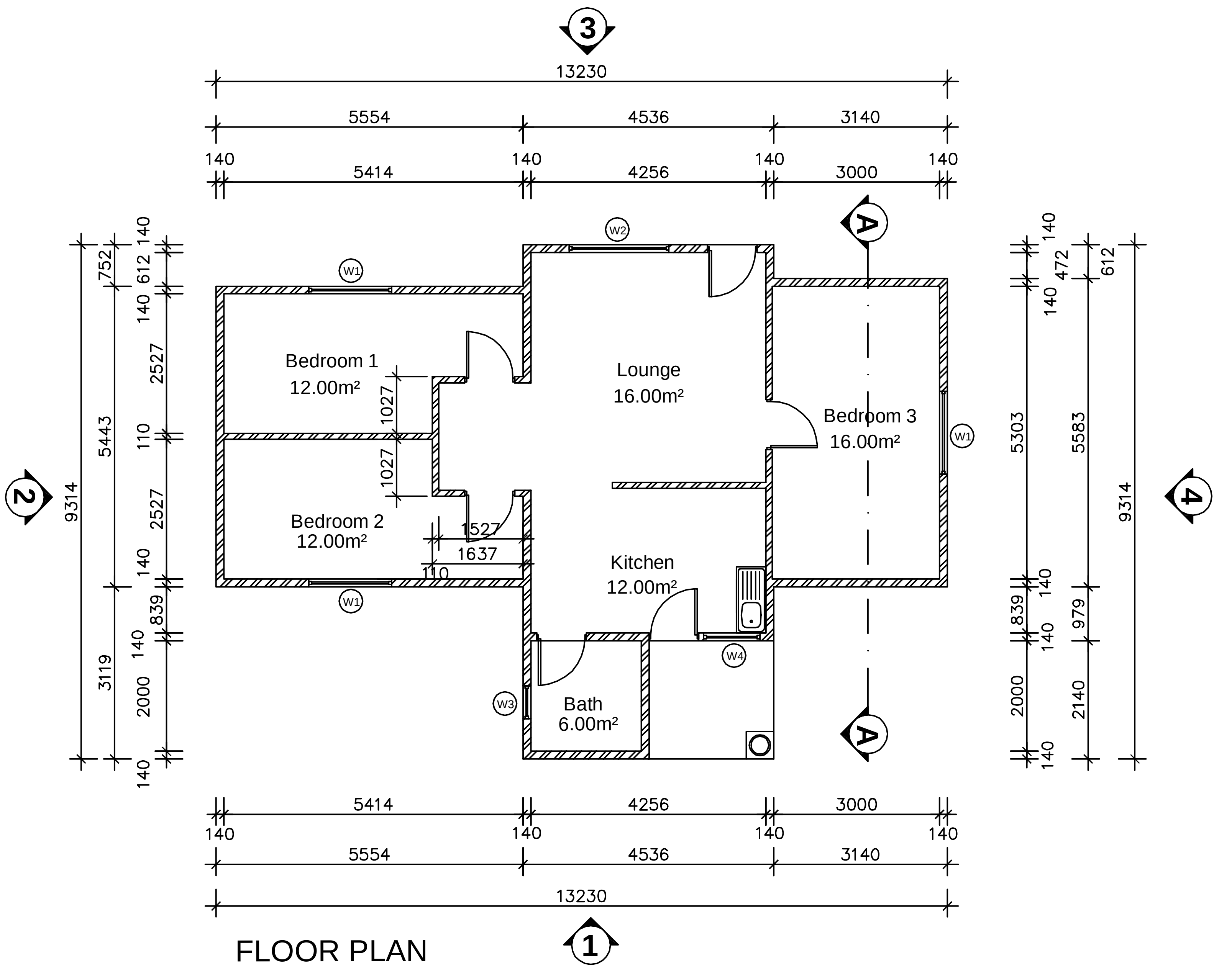
ELEVATION 3

SCALE 1: 100



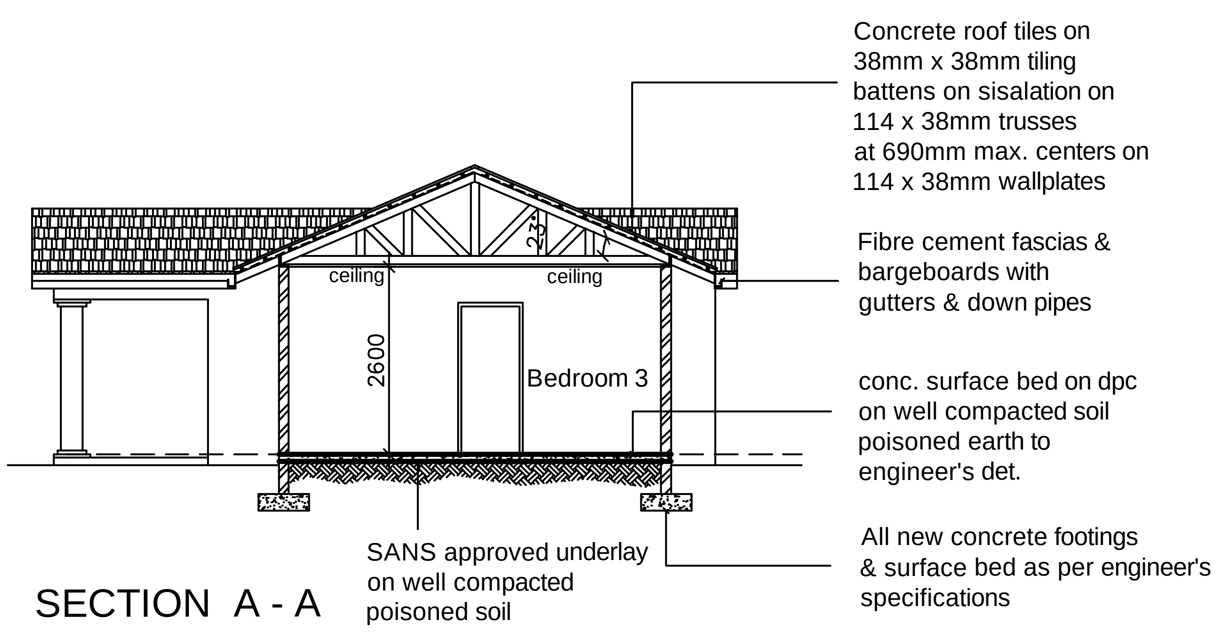
ELEVATION 4

SCALE 1: 100



FLOOR PLAN

SCALE 1: 100



SECTION A - A

SCALE 1: 100

PROJECT:
3 - V / CH : 84

SUBJECT:

SCALE:

CASE & CONSTRUCTION PATTERN:

CASE - A Base Case - No ceiling or Insulation double brick wall without cavity

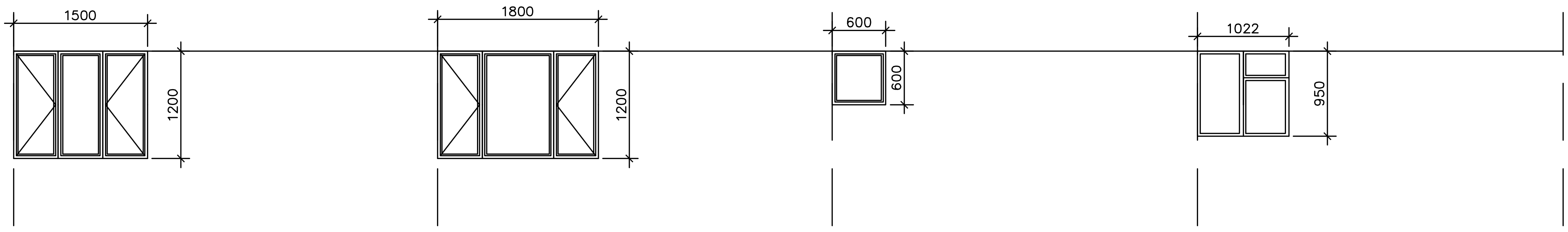
CASE - B Cavity wall - 40mm

CASE - C Cavity wall w/40mm Extruded Polystrene

CASE - D Gypsum Ceiling w/Blown Cellulose

CASE - E Double pane windows w/Wood frame

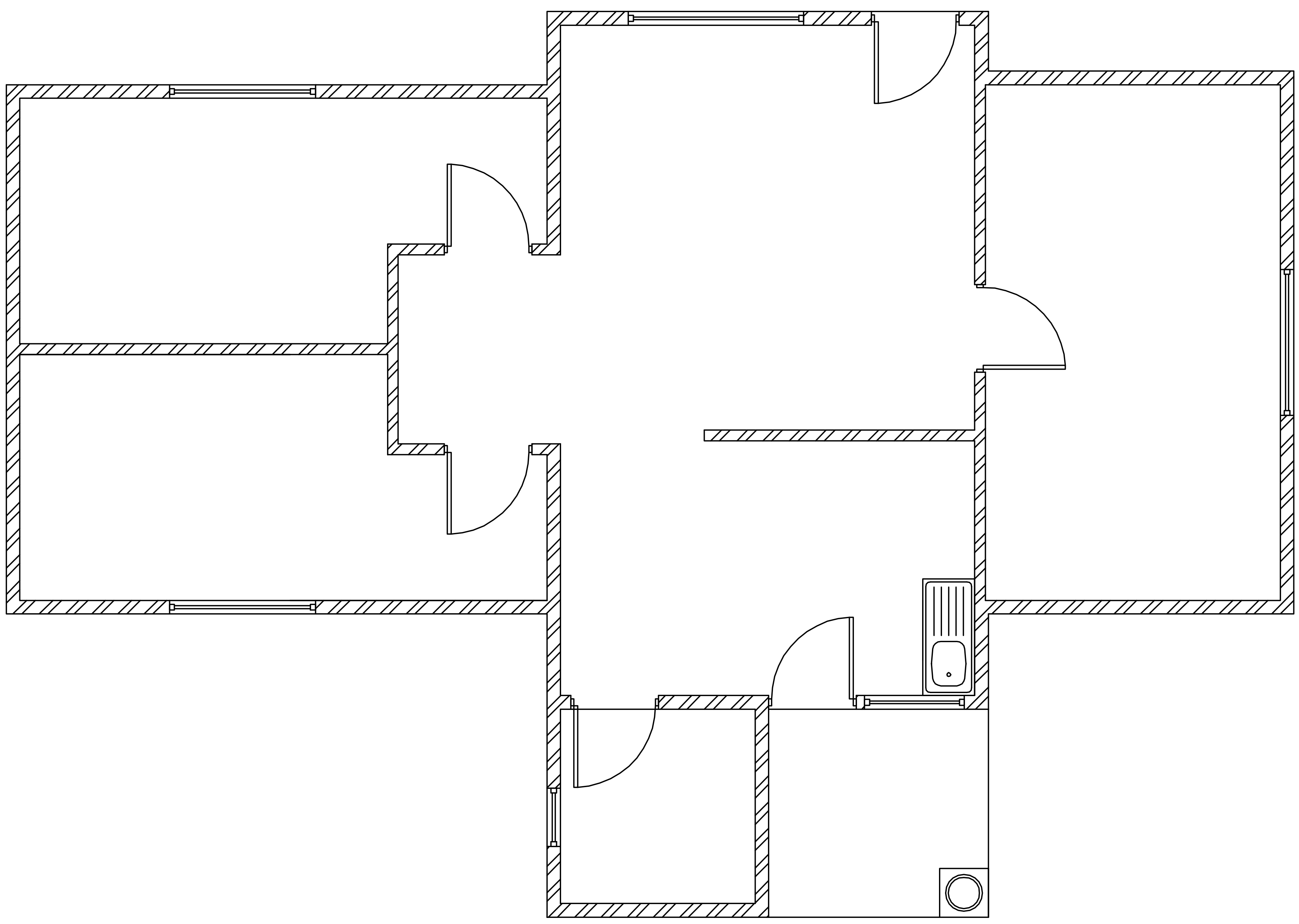
CASE - F C and D combined

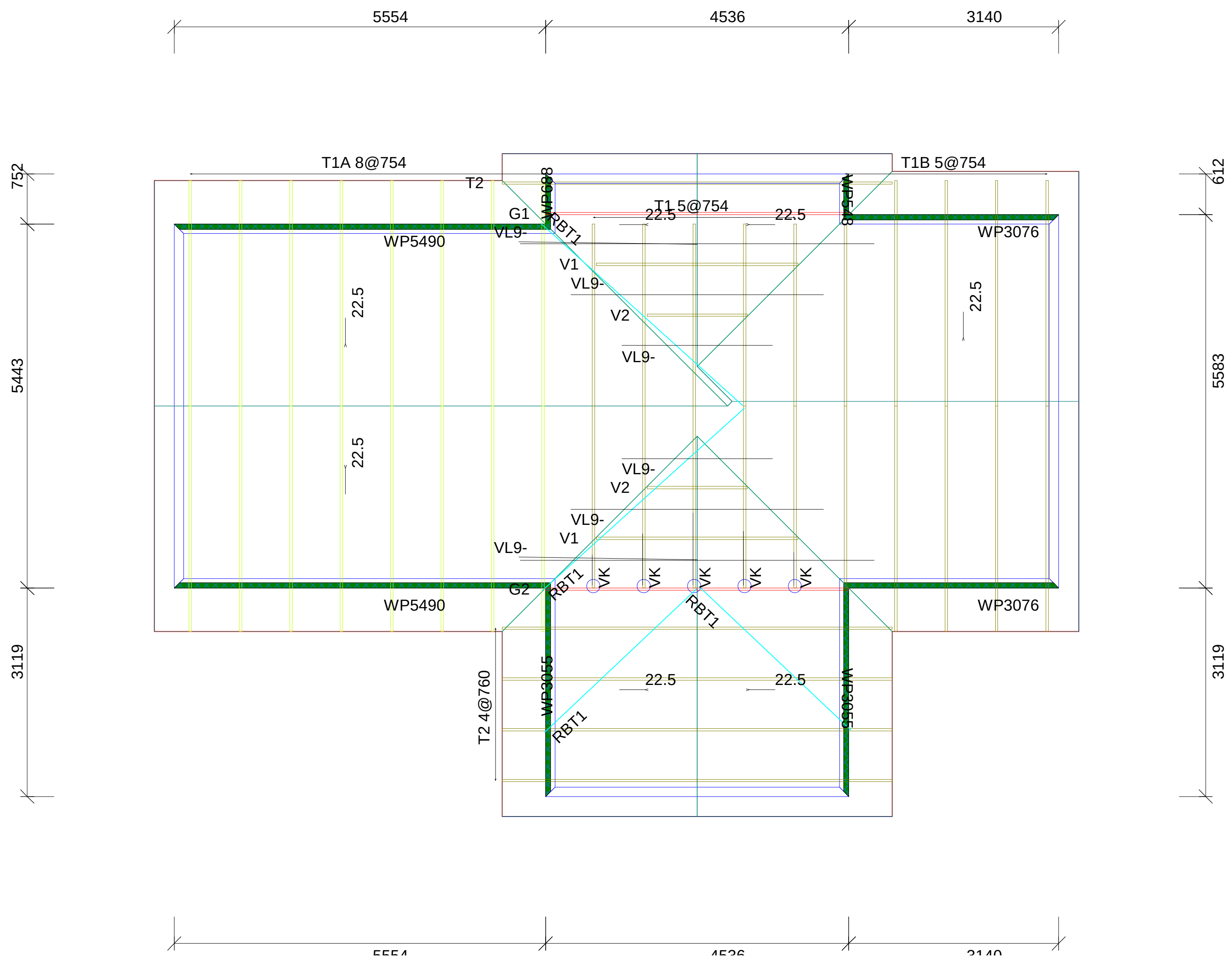


	AREA 1.80m²	AREA 2.16m²	AREA 0.36m²	AREA 0.97m²
WINDOW NO.	W1	W2	W3	W4
FRAME	Timber	Timber	Timber	Timber
GLAZING	5mm clear	5mm clear	5mm obscure	5mm clear
	monolithic glass	monolithic glass	toughened safety glass	monolithic glass
LOCATION			W.C	
NO. REQUIRED	3 off	1 off	1 off	1 off

WINDOW SCHEDULE

SCALE 1: 100





Loading:

TCDL:	0.49kN/m²
BCDL:	0.14kN/m²
Truss CC:	760mm
Purl/Batt CC:	320mm
Overhang:	650 mm

MiTek 2020
v6.2.137.0

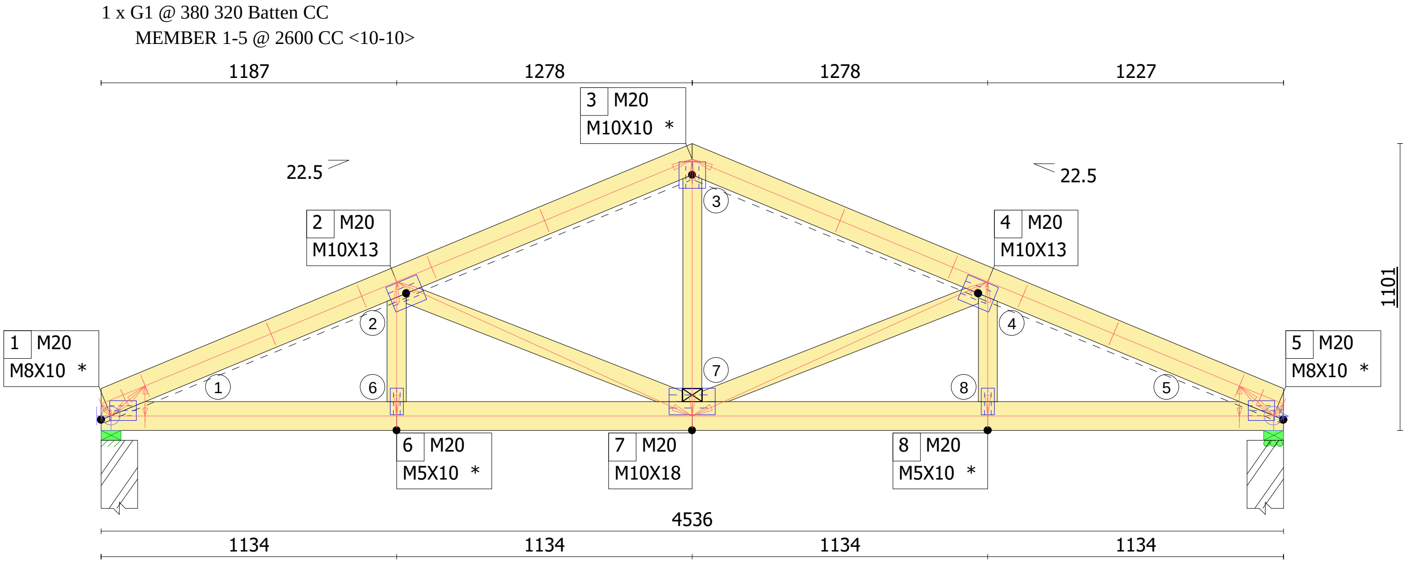
10163 LSD

Roof Area: 121.39 m²
Floor Area: 90.01 m²

Truss: G1

MiTek SA (PTY) Ltd.
MiTek 2020 6.2.1

Grade Stresses SANS10163: 2011 "The Structural use of Timber - Limit-states design"
General Loading SANS 10160: 2009 "The General Procedures and Loadings to be adopted in the Design of Buildings"
Plate values used are given in the CSIR contract reports C/WOOD 49 for M20 plates and FOR-C 60 for Gryptite plates.



Scale 1:29

Truss Input Parameters:	**General Loading:**		**General Design Info:**	
Ref: G1	Top Chord Dead	0.490 kN/m²	Top Chord CAMRI	0.454
Quantity: 1	Live Load	0.500 kN/m²	Bottom Chord CAMRI	0.251
Ply: 1	Bottom Chord Dead	0.140 kN/m²	Web CAMRI	0.105
Span: 4536	TC Man Load	1.000 kN	BC Deflection	0.753 mm
Truss C/C: 380	BC Man Load	0.000 kN	Max Allowed BC Def	17.840
TC Restraints: (Default: 320)	Floor Imposed	0.000 kNm²	Truss Weight	22.826 Kg
BC Restraints: 2600 (B1),	Floor Dead	0.000 kNm²		
	Basic Wind Speed	28 m/s		
	Peak Wind Pressure	0.545 kN/m²		

CAMRI = Combined Axial and Moment Resistance Index SRI = Shear Resistance Index

Maximum Factored Reactions (kN) and Minimum Bearings (mm)

Joint	Max Reaction (LC)	Max Uplift (LC)	Max H Reaction (LC)	Bearings Required / Designed	Bearing type
1	2.411 (8)		-0.233 (20)	14 / 76	Pinned
5	2.389 (32)			14 / 76	H-Roller

Design Results (Member):

Member	Type	Material	CAMRI	LC	SRI	LC	Length	& Angle	Buck Length IP	OP	Maximum F (kN)	M(kNm)	V(kN)	Start F(kN)	M(kNm)	End F(kN)	M(kNm)
1-2	TC	36x111 S5	0.340 IP	28	0.16528		1045	22	937	540	-3.526	0.291	0.832	-3.526	-0.140	-2.815	-0.112
2-3	TC	36x111 S5	0.454 IP	29	0.20029		1227	22	1227	540	-2.892	0.161	1.010	-2.892	-0.161	-2.175	0.089
3-4	TC	36x111 S5	0.454 IP	30	0.20030		1227	-22	1227	540	-2.175	0.416	1.010	-2.175	0.089	-2.892	-0.161
4-5	TC	36x111 S5	0.340 IP	31	0.16531		1045	-22	937	540	-2.815	0.112	0.832	-2.815	-0.112	-3.526	-0.140
1-6	BC	36x111 S5	0.251 IP	29	0.03829		965	0	965	2600	3.552	0.140	0.274	3.552	-0.140	3.552	0.084
6-7	BC	36x111 S5	0.196 IP	29	0.04018		1134	0	1134	2600	3.552	0.084	0.085	3.552	0.084	3.552	-0.038
7-8	BC	36x111 S5	0.196 IP	30	0.04018		1134	0	1134	2600	3.552	0.084	0.085	3.552	-0.038	3.552	0.084
8-5	BC	36x111 S5	0.251 IP	30	0.03830		965	0	965	2600	3.552	0.140	0.274	3.552	0.084	3.552	-0.140
6-2	WB	36x73 S5	0.008 IP	28	0.000	1	515	90	464	515	0.158	0.000	0.000	0.158	0.000	0.158	0.000
7-3	WB	36x73 S5	0.064 IP	24	0.000	1	985	90	887	985	0.566	0.000	0.000	0.566	0.000	0.566	0.000
8-4	WB	36x73 S5	0.008 IP	31	0.000	1	515	90	464	515	0.158	0.000	0.000	0.158	0.000	0.158	0.000
2-7	WB	36x73 S5	0.105 OP	28	0.000	1	1246	-24	1121	1246	-1.655	0.000	0.000	-1.655	0.000	-1.655	0.000

Truss: G1

Design Results (Member):

Member	Type	Material	CAMRI	LC	SRI	LC	Length	& Angle	Buck Length IP	OP	Maximum F (kN)	M(kNm)	V(kN)	Start F(kN)	M(kNm)	End F(kN)	M(kNm)
7-4	WB	36x73 S5	0.105	OP 31	0.000	1	1246	24	1121	1246	-1.655	0.000	0.000	-1.655	0.000	-1.655	0.000

Loadcase 2 SA: 1.2Dead Load + 1.6Live Load

(1/Ym1)	(1/Ym2)	(1/Ym3)	(1/Ym4)	(1/Ym5)	d1	d2
1.13	1.00	1.02	1.00	1.00	1.30	1.00

Members	Shear (kN)	SRI	Maximum Axial Force (kN)	Maximum Moment (kNm)	Axial Force (kN)	Axial Stress (MPa)	Axial Perm. (MPa)	Moment (kNm)	Bending Stress (MPa)	Bending Perm. (MPa)	CAMRI	T/C +/-
T1 10-9	0.325	0.042	-0.073	-0.051	-0.036	-0.018	-23.314	-0.051	0.691	8.907	0.414	C
T1 9-2	0.267	0.075	-2.714	-0.051	-2.714	-0.679	-11.398	-0.051	0.691	8.907	0.137	C
T1 2-3	0.335	0.101	-1.996	0.074	-1.857	-0.499	-12.249	0.074	0.996	8.907	0.153	C
T2 3-4	0.335	0.101	-1.996	0.074	-1.857	-0.437	-10.714	0.074	0.996	8.907	0.153	C
T2 4-13	0.267	0.075	-2.714	-0.051	-2.714	-0.626	-10.503	-0.051	0.691	8.907	0.137	C
T2 13-14	0.325	0.042	-0.073	-0.051	-0.036	-0.009	-11.398	-0.051	0.691	8.907	0.414	C
B3 12-1	0.004	0.000	0.000	0.000	0.000	0.000	11.398	0.000	0.001	8.907	0.000	T
B3 1-11	0.298	0.000	2.405	-0.038	2.405	0.602	5.189	-0.038	0.518	8.907	0.174	T
B3 11-6	0.119	0.021	2.405	-0.038	2.405	0.602	5.189	-0.038	0.518	8.907	0.174	T
B3 6-7	0.106	0.032	2.405	0.033	2.405	0.602	5.189	0.033	0.449	8.907	0.166	T
B3 7-8	0.106	0.032	2.405	0.033	2.405	0.602	5.189	0.033	0.449	8.907	0.166	T
B3 8-15	0.119	0.044	2.405	-0.038	2.405	0.602	5.189	-0.038	0.518	8.907	0.489	T
B3 15-5	0.298	0.000	2.405	-0.038	2.405	0.602	5.189	-0.038	0.518	8.907	0.174	T
B3 5-16	0.004	0.000	0.000	0.000	0.000	0.000	11.398	0.000	0.001	8.907	0.000	T
W4 6-2	0.000	0.000	-0.031	0.000	-0.031	-0.012	-11.398	0.000	0.000	8.907	0.001	C
W6 7-3	0.000	0.000	0.839	0.000	0.839	0.319	5.189	0.000	0.000	8.907	0.061	T
W8 8-4	0.000	0.000	-0.031	0.000	-0.031	-0.012	-11.398	0.000	0.000	8.907	0.001	C
W5 2-7	0.000	0.000	-0.757	0.000	-0.757	-0.288	-3.911	0.000	0.000	8.907	0.074	C
W7 7-4	0.000	0.000	-0.757	0.000	-0.757	-0.288	-3.911	0.000	0.000	8.907	0.074	C

Loadcases Considered (LC Number, LC Name):

1 , SA: 1.35Dead Load Only
2 , SA: 1.2Dead Load + 1.6Live Load
3 , SA: 0.9Dead Load + 1.3Wind Along
4 , SA: 1.2Dead Load + 1.3Wind Left(Downward) 1
5 , SA: 0.9Dead Load + 1.3Wind Left(Uplift) 1
6 , SA: 1.2Dead Load + 1.3Wind Right(Downward) 1
7 , SA: 0.9Dead Load + 1.3Wind Right(Uplift) 1
8 , SA: 1.2Dead Load + 1.6Man TC
9 , SA: 1.2Dead Load + 1.6Man BC
12 , Serviceability State (1.1Dead Only)
15 , Serviceability State (1.0Dead + 1.0Man load)
16 , SA: 1.2Dead Load + 1.3Wind Left(Downward) 2
17 , SA: 1.2Dead Load + 1.3Wind Left(Downward) 3
18 , SA: 1.2Dead Load + 1.3Wind Left(Downward) 4
19 , SA: 0.9Dead Load + 1.3Wind Left(Uplift) 2
20 , SA: 0.9Dead Load + 1.3Wind Left(Uplift) 3
21 , SA: 0.9Dead Load + 1.3Wind Left(Uplift) 4
22 , SA: 1.2Dead Load + 1.3Wind Right(Downward) 2
23 , SA: 1.2Dead Load + 1.3Wind Right(Downward) 3
24 , SA: 1.2Dead Load + 1.3Wind Right(Downward) 4
25 , SA: 0.9Dead Load + 1.3Wind Right(Uplift) 2
26 , SA: 0.9Dead Load + 1.3Wind Right(Uplift) 3
27 , SA: 0.9Dead Load + 1.3Wind Right(Uplift) 4
28 , SA: 1.2Dead Load + 1.6Man TC (1)
29 , SA: 1.2Dead Load + 1.6Man TC (2)
30 , SA: 1.2Dead Load + 1.6Man TC (3)
31 , SA: 1.2Dead Load + 1.6Man TC (4)
32 , SA: 1.2Dead Load + 1.6Man TC (5)
33 , Serviceability State (1.0Dead + 1.0Man load) (1)
34 , Serviceability State (1.0Dead + 1.0Man load)
35 , Serviceability State (1.0Dead + 1.0Man load) (3)
36 , Serviceability State (1.0Dead + 1.0Man load)
37 , Serviceability State (1.0Dead + 1.0Man load) (5)

Loading Data: SA: 1.2Dead Load + 1.6Live Load

Chord	Type	Distribution	Direction	Projected	Begin	Val1	End	Val2	Panel
Top	Dead	Uniform	Down	No	0	0.223	2268	0.223	
Top	Dead	Uniform	Down	No	2268	0.223	4536	0.223	
Top	Dead	Uniform	Down	No	0	0.028	2268	0.028	
Top	Dead	Uniform	Down	No	2268	0.028	4536	0.028	
Top	Live	Uniform	Down	Yes	0	0.304	2268	0.304	
Top	Live	Uniform	Down	Yes	2268	0.304	4536	0.304	
Bottom	Dead	Uniform	Down	No	0	0.064	4536	0.064	
Bottom	Dead	Uniform	Down	No	0	0.029	4536	0.029	

Reactions for Loadcase 2:

Joint:	Vertical Reaction:	Horizontal Reaction:
1	**1.517**	
5	**1.517**	

Truss: G2

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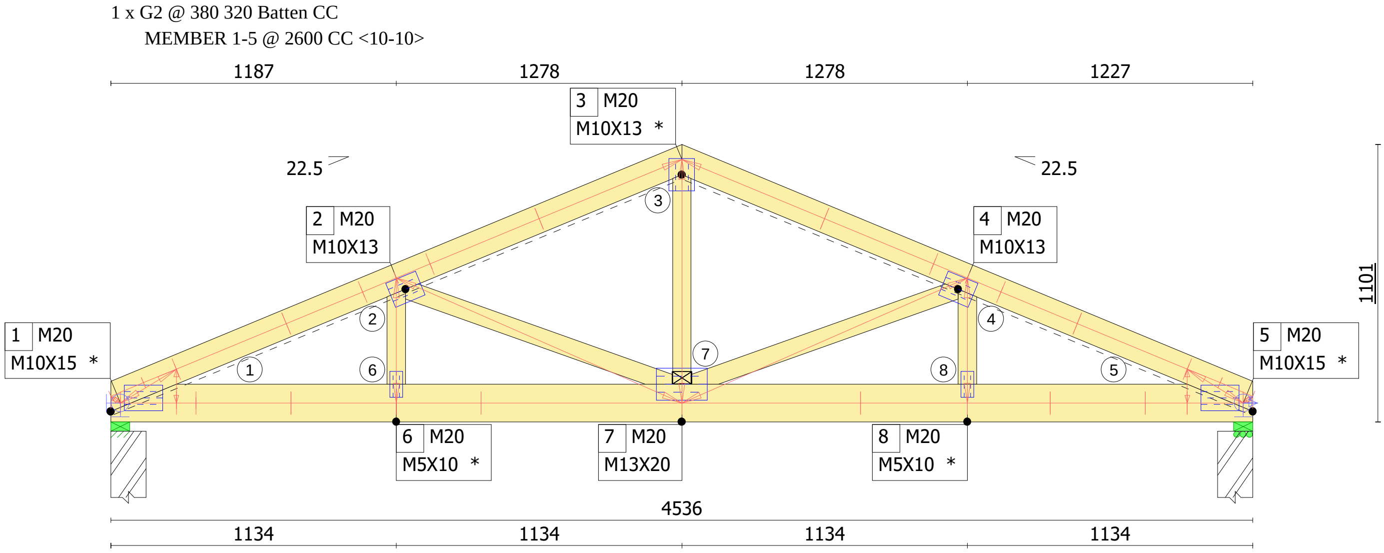
Grade Stresses SANS10163: 2011 "The Structural use of Timber - Limit-states design"
General Loading SANS 10160: 2009 "The General Procedures and Loadings to be adopted in the Design of Buildings"
Plate values used are given in the CSIR contract reports C/WOOD 49 for M20 plates and FOR-C 60 for Gryptite plates.



Scale 1:30

Truss Input Parameters:

Ref: G2
Quantity: 1
Ply: 1
Span: 4536
Truss C/C: 380
TC Restraints: (Default: 320)

BC Restraints: 2600 (B1),

General Loading:

Top Chord Dead	0.490 kN/m²
Live Load	0.500 kN/m²
Bottom Chord Dead	0.140 kN/m²
TC Man Load	1.000 kN
BC Man Load	0.000 kN
Floor Imposed	0.000 kNm²
Floor Dead	0.000 kNm²
Basic Wind Speed	28 m/s
Peak Wind Pressure	0.545 kN/m²

General Design Info:

Top Chord CAMRI	0.572
Bottom Chord CAMRI	0.763
Web CAMRI	0.655
BC Deflection	4.620 mm
Max Allowed BC Def	17.840
Truss Weight	26.786 Kg

CAMRI = Combined Axial and Moment Resistance Index SRI = Shear Resistance Index

Maximum Factored Reactions (kN) and Minimum Bearings (mm)

Joint	Max Reaction (LC)	Max Uplift (LC)	Max H Reaction (LC)	Bearings Required / Designed	Bearing type
1	8.149 (2)		0.233 (26)	34 / 76	Pinned
5	7.944 (2)			33 / 76	H-Roller

Design Results (Member):

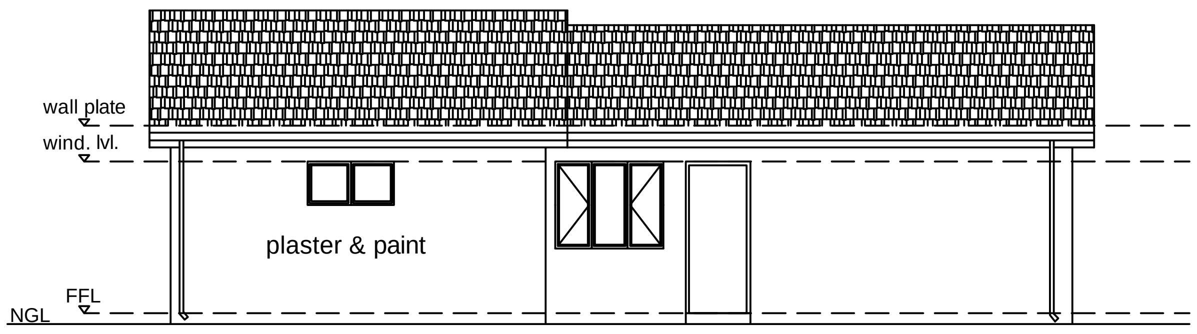
Member	Type	Material	CAMRI	LC	SRI	LC	Length	& Angle	Buck Length IP	OP	Maximum F (kN)	M(kNm)	V(kN)	Start F(kN)	M(kNm)	End F(kN)	M(kNm)
1-2	TC	36x111 S5	0.512 IP	2	0.16328		946	22	946	540	-16.008	0.084	0.934	-16.008	0.028	-15.853	0.070
2-3	TC	36x111 S5	0.570 IP	29	0.19329		1227	22	1099	540	-9.845	0.124	0.980	-9.845	-0.124	-9.129	0.093
3-4	TC	36x111 S5	0.572 IP	30	0.19230		1227	-22	1105	540	-9.127	0.437	0.975	-9.127	0.093	-9.843	-0.118
4-5	TC	36x111 S5	0.508 IP	2	0.16731		946	-22	946	540	-15.873	0.079	0.957	-15.873	0.075	-16.047	-0.019
1-6	BC	36x149 S7	0.712 IP	2	0.300	2	874	0	874	2600	14.697	0.192	1.573	14.697	-0.192	14.697	0.152
6-7	BC	36x149 S7	0.737 IP	2	0.288	2	1134	0	1134	2600	14.697	0.556	1.500	14.697	0.223	14.697	-0.385
7-8	BC	36x149 S7	0.763 IP	2	0.269	2	1134	0	1134	2600	14.703	0.595	1.404	14.703	-0.385	14.703	0.195
8-5	BC	36x149 S7	0.698 IP	2	0.261	2	874	0	874	2600	14.703	0.495	1.363	14.703	0.166	14.703	-0.216
6-2	WB	36x73 S5	0.204 IP	2	0.000	1	496	90	447	496	2.618	0.000	0.000	2.618	0.000	2.618	0.000
7-3	WB	36x73 S5	0.655 IP	2	0.000	1	966	90	870	966	8.413	0.000	0.000	8.413	0.000	8.413	0.000
8-4	WB	36x73 S5	0.207 IP	2	0.000	1	496	90	447	496	2.666	0.000	0.000	2.666	0.000	2.666	0.000
2-7	WB	36x73 S5	0.404 OP	2	0.000	1	1238	-24	1114	1238	-3.957	0.000	0.000	-3.957	0.000	-3.957	0.000

PROJECT:

4 - A / CH : 105

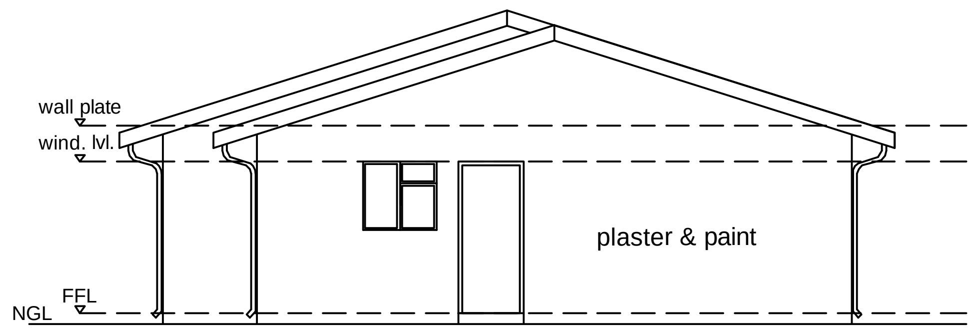
SUBJECT:

SCALE:



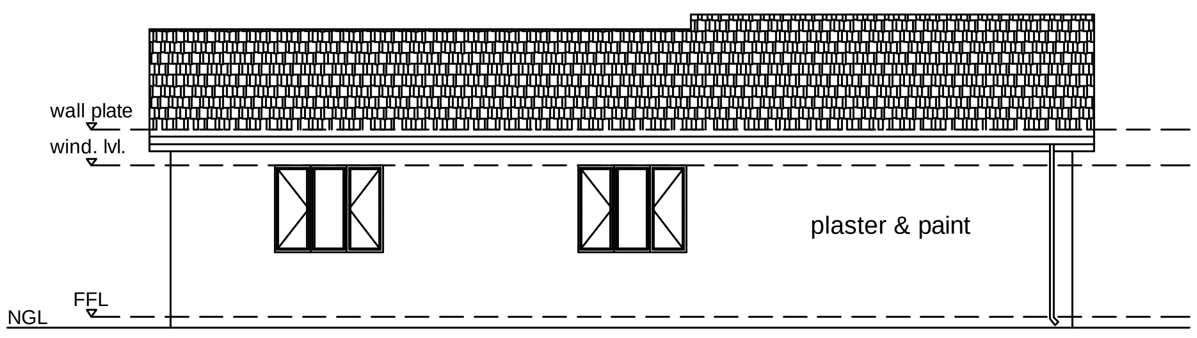
ELEVATION 1

SCALE 1: 100



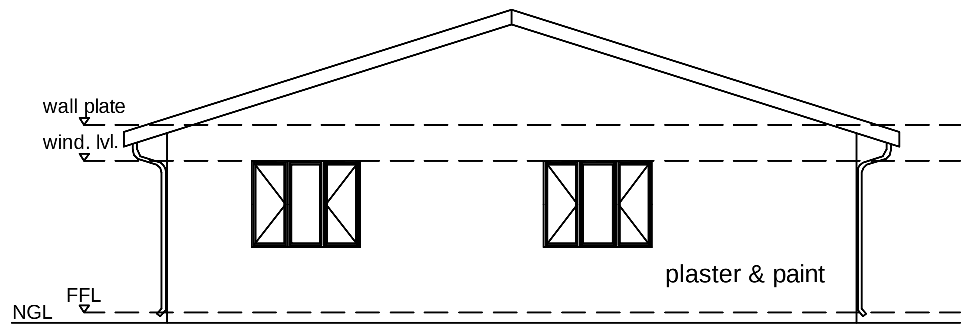
ELEVATION 2

SCALE 1: 100



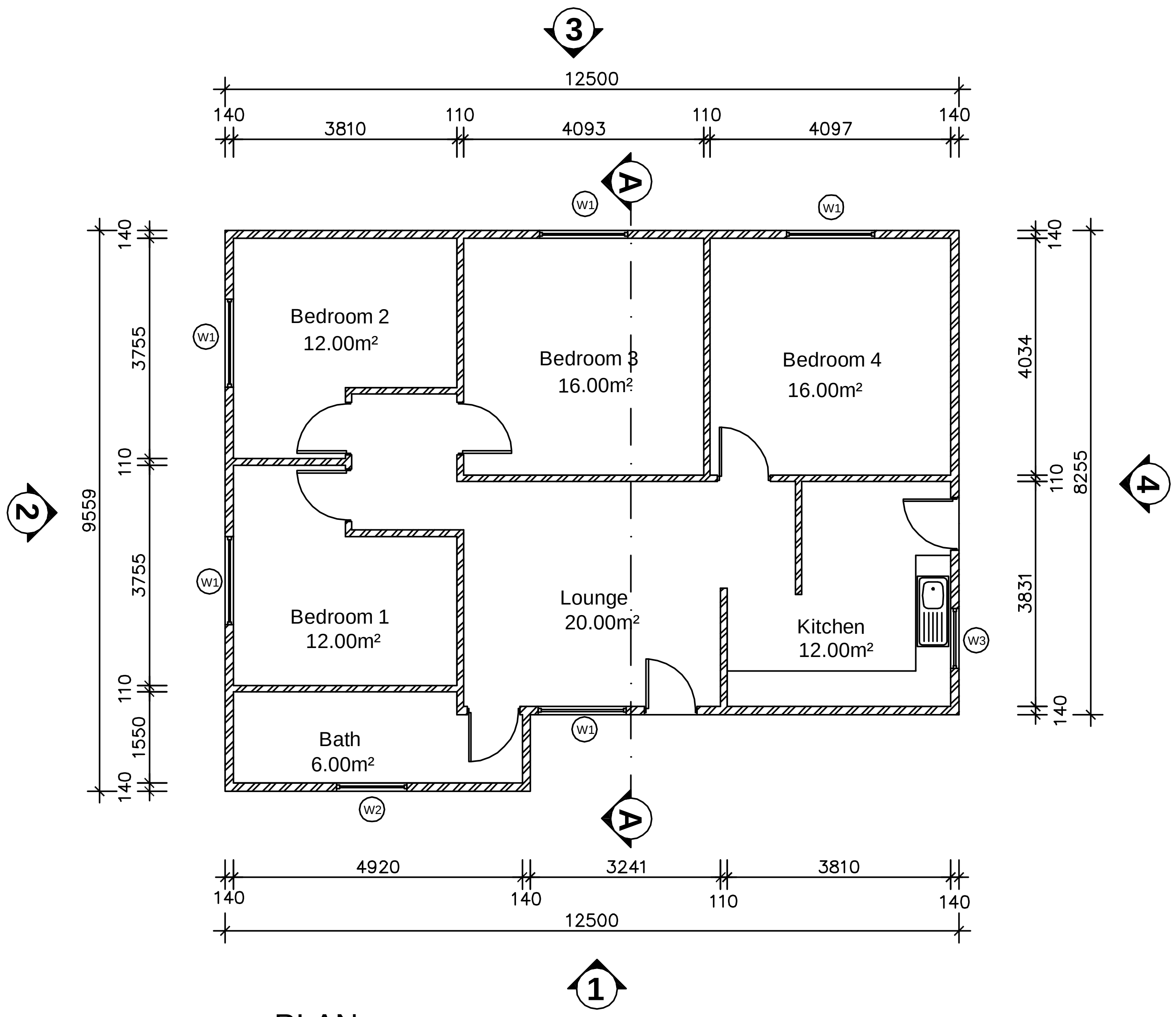
ELEVATION 3

SCALE 1: 100



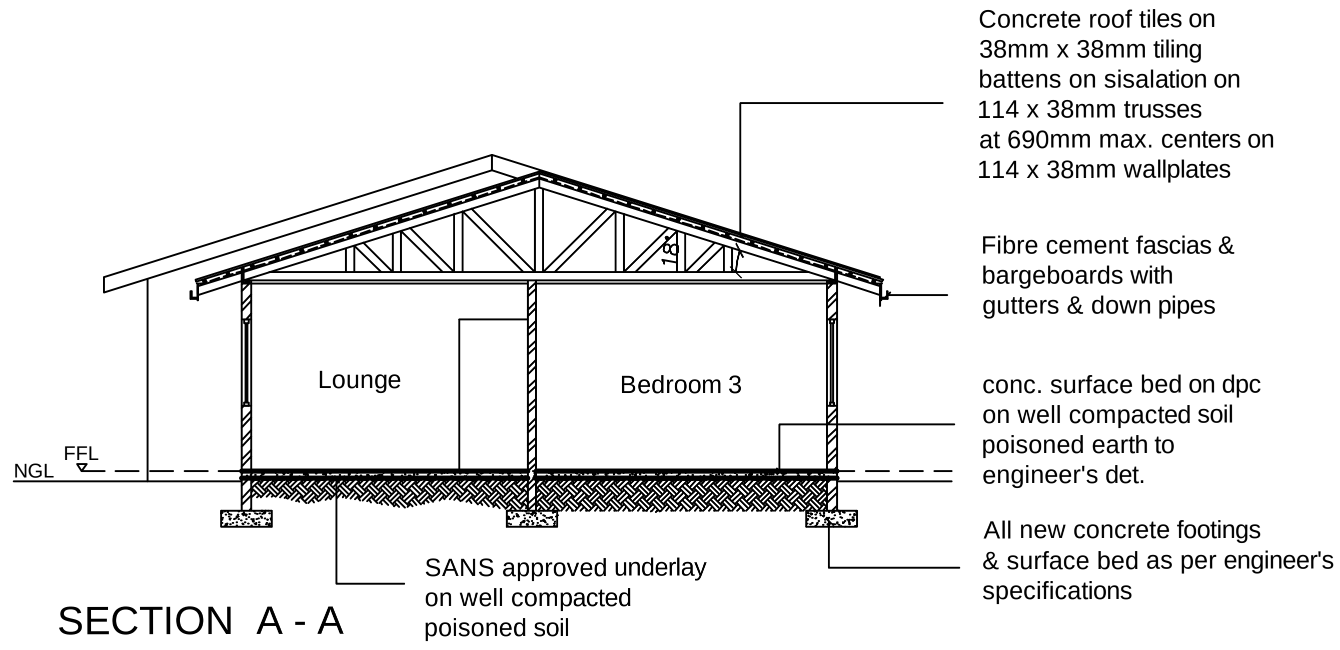
ELEVATION 4

SCALE 1: 100



PLAN

SCALE 1: 100



SECTION A - A

SCALE 1: 100

PROJECT:

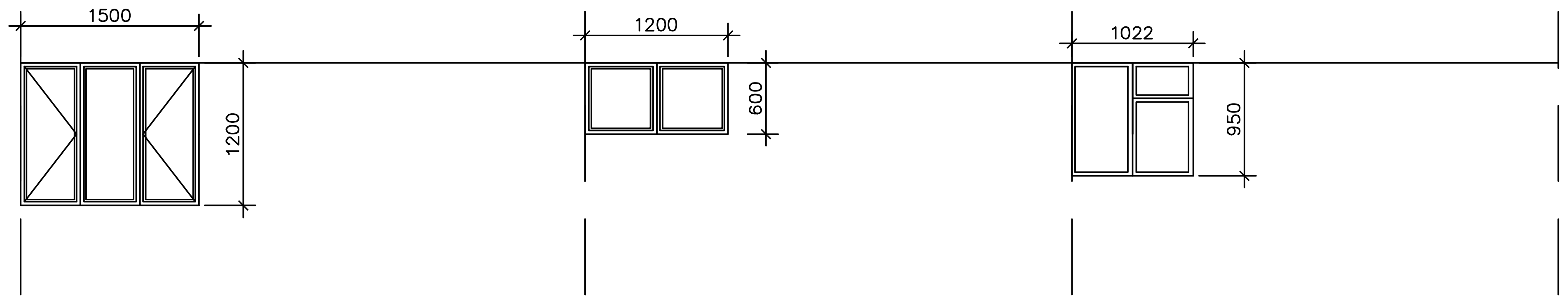
4 - A / CH : 105

SUBJECT:

SCALE:

CASE & CONSTRUCTION PATTERN:

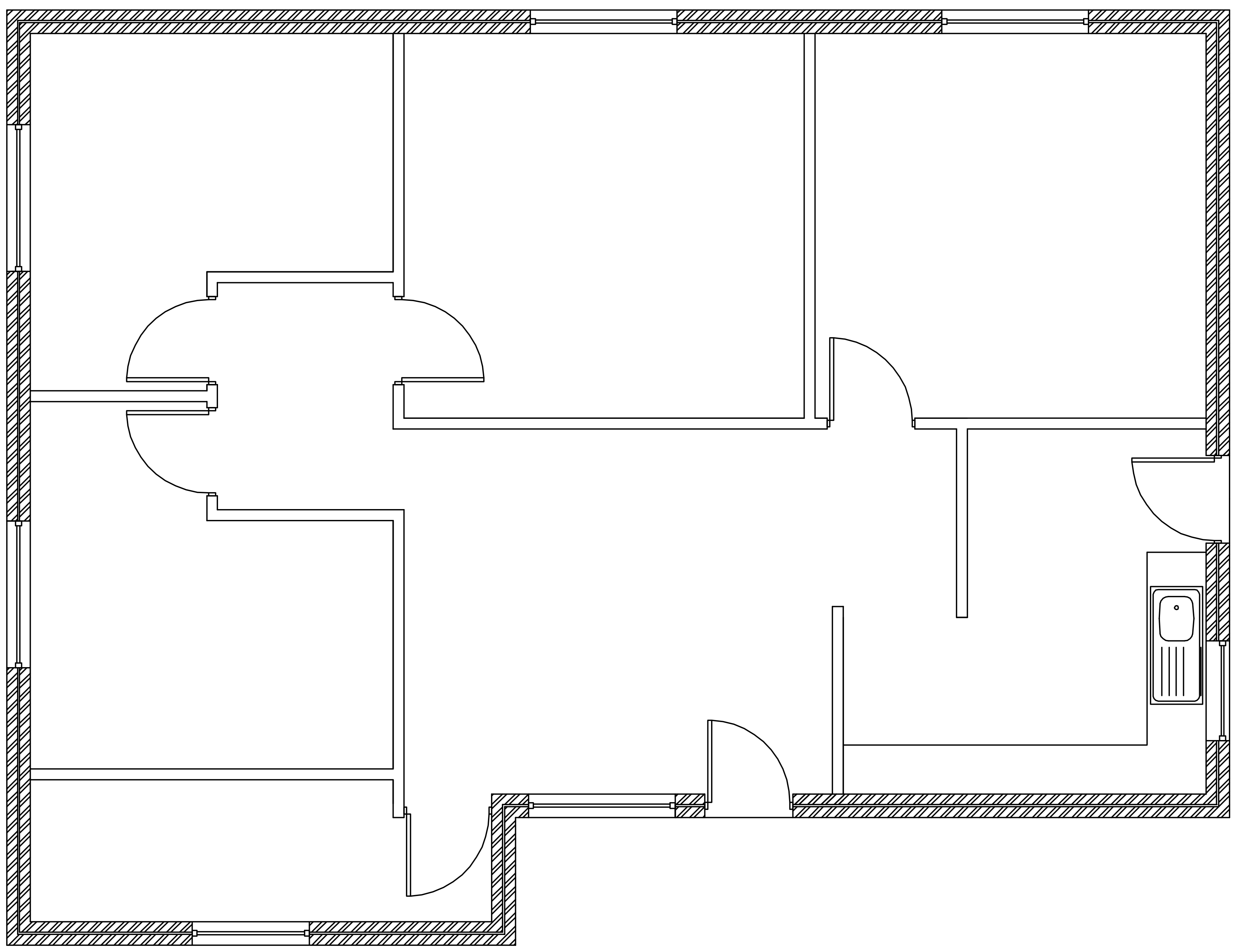
CASE - A	Base Case - No ceiling or Insulation double brick wall without cavity
CASE - B	Cavity wall - 40mm
CASE - C	Cavity wall w/40mm Extruded Polystrene
CASE - D	Gypsum Ceiling w/Blown Cellulose
CASE - E	Double pane windows w/Wood frame
CASE - F	C and D combined

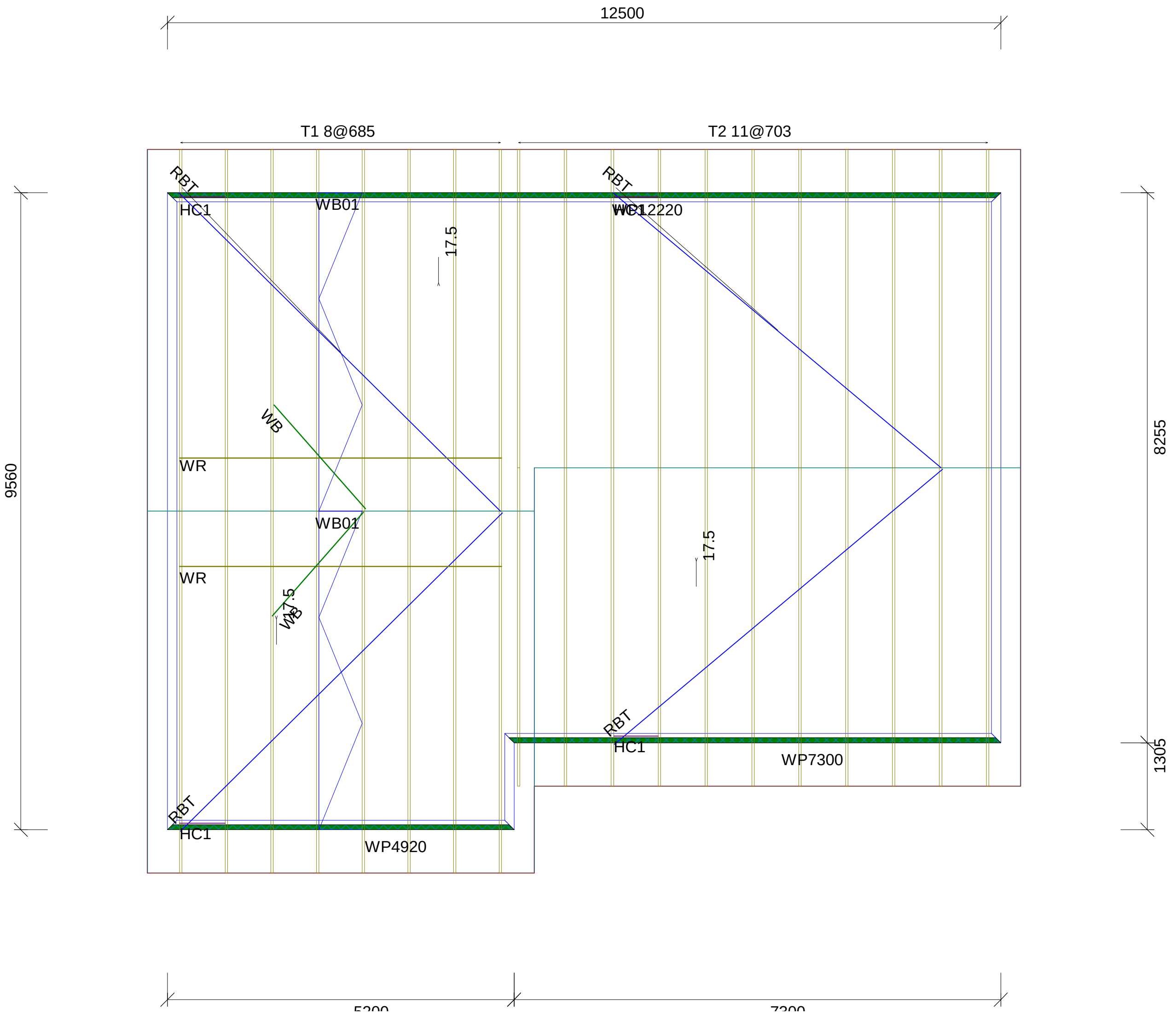


	AREA 1.80m²	AREA 0.72m²	AREA 0.97m²
WINDOW NO.	W1	W3	W4
FRAME	Timber	Timber	Timber
GLAZING	5mm clear	5mm obscure	5mm clear
	monolithic glass	toughened safety glass	monolithic glass
LOCATION		W.C	
NO. REQUIRED	4 off	1 off	1 off

WINDOW SCHEDULE

SCALE 1: 100





Loading:

TCDL:	0.49kN/m²
BCDL:	0.14kN/m²
Truss CC:	760mm
Purl/Batt CC:	320mm
Overhang:	650 mm

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10163 LSD

Roof Area: 139.18 m²
Floor Area: 110.17 m²

Truss: T1

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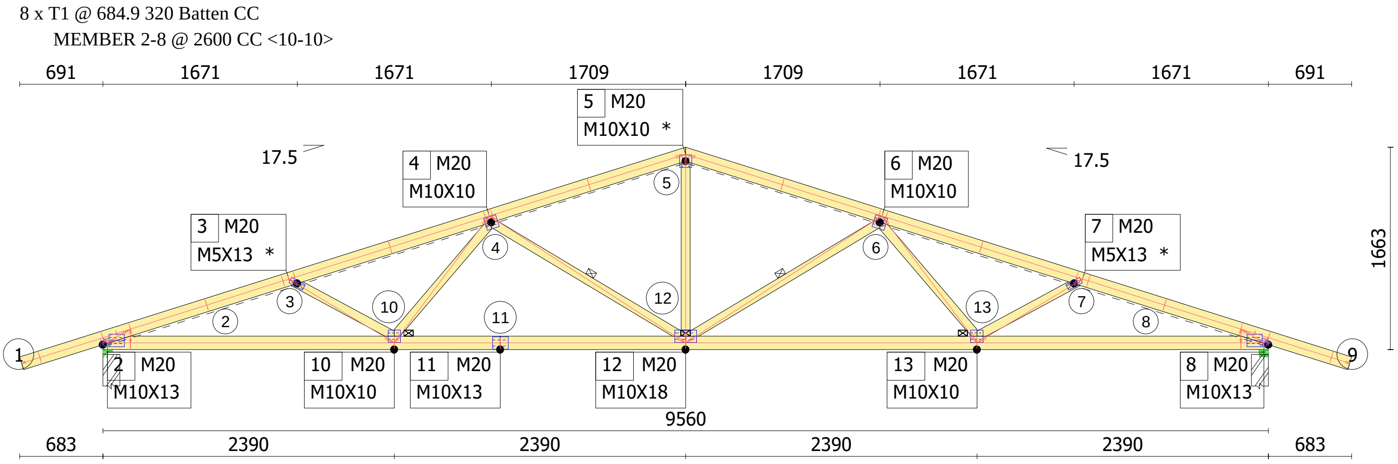
Grade Stresses SANS10163: 2011 "The Structural use of Timber - Limit-states design"
General Loading SANS 10160: 2009 "The General Procedures and Loadings to be adopted in the Design of Buildings"
Plate values used are given in the CSIR contract reports C/WOOD 49 for M20 plates and FOR-C 60 for Gryptite plates.



Scale 1:62

Truss Input Parameters:	**General Loading:**		**General Design Info:**	
Ref: T1	Top Chord Dead	0.490 kN/m²	Top Chord CAMRI	0.923
Quantity: 8	Live Load	0.500 kN/m²	Bottom Chord CAMRI	0.915
Ply: 1	Bottom Chord Dead	0.140 kN/m²	Web CAMRI	0.282
Span: 9560	TC Man Load	1.000 kN	BC Deflection	10.211 mm
Truss C/C: 685	BC Man Load	0.000 kN	Max Allowed BC Def	37.936
TC Restraints: (Default: 320)	Floor Imposed	0.000 kNm²	Truss Weight	51.088 Kg
BC Restraints: 2600 (B1,B2),	Floor Dead	0.000 kNm²		
	Basic Wind Speed	28 m/s		
	Peak Wind Pressure	0.545 kN/m²		

CAMRI = Combined Axial and Moment Resistance Index   SRI = Shear Resistance Index

Maximum Factored Reactions (kN) and Minimum Bearings (mm)

Joint	Max Reaction (LC)	Max Uplift (LC)	Max H Reaction (LC)	Bearings Required / Designed	Bearing type
2	5.650 (2)			33 / 76	Pinned
8	5.650 (2)			33 / 76	H-Roller

Design Results (Member):

Member	Type	Material	CAMRI	LC	SRI	LC	Length & Angle		Buck Length IP	OP	Maximum F (kN)	M(kNm)	V(kN)	Start F(kN)	M(kNm)	End F(kN)	M(kNm)
1-2	TC	36x111 S5	0.636 IP	8	0.201	8	699	18	1398	540	0.009	0.001	1.048	0.009	-0.001	0.331	-0.513
2-3	TC	36x111 S5	0.923 IP	2	0.203	17	1312	18	1312	540	-12.248	0.398	1.201	-12.248	-0.398	-11.938	0.064
3-4	TC	36x111 S5	0.781 IP	18	0.276	2	1639	18	1316	540	-9.493	0.581	0.863	-9.493	0.076	-8.822	-0.288
4-5	TC	36x111 S5	0.764 IP	19	0.285	19	1664	18	1386	540	-7.011	0.601	1.312	-7.011	-0.349	-6.337	0.141
5-6	TC	36x111 S5	0.764 IP	20	0.285	20	1664	-18	1386	540	-6.337	0.601	1.312	-6.337	0.141	-7.011	-0.349
6-7	TC	36x111 S5	0.781 IP	21	0.276	2	1639	-18	1316	540	-8.822	0.581	0.863	-8.822	-0.288	-9.493	0.076
7-8	TC	36x111 S5	0.923 IP	2	0.203	22	1312	-18	1312	540	-11.938	0.070	1.201	-11.938	0.064	-12.248	-0.398
8-9	TC	36x111 S5	0.636 IP	24	0.201	24	699	-18	1398	540	0.331	0.513	1.048	0.331	-0.513	0.009	-0.001
2-10	BC	36x111 S5	0.915 IP	2	0.055	2	2164	0	2164	2600	11.416	0.207	0.277	11.416	-0.207	11.416	0.069
10-12	BC	36x111 S5	0.694 IP	2	0.083	1	2390	0	2390	2600	10.012	0.096	0.229	10.012	0.084	10.012	-0.114
12-13	BC	36x111 S5	0.694 IP	2	0.083	1	2390	0	2390	2600	10.012	0.114	0.229	10.012	-0.114	10.012	0.084
13-8	BC	36x111 S5	0.915 IP	2	0.055	2	2164	0	2164	2600	11.416	0.207	0.277	11.416	0.069	11.416	-0.207

Truss: T1

Design Results (Member):

Member	Type	Material	CAMRI	LC	SRI	LC	Length	& Angle	Buck Length IP	Buck Length OP	Maximum F (kN)	Maximum M(kNm)	Maximum V(kN)	Start F(kN)	Start M(kNm)	End F(kN)	End M(kNm)
3-10	WB	36x73 S5	0.082	OP 17	0.000	1	1011	-31	910	1011	-1.672	0.000	0.000	-1.672	0.000	-1.672	0.000
10-4	WB	36x73 S5	0.076	IP 17	0.000	1	1302	53	1171	1302	1.453	0.000	0.000	1.453	0.000	1.453	0.000
4-12	WB	36x73 S5	0.192	OP 2	0.000	1	1918	-33	1726	959	-2.902	0.000	0.000	-2.902	0.000	-2.902	0.000
12-5	WB	36x73 S5	0.282	IP 2	0.000	1	1550	90	1395	1550	3.637	0.000	0.000	3.637	0.000	3.637	0.000
12-6	WB	36x73 S5	0.192	OP 2	0.000	1	1918	33	1726	959	-2.902	0.000	0.000	-2.902	0.000	-2.902	0.000
6-13	WB	36x73 S5	0.076	IP 22	0.000	1	1302	-53	1171	1302	1.453	0.000	0.000	1.453	0.000	1.453	0.000
13-7	WB	36x73 S5	0.082	OP 22	0.000	1	1011	31	910	1011	-1.672	0.000	0.000	-1.672	0.000	-1.672	0.000

Loadcase 2 SA: 1.2Dead Load + 1.6Live Load

(1/Ym1)	(1/Ym2)	(1/Ym3)	(1/Ym4)	(1/Ym5)	d1	d2
1.13	1.00	.97	1.00	1.00	1.30	1.00

Members	Shear (kN)	SRI	Maximum Axial Force (kN)	Maximum Moment (kNm)	Axial Force (kN)	Axial Stress (MPa)	Axial Perm. (MPa)	Moment (kNm)	Bending Stress (MPa)	Bending Perm. (MPa)	CAMRI	T/C +/-
T1 1-15	0.582	0.115	0.184	-0.203	0.184	0.000	4.907	-0.203	2.752	8.422	0.336	T
T1 15-14	0.919	0.263	0.182	-0.398	0.182	0.030	3.235	-0.398	5.380	8.422	0.648	T
T1 14-19	0.882	0.175	-12.248	-0.398	-12.248	-3.065	-10.777	-0.398	5.380	8.422	0.923	C
T1 19-3	0.252	0.000	-11.904	0.043	-11.904	-2.979	-10.777	0.043	0.586	8.422	0.346	C
T1 3-18	0.544	0.000	-11.190	0.058	-11.177	-2.800	-10.791	0.059	0.801	8.422	0.355	C
T1 18-20	0.863	0.276	-11.177	-0.238	-10.747	-2.797	-11.209	-0.238	3.214	8.422	0.631	C
T1 20-4	0.892	0.000	-10.747	-0.268	-10.739	-2.689	-10.785	-0.267	3.615	8.422	0.679	C
T1 4-21	0.861	0.000	-8.216	-0.268	-8.216	-2.056	-10.777	-0.268	3.622	8.422	0.621	C
T1 21-5	0.841	0.269	-8.209	-0.247	-8.209	-2.054	-10.777	-0.247	3.341	8.422	0.587	C
T2 5-22	0.841	0.269	-8.209	-0.247	-8.209	-1.945	-10.204	-0.247	3.341	8.422	0.587	C
T2 22-6	0.861	0.000	-8.216	-0.268	-8.209	-2.054	-10.777	-0.268	3.619	8.422	0.620	C
T2 6-23	0.892	0.000	-10.747	-0.268	-10.738	-2.687	-10.777	-0.268	3.622	8.422	0.679	C
T2 23-24	0.863	0.276	-11.177	-0.238	-10.747	-2.689	-10.777	-0.238	3.214	8.422	0.631	C
T2 24-7	0.544	0.000	-11.190	0.058	-11.177	-2.797	-10.777	0.058	0.787	8.422	0.353	C
T2 7-25	0.252	0.000	-11.904	0.043	-11.904	-2.976	-10.765	0.043	0.586	8.422	0.346	C
T2 25-26	0.882	0.175	-12.248	-0.398	-12.248	-2.979	-10.474	-0.398	5.380	8.422	0.923	C
T2 26-27	0.919	0.263	0.182	-0.398	0.182	0.046	4.907	-0.398	5.380	8.422	0.648	T
T2 27-9	0.582	0.115	0.184	-0.203	0.184	0.046	4.907	-0.203	2.752	8.422	0.336	T
B3 17-2	0.005	0.000	0.000	0.000	0.000	0.000	10.777	-0.000	0.001	8.422	0.000	T
B3 2-16	1.117	0.000	11.416	-0.207	11.416	2.857	4.907	-0.207	2.805	8.422	0.915	T
B3 16-10	0.277	0.055	11.416	-0.207	11.416	2.857	4.907	-0.207	2.805	8.422	0.915	T
B3 10-11	0.090	0.029	10.012	0.096	10.012	2.506	4.907	0.096	1.299	8.422	0.665	T
B3 11-12	0.242	0.077	10.012	-0.114	10.012	2.506	4.907	-0.114	1.546	8.422	0.694	T
B3 12-13	0.242	0.077	10.012	-0.114	10.012	2.506	4.907	-0.114	1.546	8.422	0.694	T
B3 13-28	0.277	0.055	11.416	-0.207	11.416	2.857	4.907	-0.207	2.805	8.422	0.915	T
B3 28-8	1.117	0.000	11.416	-0.207	11.416	2.857	4.907	-0.207	2.805	8.422	0.915	T
B3 8-29	0.005	0.000	0.000	-0.000	0.000	0.000	10.777	-0.000	0.001	8.422	0.000	T
W4 3-10	0.000	0.000	-1.061	0.000	-1.061	-0.404	-5.290	0.000	0.000	8.422	0.076	C
W5 10-4	0.000	0.000	0.828	0.000	0.828	0.315	4.907	0.000	0.000	8.422	0.064	T
W6 4-12	0.000	0.000	-2.902	0.000	-2.902	-1.104	-5.749	0.000	0.000	8.422	0.192	C
W7 12-5	0.000	0.000	3.637	0.000	3.637	1.384	4.907	0.000	0.000	8.422	0.282	T
W8 12-6	0.000	0.000	-2.902	0.000	-2.902	-1.104	-5.749	0.000	0.000	8.422	0.192	C
W9 6-13	0.000	0.000	0.828	0.000	0.828	0.315	4.907	0.000	0.000	8.422	0.064	T
W10 13-7	0.000	0.000	-1.061	0.000	-1.061	-0.404	-5.290	0.000	0.000	8.422	0.076	C

Loadcases Considered (LC Number, LC Name):

1 , SA: 1.35Dead Load Only
2 , SA: 1.2Dead Load + 1.6Live Load
8 , SA: 1.2Dead Load + 1.6Man TC
9 , SA: 1.2Dead Load + 1.6Man BC
12 , Serviceability State (1.1Dead Only)
15 , Serviceability State (1.0Dead + 1.0Man load)
16 , SA: 1.2Dead Load + 1.6Man TC (1)
17 , SA: 1.2Dead Load + 1.6Man TC (2)
18 , SA: 1.2Dead Load + 1.6Man TC (3)
19 , SA: 1.2Dead Load + 1.6Man TC (4)
20 , SA: 1.2Dead Load + 1.6Man TC (5)
21 , SA: 1.2Dead Load + 1.6Man TC (6)
22 , SA: 1.2Dead Load + 1.6Man TC (7)
23 , SA: 1.2Dead Load + 1.6Man TC (8)
24 , SA: 1.2Dead Load + 1.6Man TC (9)
25 , Serviceability State (1.0Dead + 1.0Man load)
26 , Serviceability State (1.0Dead + 1.0Man load) (2)
27 , Serviceability State (1.0Dead + 1.0Man load)
28 , Serviceability State (1.0Dead + 1.0Man load) (4)
29 , Serviceability State (1.0Dead + 1.0Man load)
30 , Serviceability State (1.0Dead + 1.0Man load) (6)
31 , Serviceability State (1.0Dead + 1.0Man load)
32 , Serviceability State (1.0Dead + 1.0Man load) (8)
33 , Serviceability State (1.0Dead + 1.0Man load)

Loading Data: **SA: 1.2Dead Load + 1.6Live Load**

Chord	Type	Distribution	Direction	Projected	Begin	Val1	End	Val2	Panel
Top	Dead	Uniform	Down	No	-667	0.025	10227	0.025	Filter
Top	Dead	Uniform	Down	No	-667	0.403	4780	0.403	
Top	Dead	Uniform	Down	No	4780	0.403	10227	0.403	
Top	Live	Uniform	Down	Yes	-667	0.467	4780	0.467	

Truss: T1

Loading Data: **SA: 1.2Dead Load + 1.6Live Load**

Chord	Type	Distribution	Direction	Projected	Begin	Val1	End	Val2	Panel
Top	Live	Uniform	Down	Yes	-667	0.467	4780	0.467	
Top	Live	Uniform	Down	Yes	4780	0.467	10227	0.467	
Bottom	Dead	Uniform	Down	No	0	0.024	9560	0.024	Filter
Bottom	Dead	Uniform	Down	No	0	0.115	9560	0.115	

Reactions for Loadcase 2:

Joint:	Vertical Reaction:	Horizontal Reaction:
2	**5.650**	
8	**5.650**	

Truss: T2

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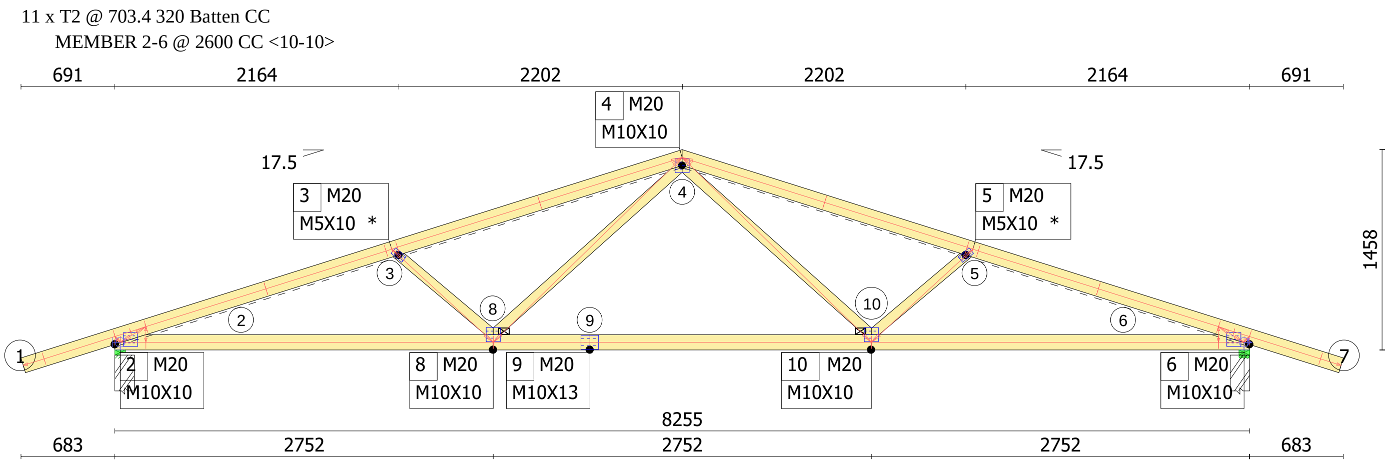
Grade Stresses SANS10163: 2011 "The Structural use of Timber - Limit-states design"
General Loading SANS 10160: 2009 "The General Procedures and Loadings to be adopted in the Design of Buildings"
Plate values used are given in the CSIR contract reports C/WOOD 49 for M20 plates and FOR-C 60 for Gryptite plates.



Scale 1:55

Truss Input Parameters:	General Loading:		General Design Info:	
Ref: T2	Top Chord Dead	0.490 kN/m²	Top Chord CAMRI	0.821
Quantity: 11	Live Load	0.500 kN/m²	Bottom Chord CAMRI	0.759
Ply: 1	Bottom Chord Dead	0.140 kN/m²	Web CAMRI	0.189
Span: 8255	TC Man Load	1.000 kN	BC Deflection	8.738 mm
Truss C/C: 703	BC Man Load	0.000 kN	Max Allowed BC Def	32.716
TC Restraints: (Default: 320)	Floor Imposed	0.000 kNm²	Truss Weight	43.306 Kg
BC Restraints: 2600 (B1,B2),	Floor Dead	0.000 kNm²		
	Basic Wind Speed	28 m/s		
	Peak Wind Pressure	0.545 kN/m²		

CAMRI = Combined Axial and Moment Resistance Index   SRI = Shear Resistance Index

Maximum Factored Reactions (kN) and Minimum Bearings (mm)

Joint	Max Reaction (LC)	Max Uplift (LC)	Max H Reaction (LC)	Bearings Required / Designed	Bearing type
2	5.167 (2)			31 / 76	Pinned
6	5.167 (2)			31 / 76	H-Roller

Design Results (Member):

Member	Type	Material	CAMRI	LC	SRI	LC	Length & Angle		Buck Length IP	OP	Maximum F (kN)	M(kNm)	V(kN)	Start F(kN)	M(kNm)	End F(kN)	M(kNm)
1-2	TC	36x111 S7	0.473 IP	8	0.164	8	699	18	1398	563	0.009	0.001	1.056	0.009	-0.001	0.333	-0.516
2-3	TC	36x111 S7	0.617 IP	2	0.198	17	1831	18	872	563	-10.714	0.373	1.130	-10.714	-0.373	-10.211	-0.251
3-4	TC	36x111 S7	0.821 IP	18	0.261	2	2173	18	1904	563	-7.947	0.898	1.055	-7.947	-0.357	-7.207	0.217
4-5	TC	36x111 S7	0.821 IP	19	0.261	2	2173	-18	1904	563	-7.207	0.898	1.055	-7.207	0.217	-7.947	-0.357
5-6	TC	36x111 S7	0.617 IP	2	0.198	20	1831	-18	872	563	-10.211	0.251	1.130	-10.211	-0.251	-10.714	-0.373
6-7	TC	36x111 S7	0.473 IP	22	0.164	22	699	-18	1398	563	0.333	0.516	1.056	0.333	-0.516	0.009	-0.001
2-8	BC	36x111 S5	0.759 IP	2	0.060	1	2526	0	1311	2600	9.958	0.173	0.220	9.958	-0.173	9.958	-0.025
8-10	BC	36x111 S5	0.491 IP	2	0.075	1	2752	0	2484	2600	6.570	0.076	0.213	6.570	-0.025	6.570	-0.025
10-6	BC	36x111 S5	0.759 IP	2	0.060	1	2526	0	1311	2600	9.958	0.173	0.220	9.958	-0.025	9.958	-0.173
3-8	WB	36x73 S5	0.147 OP	2	0.000	1	1002	-43	902	1002	-2.148	0.000	0.000	-2.148	0.000	-2.148	0.000
8-4	WB	36x73 S5	0.189 IP	2	0.000	1	1923	44	1731	1923	2.523	0.000	0.000	2.523	0.000	2.523	0.000
4-10	WB	36x73 S5	0.189 IP	2	0.000	1	1923	-44	1731	1923	2.523	0.000	0.000	2.523	0.000	2.523	0.000

Truss: T2

Design Results (Member):

Member	Type	Material	CAMRI	LC	SRI	LC	Length & Angle		Buck Length IP	Buck Length OP	Maximum F (kN)	Maximum M(kNm)	Maximum V(kN)	Start F(kN)	Start M(kNm)	End F(kN)	End M(kNm)
10-5	WB	36x73 S5	0.147	OP 2	0.000	1	1002	43	902	1002	-2.148	0.000	0.000	-2.148	0.000	-2.148	0.000

Loadcase 2 SA: 1.2Dead Load + 1.6Live Load

(1/Ym1)	(1/Ym2)	(1/Ym3)	(1/Ym4)	(1/Ym5)	d1	d2
1.13	1.00	1.00	1.00	1.00	1.29	1.00

Members	Shear (kN)	SRI	Maximum Axial Force (kN)	Maximum Moment (kNm)	Axial Force (kN)	Axial Stress (MPa)	Axial Perm. (MPa)	Moment (kNm)	Bending Stress (MPa)	Bending Perm. (MPa)	CAMRI	T/C +/-
T1 1-12	0.609	0.093	0.192	-0.213	0.192	0.000	7.592	-0.213	2.878	11.996	0.246	T
T1 12-11	0.781	0.168	0.272	-0.373	0.272	0.052	5.779	-0.373	5.049	11.996	0.430	T
T1 11-16	0.864	0.181	-10.714	-0.373	-10.714	-2.681	-13.649	-0.373	5.049	11.996	0.617	C
T1 16-3	0.768	0.000	-10.211	-0.284	-10.199	-2.555	-14.043	-0.283	3.825	11.996	0.501	C
T1 3-15	1.093	0.000	-9.126	-0.284	-9.126	-2.284	-14.027	-0.284	3.836	11.996	0.483	C
T1 15-4	1.055	0.261	-9.114	0.402	-8.782	-2.281	-14.166	0.402	5.443	11.996	0.615	C
T2 4-17	1.055	0.261	-9.114	0.402	-8.782	-2.132	-13.239	0.402	5.443	11.996	0.615	C
T2 17-5	1.093	0.000	-9.126	-0.284	-9.126	-2.281	-14.008	-0.283	3.825	11.996	0.482	C
T2 5-18	0.768	0.000	-10.211	-0.284	-10.199	-2.552	-14.027	-0.284	3.836	11.996	0.502	C
T2 18-19	0.864	0.181	-10.714	-0.373	-10.714	-2.555	-13.008	-0.373	5.049	11.996	0.617	C
T2 19-20	0.781	0.168	0.272	-0.373	0.272	0.068	7.592	-0.373	5.049	11.996	0.430	T
T2 20-7	0.609	0.093	0.192	-0.213	0.192	0.048	7.592	-0.213	2.878	11.996	0.246	T
B3 14-2	0.005	0.000	0.000	0.000	0.000	0.000	10.882	-0.000	0.001	8.731	0.000	T
B3 2-13	0.936	0.000	9.958	-0.173	9.958	2.492	5.087	-0.173	2.345	8.731	0.759	T
B3 13-8	0.236	0.045	9.958	-0.173	9.958	2.492	5.087	-0.173	2.345	8.731	0.759	T
B3 8-9	0.193	0.060	6.570	0.076	6.570	1.644	5.087	0.076	1.033	8.731	0.442	T
B3 9-10	0.193	0.060	6.570	0.108	6.570	1.644	5.087	0.108	1.461	8.731	0.491	T
B3 10-21	0.236	0.045	9.958	-0.173	9.958	2.492	5.087	-0.173	2.345	8.731	0.759	T
B3 21-6	0.936	0.000	9.958	-0.173	9.958	2.492	5.087	-0.173	2.345	8.731	0.759	T
B3 6-22	0.005	0.000	0.000	-0.000	0.000	0.000	10.882	-0.000	0.001	8.731	0.000	T
W4 3-8	0.000	0.000	-2.148	0.000	-2.148	-0.817	-5.562	0.000	0.000	8.731	0.147	C
W5 8-4	0.000	0.000	2.523	0.000	2.523	0.960	5.087	0.000	0.000	8.731	0.189	T
W6 4-10	0.000	0.000	2.523	0.000	2.523	0.960	5.087	0.000	0.000	8.731	0.189	T
W7 10-5	0.000	0.000	-2.148	0.000	-2.148	-0.817	-5.562	0.000	0.000	8.731	0.147	C

Loadcases Considered (LC Number, LC Name):

1 , SA: 1.35Dead Load Only
2 , SA: 1.2Dead Load + 1.6Live Load
8 , SA: 1.2Dead Load + 1.6Man TC
9 , SA: 1.2Dead Load + 1.6Man BC
12 , Serviceability State (1.1Dead Only)
15 , Serviceability State (1.0Dead + 1.0Man load)
16 , SA: 1.2Dead Load + 1.6Man TC (1)
17 , SA: 1.2Dead Load + 1.6Man TC (2)
18 , SA: 1.2Dead Load + 1.6Man TC (3)
19 , SA: 1.2Dead Load + 1.6Man TC (4)
20 , SA: 1.2Dead Load + 1.6Man TC (5)
21 , SA: 1.2Dead Load + 1.6Man TC (6)
22 , SA: 1.2Dead Load + 1.6Man TC (7)
23 , Serviceability State (1.0Dead + 1.0Man load)
24 , Serviceability State (1.0Dead + 1.0Man load) (2)
25 , Serviceability State (1.0Dead + 1.0Man load)
26 , Serviceability State (1.0Dead + 1.0Man load) (4)
27 , Serviceability State (1.0Dead + 1.0Man load)
28 , Serviceability State (1.0Dead + 1.0Man load) (6)
29 , Serviceability State (1.0Dead + 1.0Man load)

Loading Data: **SA: 1.2Dead Load + 1.6Live Load**

Chord	Type	Distribution	Direction	Projected	Begin	Val1	End	Val2	Panel
Top	Dead	Uniform	Down	No	-667	0.025	8922	0.025	Filter
Top	Dead	Uniform	Down	No	-667	0.414	4128	0.414	
Top	Dead	Uniform	Down	No	4128	0.414	8922	0.414	
Top	Live	Uniform	Down	Yes	-667	0.497	4128	0.497	
Top	Live	Uniform	Down	Yes	4128	0.497	8922	0.497	
Bottom	Dead	Uniform	Down	No	0	0.022	8255	0.022	Filter
Bottom	Dead	Uniform	Down	No	0	0.118	8255	0.118	

Reactions for Loadcase 2:

Joint:	Vertical Reaction:	Horizontal Reaction:
2	**5.167**	
6	**5.167**	

Truss: WB01

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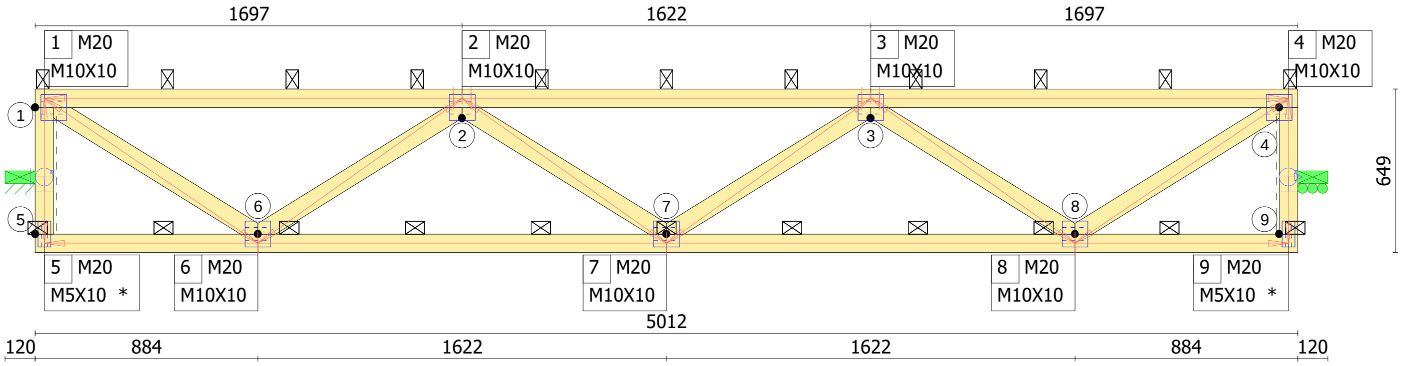
Grade Stresses SANS10163: 2011 "The Structural use of Timber - Limit-states design"
General Loading SANS 10160: 2009 "The General Procedures and Loadings to be adopted in the Design of Buildings"
Plate values used are given in the CSIR contract reports C/WOOD 49 for M20 plates and FOR-C 60 for Gryptite plates.

2 x WB01 @ 10 540 Batten CC
MEMBER 5-9 @ 540 CC <10-10>



Scale 1:30

Truss Input Parameters:	General Loading:		General Design Info:	
Ref: WB01	Top Chord Dead	0.140 kN/m²	Top Chord CAMRI	0.002
Quantity: 2	Live Load	0.500 kN/m²	Bottom Chord CAMRI	0.002
Ply: 1	Bottom Chord Dead	0.140 kN/m²	Web CAMRI	0.001
Span: 5012	TC Man Load	0.000 kN	BC Deflection	0.018 mm
Truss C/C: 10	BC Man Load	0.000 kN	Max Allowed BC Def	939.000
TC Restraints:	Floor Imposed	0.000 kNm²	Truss Weight	20.696 Kg
BC Restraints: 540 (B1),	Floor Dead	0.000 kNm²		
	Basic Wind Speed	40 m/s		
	Peak Wind Pressure	1.300 kN/m²		

CAMRI = Combined Axial and Moment Resistance Index   SRI = Shear Resistance Index

Maximum Factored Reactions (kN) and Minimum Bearings (mm)

Joint	Max Reaction (LC)	Max Uplift (LC)	Max H Reaction (LC)	Bearings Required / Designed	Bearing type
10	0.007 (2)	-0.005 (1)			Pinned
11	0.007 (2)	-0.005 (1)			H-Roller

Design Results (Member):

Member	Type	Material	CAMRI	LC	SRI	LC	Length	& Angle	Buck Length IP	OP	Maximum F (kN)	M(kNm)	V(kN)	Start F(kN)	M(kNm)	End F(kN)	M(kNm)
1-2	TC	36x73 S5	0.002 IP	2	0.001	2	1624	0	1358	540	-0.008	0.000	0.001	-0.008	0.000	-0.008	-0.000
2-3	TC	36x73 S5	0.002 IP	2	0.001	2	1553	0	799	540	-0.015	0.000	0.001	-0.015	-0.000	-0.015	-0.000
3-4	TC	36x73 S5	0.002 IP	2	0.001	2	1624	0	1358	540	-0.008	0.000	0.001	-0.008	-0.000	-0.008	0.000
5-10	TC	36x73 S5	0.000 IP	2	0.000	1	263	90	263	540	0.000	0.000	0.000	0.000	0.000	0.000	0.000
10-1	TC	36x73 S5	0.000 IP	1	0.000	1	313	90	313	540	0.005	0.000	0.000	0.005	0.000	0.005	0.000
9-11	TC	36x73 S5	0.000 IP	2	0.000	1	263	90	263	540	0.000	0.000	0.000	0.000	0.000	0.000	0.000
11-4	TC	36x73 S5	0.000 IP	1	0.000	1	313	90	313	540	0.005	0.000	0.000	0.005	0.000	0.005	0.000
5-6	BC	36x73 S5	0.001 IP	2	0.000	2	848	0	588	540	0.000	0.000	0.001	0.000	0.000	0.000	-0.000
6-7	BC	36x73 S5	0.002 IP	2	0.001	2	1622	0	1067	540	0.013	0.000	0.001	0.013	-0.000	0.013	-0.000
7-8	BC	36x73 S5	0.002 IP	2	0.001	2	1622	0	1067	540	0.013	0.000	0.001	0.013	-0.000	0.013	-0.000
8-9	BC	36x73 S5	0.001 IP	2	0.000	2	848	0	588	540	0.000	0.000	0.001	0.000	-0.000	0.000	0.000
1-6	WB	36x73 S5	0.001 IP	2	0.000	1	1025	-34	922	1025	0.010	0.000	0.000	0.010	0.000	0.010	0.000

Truss: WB01

Design Results (Member):

Member	Type	Material	CAMRI	LC	SRI	LC	Length & Angle		Buck Length IP	OP	Maximum F (kN)	M(kNm)	V(kN)	Start F(kN)	M(kNm)	End F(kN)	M(kNm)
6-2	WB	36x73 S5	0.000	OP 2	0.000	1	995	35	895	995	-0.006	0.000	0.000	-0.006	0.000	-0.006	0.000
2-7	WB	36x73 S5	0.000	IP 2	0.000	1	995	-35	895	995	0.002	0.000	0.000	0.002	0.000	0.002	0.000
7-3	WB	36x73 S5	0.000	IP 2	0.000	1	995	35	895	995	0.002	0.000	0.000	0.002	0.000	0.002	0.000
3-8	WB	36x73 S5	0.000	OP 2	0.000	1	995	-35	895	995	-0.006	0.000	0.000	-0.006	0.000	-0.006	0.000
8-4	WB	36x73 S5	0.001	IP 2	0.000	1	1025	34	922	1025	0.010	0.000	0.000	0.010	0.000	0.010	0.000

Loadcase 2 SA: Brace Frame DOWN

(1/Ym1)	(1/Ym2)	(1/Ym3)	(1/Ym4)	(1/Ym5)	d1	d2
1.00	1.00	1.07	1.00	1.00	1.67	1.00

Members	Shear (kN)	SRI	Maximum Axial Force (kN)	Maximum Moment (kNm)	Axial Force (kN)	Axial Stress (MPa)	Axial Perm. (MPa)	Moment (kNm)	Bending Stress (MPa)	Bending Perm. (MPa)	CAMRI	T/C +/-
T2 1-12	0.001	0.001	-0.008	0.000	-0.008	-0.003	-10.561	0.000	0.010	8.253	0.002	C
T2 12-2	-0.001	0.000	-0.008	-0.000	-0.008	-0.003	-10.561	-0.000	0.011	8.253	0.002	C
T2 2-13	0.001	0.000	-0.015	-0.000	-0.015	-0.006	-10.561	-0.000	0.011	8.253	0.002	C
T2 13-14	0.001	0.001	-0.015	-0.000	-0.015	-0.006	-10.561	-0.000	0.010	8.253	0.002	C
T2 14-3	-0.001	0.000	-0.015	-0.000	-0.015	-0.006	-10.561	-0.000	0.011	8.253	0.002	C
T2 3-15	0.001	0.000	-0.008	-0.000	-0.008	-0.003	-10.561	-0.000	0.011	8.253	0.002	C
T2 15-4	0.001	0.001	-0.008	-0.000	-0.008	-0.003	-10.561	0.000	0.010	8.253	0.002	C
T1 5-10	0.000	0.000	0.000	0.000	0.000	0.000	4.808	0.000	0.000	8.253	0.000	T
T1 10-1	0.000	0.000	-0.007	0.000	-0.007	-0.003	-10.561	0.000	0.000	8.253	0.000	C
T3 9-11	0.000	0.000	0.000	0.000	0.000	0.000	4.808	0.000	0.000	8.253	0.000	T
T3 11-4	0.000	0.000	-0.007	0.000	-0.007	-0.003	-10.561	0.000	0.000	8.253	0.000	C
B4 5-6	0.001	0.000	0.000	0.000	0.000	0.000	10.561	-0.000	0.007	8.253	0.001	T
B4 6-7	0.001	0.001	0.013	-0.000	0.013	0.005	4.808	-0.000	0.010	8.253	0.002	T
B4 7-8	0.001	0.001	0.013	-0.000	0.013	0.005	4.808	-0.000	0.010	8.253	0.002	T
B4 8-9	0.001	0.000	0.000	-0.000	0.000	0.000	10.561	-0.000	0.007	8.253	0.001	T
W5 1-6	0.000	0.000	0.010	0.000	0.010	0.004	4.808	0.000	0.000	8.253	0.001	T
W6 6-2	0.000	0.000	-0.006	0.000	-0.006	-0.002	-5.319	0.000	0.000	8.253	0.000	C
W7 2-7	0.000	0.000	0.002	0.000	0.002	0.001	4.808	0.000	0.000	8.253	0.000	T
W8 7-3	0.000	0.000	0.002	0.000	0.002	0.001	4.808	0.000	0.000	8.253	0.000	T
W9 3-8	0.000	0.000	-0.006	0.000	-0.006	-0.002	-5.319	0.000	0.000	8.253	0.000	C
W10 8-4	0.000	0.000	0.010	0.000	0.010	0.004	4.808	0.000	0.000	8.253	0.001	T

Displacements: LC 2 Max Allowable = Span/250

Member	Type:	Start Displacements: x	y	End Displacements: x	y
T2 1-12	T	0.00	-0.00	0.00	-0.01
T2 12-2	T	0.00	-0.01	0.00	-0.01
T2 2-13	T	0.00	-0.01	0.00	-0.01
T2 13-14	T	0.00	-0.01	0.00	-0.01
T2 14-3	T	0.00	-0.01	0.00	-0.01
T2 3-15	T	0.00	-0.01	0.00	-0.01
T2 15-4	T	0.00	-0.01	0.00	-0.00
T1 5-10	T	0.00	0.00	0.00	0.00
T1 10-1	T	0.00	0.00	0.00	-0.00
T3 9-11	T	0.00	0.00	0.00	0.00
T3 11-4	T	0.00	0.00	0.00	-0.00
B4 5-6	B	0.00	0.00	0.00	0.00
B4 6-7	B	0.00	0.00	0.00	-0.01
B4 7-8	B	0.00	-0.01	0.00	0.00
B4 8-9	B	0.00	0.00	0.00	0.00
W5 1-6	W	0.00	-0.00	0.00	0.00
W6 6-2	W	0.00	0.00	0.00	-0.01
W7 2-7	W	0.00	-0.01	0.00	-0.01
W8 7-3	W	0.00	-0.01	0.00	-0.01
W9 3-8	W	0.00	-0.01	0.00	0.00
W10 8-4	W	0.00	0.00	0.00	-0.00

Loadcases Considered (LC Number, LC Name):

1 , SA: Brace Frame UP

2 , SA: Brace Frame DOWN

Loading Data: **SA: Brace Frame DOWN**

Chord	Type	Distribution	Direction	Projected	Begin	Val1	End	Val2	Panel
Top	Dead	Uniform	Down	No	37	0.001	4976	0.001	
Bottom	Dead	Uniform	Down	No	37	0.001	4976	0.001	

Reactions for Loadcase 2:

Joint:	Vertical Reaction:	Horizontal Reaction:

Truss: WB01

Reactions for Loadcase 2:

Joint:	Vertical Reaction:	Horizontal Reaction:
10	**0.007**	
11	**0.007**	

Item No		Quantity	Rate	Amount
	BILL NO. 1			
	PRELIMINARIES			
	FIXED CHARGE AND VALUE RELATED ITEMS			
1	Contractual requirements		SUM	900.00
	Establistment of Facilities on Site			
	a) Client			
2	Name boards - 1No.		SUM	500.00
	a) Facilities for Contractor			
3	Ablution and latrine facilities		SUM	500.00
4	Office and storage sheds		SUM	1,000.00
5	Tools and equipment		SUM	2500
6	Dealing with water		SUM	1,000.00
7	Access		SUM	250.00
	Name board - 1 No.		SUM	250.00
8	Other fixed charge obligations		SUM	500.00
9			SUM	392.08
	TIME RELATED ITEMS			
10	Contractural requirements		SUM	900.00
	a) **Facilities for Contractors for duration of contraction, except where otherwise stated**			
11	Office and storage sheds		SUM	1,615.84
	Operate and maintain facilities on site			
12	Ablution and latrine facilities		SUM	250.00
	Carried Forward		R	8,057.92
	Bill No. 1 PRELIMINARIES			

	Brought Forward			R	8,057.92
13	Tools and equipment			SUM	250.00
14	Dealing with water			SUM	750.00
15	Company and head office overhead costs			SUM	1,000.00
16	Other time related costs			SUM	500.00
	ENVIRONMENTAL CONTROL				
17	The Contractor is to comply, in all respects, with the requirements of the Environmental Specification for the Contruction Project			SUM	500.00
	Carried to Summary			R	11,057.92
	Bill No. 1 PRELIMINARIES				

Item No			Quantity	Rate	Amount
	BILL NO. 2				
	EARTHWORKS				
	SUPPLEMENTARY PREAMBLES				
	Nature of ground				
	A Geotechnical investigation has been carried out on site by the Engineer and the report is available on request. Descriptions of excavations shall be deemed to include all ground conditions classifiable as "earth" described in the above report and where conditions of a more difficult character are indicated these are separately measured.				
	Carting away of excavated material				
	Descriptions of carting away of excavated material shall be deemed to include loading excavated material onto trucks directly from the excavations or, alternatively, from stock piles situated on the building site				
	SITE CLEARANCE ETC				
	Site clearance				
1	Digging up and removing rubbish, debris, vegetation, hedges, shrubs and trees not exceeding 200mm girth, bush, etc	m2	61	2.00	122.00
2	Stripping average 150mm thick layer of top soil and stockpiling on site	m2	61	2.00	122.00
	REMOVAL OF TREES ETC				
	Taking out and removing, grubbing up roots and filling in holes				
3	Hedge not exceeding 2500mm high	m	6	10.00	60.00
4	Tree exceeding 200mm and not exceeding 500mm girth	No	1	400.00	400.00
5	Tree exceeding 500mm and not exceeding 1000mm girth	No	1	500.00	500.00
	Carried Forward			R	1,204.00
	Bill No. 2 EARTHWORKS				

	Brought Forward			R	1,204.00
	<u>EXCAVATION, FILLING, ETC OTHER THAN BULK</u>				
	<u>Excavation in earth not exceeding 2m deep</u>				
6	Trenches	m3	2	40.00	80.00
	<u>Extra over all excavations for carting away</u>				
7	Surplus material from excavations to stock piles on site	m3	2	30.00	60.00
	<u>Risk of collapse of excavations</u>				
8	Sides of excavations not exceeding 1,5m deep	m2	14	7.00	98.00
	<u>Keeping excavations free of water</u>				
9	Keeping excavations free of all water other than subterranean water		Item		200.00
	<u>Earth filling with material from the excavations and /or prescribed stock piles on site compacted to 95% Mod AASHTO</u>				
10	Under floors, etc	m3	4	300.00	1,200.00
	<u>Compaction of surfaces</u>				
11	Compaction of ground surface under floors etc including scarifying for a depth of 150mm, breaking down oversize material, adding suitable material where necessary and compacting to 95% Mod AASHTO density	m2	39	12.00	468.00
	<u>Prescribed density tests on filling</u>				
12	"Modified AASHTO Density" test	No	2	300.00	600.00
	<u>SOIL POISONING</u>				
	<u>Soil insecticide by specialist</u>				
13	Under floors etc including forming and poisoning shallow furrows against foundation walls etc, filling in furrows and ramming	m2	41	9.00	369.00
14	To bottoms and sides of trenches etc	m2	18	9.00	162.00
	Carried to Summary			R	4,441.00
	Bill No. 2 EARTHWORKS				

Item No			Quantity	Rate	Amount
	BILL NO. 3				
	CONCRETE, FORMWORK AND REINFORCEMENT				
	SUPPLEMENTARY PREAMBLES				
	All in accordance with SANS 10400				
	Cost of tests				
	The costs of making, storing and testing of concrete test cubes as required under clause 7 "Tests" of SABS 1200 G shall include the cost of providing cube moulds necessary for the purpose, for testing costs and for submitting reports on the tests to the architect. The testing shall be undertaken by an independent firm or institution nominated by the contractor to the approval of the architect. (Test cubes are measured separately)				
	UNREINFORCED CONCRETE CAST AGAINST EXCAVATED SURFACES				
	25MPa/19mm concrete				
1	Strip footings	m3	1	1,000.00	1,000.00
	REINFORCED CONCRETE				
	25MPa/19mm concrete				
2	Surface beds on waterproofing	m3	4	1,000.00	4,000.00
	TEST BLOCKS				
3	Making and testing 150 x 150 x 150mm concrete strength test cube (Provisional)	No	1	200.00	200.00
	REINFORCEMENT				
	Fabric reinforcement				
4	Type 193 fabric reinforcement in concrete surface beds, slabs, etc	m2	40	25.00	1,000.00
	Carried to Summary			R	6,200.00
	Bill No. 3 CONCRETE, FORMWORK AND REINFORCEMENT				

Item No			Quantity	Rate	Amount
	BILL NO. 4				
	MASONRY				
	SUPPLEMENTARY PREAMBLES				
	BRICKWORK				
	Sizes in descriptions				
	Where sizes in descriptions are given in brick units, "one brick" shall represent the length and "half brick" the width of a brick				
	Face bricks				
	Bricks shall be ordered timeously to obtain uniformity in size and colour				
	Pointing				
	Descriptions of recessed pointing to fair face brickwork and face brickwork shall be deemed to include square recessed, hollow recessed, weathered pointing, etc				
	FOUNDATIONS (PROVISIONAL)				
	Brickwork of NFX bricks (14 MPa nominal compressive strength) in class I mortar				
1	One brick walls	m2	14	250.00	3,500.00
	SUPERSTRUCTURE				
	Brickwork of NFP bricks in class II mortar				
2	One brick walls	m2	79	275.00	21,725.00
3	Half brick walls	m2	14	150.00	2,100.00
	BRICKWORK SUNDRIES				
4	75mm Wide reinforcement built in horizontally	m	234	2.00	468.00
5	150mm Wide reinforcement built in horizontally	m	125	3.00	375.00
	Carried to Summary			R	28,168.00
	Bill No. 4 MASONRY				

Item No			Quantity	Rate	Amount
	BILL NO. 5				
	WATERPROOFING				
	SUPPLEMENTARY PREAMBLES				
	Waterproofing				
	Waterproofing of roofs, basements, etc shall be laid under a ten year guarantee. Waterproofing to roofs shall be laid to even falls to outlets etc with necessary ridges, hips and valleys. Descriptions of sheet or membrane waterproofing shall be deemed to include additional labour to turn-ups and turn-downs				
	DAMP-PROOFING OF WALLS AND FLOORS				
	One layer of 375 micron "Consol Plastics Brikgrip DPC" embossed damp proof course				
1	In walls	m2	3	22.00	66.00
	One layer of 375 micron "Consol Plastics Hyperlastic Orange" waterproof sheeting sealed at laps with "Superstik" tape				
2	Under surface beds	m2	41	25.00	1,025.00
	Carried to Summary			R	1,091.00
	Bill No. 5 WATERPROOFING				

Item No			Quantity	Rate	Amount
	BILL NO. 6				
	ROOF COVERINGS ETC				
	PROFILED METAL SHEETING AND ACCESSORIES				
	Concrete tiles laid on an underlay of 350 micron "Dakseel" plastic sheeting with 75mm lapped and sealed joints and nailed through underlay with non-corrosive tile nails and/or fixed with suitable non-corrosive clips as required nailed through underlay to 38 x 38mm sawn softwood battens at 300mm centres				
1	Roof covering with 55 degrees pitch	m2	48	100.00	4,800.00
2	Ridge tiles to match roofing tiles bedded and pointed in 1:3 cement mortar tinted to match tile colour	m	7	59.00	413.00
	Carried to Summary			R	5,213.00
	Bill No. 6 ROOF COVERINGS, CLADDINGS, ETC.				

Item No			Quantity	Rate	Amount
	BILL NO. 7				
	CARPENTRY AND JOINERY				
	ROOFS ETC				
	ROOF CONSTRUCTION				
	Plate nailed timber roof truss construction				
1	Roof construction to double pitched roof with pitch not exceeding 28 degrees with gable and 600mm verge projection at both ends, including wall plates, trusses, permanent bracing and 38 x 38mm battens to receive concrete tiles		Item		9,200.00
	EAVES, VERGES, ETC				
	"Everite Flexit" pressed nutec-cement				
2	Nutec fascia boards, high density plain, fittings and fixing accessories, fixed to ends of steel rafters with and including jointing strips for butt-jointing, size 12 x 225mm high (code 041 -202)	m	13	50.00	650.00
3	Nutec barge boards, plain, fittings and fixing accessories fixed to steel purlins with and including jointing strips for butt-jointing and apex jointing including all cutting and waste, size 80 x 200mm high (code 721 -731)	m	14	45.00	630.00
	FRAMED FRAMES ETC				
	Wrought meranti by "Swartland" or other approved				
4	114 x 50mm Frames	m	20	120.00	2,400.00
	DOORS ETC				
	Masonite hollow core flush doors with 3,2mm standard hardboard covering on both sides hung to steel frames				
5	Size 44 x 813 x 2032mm high	No	3	210.00	630.00
	Carried Forward			R	13,510.00
	Bill No. 7 CARPENTRY AND JOINERY				

	Brought Forward			R	13,510.00
	Wrought meranti by "Swartland" or other approved				
6	External door size 950 x 2100	m	2	500.00	1,000.00
	WINDOWS, ETC				
	Wrought meranti by "Swartland" or other approved				
7	Windows size 600 x 1200mm	No	2	350.00	700.00
8	Windows size 1200 x 1200mm	No	3	450.00	1,350.00
	Carried to Summary			R	16,560.00

Bill No. 7
CARPENTRY AND JOINERY

Item No			Quantity	Rate	Amount
	BILL NO. 8				
	IRONMONGERY				
	LOCKSETS, ETC				
1	Union 2 lever lockset	No	3	120.00	360.00
	Carried to Summary			R	360.00
	Bill No. 8 IRONMONGERY				

Item No			Quantity	Rate	Amount
	BILL NO. 9				
	PLASTERING				
	SCREEDS				
	Grano on concrete				
1	30mm Thick on floors and landings	m2	42	50.00	2,100.00
	INTERNAL PLASTER				
	Cement plaster on brickwork				
2	On walls	m2	60	40.00	2,400.00
	EXTERNAL PLASTER				
	Cement plaster on brickwork				
3	On walls	m2	61	35.00	2,135.00
	Carried to Summary			R	6,635.00
	Bill No. 9 PLASTERING				

Item No			Quantity	Rate	Amount
	BILL NO. 10				
	PLUMBING AND DRAINAGE (PROVISIONAL)				
	RAINWATER DISPOSAL				
	"Watertite" or other equally approved aluminium gutters, etc. to match existing				
1	115 x 140mm Eaves gutters	m	13	90.00	1,170.00
2	Extra over eaves gutter for outlet for 75 x 75mm pipe	No	2	70.00	140.00
3	Extra over eaves gutter for stopped end	No	4	75.00	300.00
4	75 x 75mm Rainwater pipes	m	5	50.00	250.00
5	Extra over rainwater pipe for shoe	No	2	69.00	138.00
6	Extra over rainwater pipe for bends	No	4	75.00	300.00
7	Extra over rainwater pipe for eaves or plinth offset 600mm projection	No	2	70.00	140.00
	SOIL DRAINAGE				
	uPVC pipes				
8	50mm Pipes laid in and including trenches not exceeding 1m deep	m	4	90.00	360.00
9		m	5	75.00	375.00
10	110mm Pipes laid in and including trenches not exceeding 1m deep	m	20	110.00	2,200.00
	Extra over all excavations				
11	Extra over all excavations in compacted pickable material for excavation in soft rock as described.	m3	2	100.00	200.00
12	Extra over all excavations in compacted pickable material for excavation in hard rock as described.	m3	2	200.00	400.00
	Carried Forward			R	5,973.00
	Bill No. 10 PLUMBING AND DRAINAGE				

	Brought Forward			R	5,973.00
	Extra over uPVC pipes for fittings				
13	110mm Access bend	No	3	175.00	525.00
14	50mm Access bend	No	2	90.00	180.00
15	110mm Bend	No	2	165.00	330.00
16	110mm Access junction	No	2	195.00	390.00
17	50mm Access junction	No	1	125.00	125.00
	SANITARY FITTINGS ETC				
	Vitreous China/Ceramic Fireclay fittings including assembling and fixing in position, expanding bolts and mortice in brick or concrete walls, connecting up to waste and water supplies complete and sealed around				
18	Vaal "Hibiscus" close coupled WC suite with 90 degree outlet rim with top dual flush suite (Code 772656) and Jazz themoset toilet seat (Code 8531Z0)	No	1	350.00	350.00
19	Vaal "Hibiscus" white wash hand basin size 510 x 405mm with two semi-punched taphole, intergrated overflow and chainstay hole through centre semi-punched taphole (Code 7023) and basin to be wall mounted with 10mm bolts (Code 8448Z0).	No	1	350.00	350.00
	TRAPS, ETC				
20	Plumbcrazy rubber 32 x 40mm plain P-trap (code YA1), colour white.	No	1	150.00	150.00
	TAPS, VALVES, ETC.				
	"Cobra watertech"				
21	12mm CP lever action pillar tap	No	2	575.00	1,150.00
	Chromium Plated Brass Fitting				
22	15mm Chromium plated fullway ballcock (class 20)	No	1	350.00	350.00
	SANITARY PLUMBING				
	Carried Forward			R	9,873.00

Bill No. 10
PLUMBING AND DRAINAGE

	Brought Forward			R	9,873.00
	uPVC pipe				
23	50mm Pipes	m	10	75.00	750.00
24	110mm Pipes	m	3	100.00	300.00
	Extra over uPVC pipes for fittings				
25	50mm Access bend	No	4	75.00	300.00
26	50mm Bend	No	4	70.00	280.00
27	110mm Access bend	No	2	185.00	370.00
28	50 x 35mm BSP adaptor	No	1	75.00	75.00
	WATER SUPPLY				
	Hdpe pipes				
29	25mm Pipes including excavation 700mm deep	m	30	65.00	1,950.00
	Extra over class 3 pipes for brass compression fittings				
	Extra over Hdpe pipes for brass compression fittings				
30	15mm Fittings	No	27	65.00	1,755.00
31	25mm Fittings	No	10	75.00	750.00
	ELECTRIC WATER HEATERS				
	" Zip Hydroboil"				
32	Wall mounted five litre white epoxy coated instant boiling water unit size 318 x 150 x 460mm (Code 380002)	No	1	1,000.00	1,000.00
	Carried to Summary			R	17,403.00
	Bill No. 10 PLUMBING AND DRAINAGE				

Item No			Quantity	Rate	Amount
	BILL NO. 11				
	ELECTRICAL WORK				
	LIGHTING AND SMALL POWER				
	SUPPLY CABLE				
1	15mm2 - 3 core 600/1000V pvc/swa copper cable laid in trenches not exceeding 1m deep including excavation, bedding, backfilling and compaction and disposal of surplus materials	m	10	125.00	1,250.00
	DISTRIBUTION BOARD				
2	Flush mounted PVC single phase distribution board, size 350 x 250mm high complete with all necessary circuit breakers, legend card, earth leakage unit, busbars, jumpers, neutral bars, internal wiring, connections and blanking	No	1	700.00	700.00
	RIGID PVC CONDUIT				
	Cast in concrete, surface bed or screed				
3	20mm Diameter	m	125	12.00	1,500.00
	Chased and/or fixed in brickwork not exceeding 3000mm above floor level (making good of chase by others)				
4	20mm Diameter	m	109	15.00	1,635.00
	CONDUIT BOXES AND FITTINGS				
	PVC type fixed onto conduit				
5	100 x 100 x 50mm Deep expansion joint box complete with conduit sleeve, earth strap, cover plate, etc	No	5	150.00	750.00
	CONDUCTORS				
	Carried Forward			R	5,835.00

Bill No. 11
ELECTRICAL WORK

	Brought Forward			R	5,835.00
	PVC insulated stranded copper conductor drawn into wireways				
6	2,5mm²	m	250	20.00	5,000.00
7	4mm²	m	20	40.00	800.00
	LIGHT SWITCHES, SWITCHED SOCKET OUTLETS, ETC.				
	Switches, etc complete with cover plate fixed in flush box				
8	16A One-lever one-way switch	No	4	200.00	800.00
9	16A Three-pin socket outlet with 15A double pole circuit breaker	No	1	300.00	300.00
	LUMINAIRES AND EQUIPMENT				
10	Type A	No	3	100.00	300.00
11	Type B	No	2	150.00	300.00
	SUNDRIES				
	Testing and commissioning				
12	Allow for testing, balancing and commissioning the complete electrical installation		Item		100.00
	Carried to Summary			R	13,435.00
	Bill No. 11 ELECTRICAL WORK				

Item No			Quantity	Rate	Amount
	BILL NO. 12				
	GLAZING				
	GLAZING TO STEEL WITH PUTTY				
	3mm clear float glass				
1	Panes exceeding 0,5m2 and not exceeding 2m2	m2	4	100.00	400.00
	4mm Obscure float glass				
2	Panes exceeding 0,1m2 and not exceeding 0,5m2	m2	1	150.00	150.00
	MIRRORS				
	Mirror manufactured from 8mm thick 18/10 stainless steel with reflective polished surface				
3	Size 300 x 400mm high	No	1	150.00	150.00
	Carried to Summary			R	700.00
	Bill No. 12 GLAZING				

Item No			Quantity	Rate	Amount
	BILL NO. 13				
	PAINTWORK				
	ON FLOATED PLASTER				
	One filler coat and two coats exterior quality PVA emulsion paint				
1	On external walls	m2	61	30.00	1,830.00
	One coat primer and two coats interior quality PVA emulsion paint				
2	On internal walls	m2	121	35.00	4,235.00
	Carried to Summary			R	6,065.00
	Bill No. 13 PAINTWORK				

APPENDIX 2
BILLS OF QUANTITIES
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FINAL SUMMARY

Bill No		Page No		Amount
1	PRELIMINARIES	165		11,057.92
2	EARTHWORKS	167		4,441.00
3	CONCRETE, FORMWORK AND REINFORCEMENT	168		6,200.00
4	MASONRY	169		28,168.00
5	WATERPROOFING	170		1,091.00
6	ROOF COVERINGS, CLADDINGS, ETC.	171		5,213.00
7	CARPENTRY AND JOINERY	173		16,560.00
8	IRONMONGERY	174		360.00
9	PLASTERING	175		6,635.00
10	PLUMBING AND DRAINAGE	178		17,403.00
11	ELECTRICAL WORK	180		13,435.00
12	GLAZING	181		700.00
13	PAINTWORK	182		6,065.00
	Sub Total		R	117,328.92
	VALUE ADDED TAX 15%		R	17,599.34
	Carried to Form of Tender		R	134,928.26