ENERGY EFFICIENCY INTERVENTIONS FOR RESIDENTIAL BUILDINGS IN BLOEMFONTEIN USING PASSIVE ENERGY TECHNIQUES.

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DECLARATION OF INDEPENDENT WORK

DECLARATION WITH REGARD TO INDEPENDENT WORK

I, TICHAONA KUMIRAI, passport number AN447749 and student number 208065318, do hereby declare that this research project submitted to the Central University of Technology, Free State, for the degree MASTER TECHNOLOGY: ENGINEERING: MECHANICAL, is my own independent work; and complies with the code of Academic Integrity, as well as other relevant policies, procedures, rules and regulations of the Central University of Technology, Free State; and has not been submitted before to any institution by myself or any other person in fulfilment of the requirements for the attainment of any qualification.

SIGNATURE OF STUDENT

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ABSTRACT

The purpose of this research is to minimize the use of active systems in providing thermal comfort in single-family detached, middle to high income residential buildings in Bloemfontein. The typical case study house was selected according to the criteria as reviewed by Mathews et al., (1999).

Measurements were taken for seven days (18 – 24 May 2009). The measurements were carried out in the winter period for Bloemfontein, South Africa. Ecolog TH1, humidity and temperature data logger was used in doing the measurements. These measurements included indoor temperatures and indoor relative humidity.

Temperature swings of 8.43 °C and thermal lag of 1 hour were observed. For the period of seven days (168 hours), the house was thermally comfortable for 84 hours.

Thermal analysis for the base case house was done using Ecotect™ (building analysis software) and the simulated results were compared with the measured results. A mean bias error (MBE) of between $10.3\% \leq \varepsilon \leq 11.5\%$ was obtained on the initial calibration. The final calibration of the model yielded error between $0.364\% \leq \varepsilon \leq 0.365\%$. The final calibration model which presented a small error was adopted as the base case.

Passive strategies were incorporated to the Ecotect™ model (final calibrated model) singly and in combination; then both thermal and space load simulations were obtained and compared to simulations from the original situation (base case) for assessing improvements in terms of thermal comfort and heating, ventilation and air conditioning (HVAC) energy consumption. Annual HVAC electricity savings of up to 55.2 % were obtained from incorporating passive strategies in combination. Incorporating passive strategies resulted in small improvements in thermal comfort.

Key words: Passive, Energy efficiency, Thermal comfort, Residential buildings.

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GLOSSARY

Latent gain: The additional load caused by humidity reduction.

R-value: Thermal resistance value of an insulator.

Sensible gain: The increase in temperature where moisture is not involved

U-value: Overall heat transfer co- efficient.

Zone: A completely enclosed volume within a building.

ABREVIATIONS

ACH: Air changes per hour.

HVAC: Heating ventilation and air conditioning system.

SANS: South Africa National Standards.

USA: United States of America.

UNFCCC: United Nations Framework Convention on Climate Change

EDRC: South Africa's Energy & Development Research Centre.

RES: Renewable energy sources

EU: European Union.

SABC: South African Residential Building Code.

CFD: Computational fluid dynamics.

ISO: International organization for standardisation.

CIBSE: Chartered institution of building services Engineers

MBE: Mean Bias Error

DME: South Africa's Department of Minerals and Energy.

DOE: United States of America Department of Energy.

ASHRAE: American Society of Heating, Refrigerating, and Air-Conditioning Engineers.

Chapter 1: INTRODUCTION

1.1 Background

There are two broad methods of regulating the internal climate of a house: active and passive climate control. Active climate control refers to the conversion of electricity into energy to regulate the internal climate. Passive climatic control relies on material properties, placement and the external environment to influence the internal climate (Duell et al., 2006). The idea of passive climatic control is to achieve thermal comfort with minimal conventional energy input (Klunne, 2004). Examples of active and passive climate control devices are listed in Table 1.1 below. Currently, there is a shift towards passive climatic control due to its reduced energy consumption, potentially lower maintenance and reduced impact on the environment.

Table 1.1: Forms of climatic control- active and passive

Active climate control	**Passive climate control**
Refrigrative/ Evaporative air conditioning	Thermal mass
Ceiling fans	Shading
Gas heating	Insulation
Radiant heating (bar heaters)	Glazing

The domestic sector is the largest electricity consumer in South Africa (Surtees, 2000). Households account for 29% of municipal electricity consumption (Surtees, 1993). In South Africa, 24% electrical energy is used to supply indoor climatic comfort in residential buildings. South Africa is experiencing a rapidly increasing peak demand, of which households contribute over 20% (Lane et al., 2000). To forestall the building of costly new power stations, the peak demand must be reduced. Electricity consumption in the domestic sector therefore has potential impact.

Several studies have been conducted to determine energy saving methods. These suggestions attempt to reduce electricity consumption by changing people's usage patterns. However, this approach is not always successful. People are not prepared to put any conscious effort into saving electricity. Since electricity is relatively cheap in South Africa, it is especially difficult to motivate people to alter their wasteful habits (Mathews et al., 1999).

An alternative approach is to improve the thermal performance of the residential building envelope. The main benefit of this strategy is that once a house is designed to be thermally efficient, no further effort is required. The energy savings are still realised, even if the house is sold to new owners (Mathews et al., 1999).

Literature suggests that most houses in South Africa are characterized by poor craftsmanship and design with no regard to passive features (Lombard et al., 1999). This results in an uncomfortable indoor thermal environment which leads to high electrical energy consumption from heating, ventilation and air conditioning (HVAC) systems.

Siti (2000) found that there is a correlation between household income and electricity consumption. Figure 1.1 shows that high income households consume more electricity than low income ones. Thus there are greater electrical energy savings potential when higher income households are targeted.

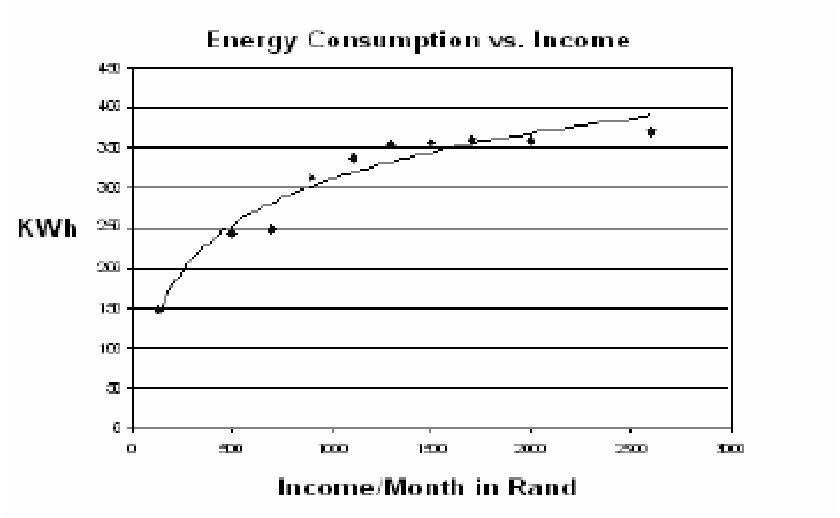


Figure 1.1 Energy consumption vs. Income: (Siti, 2000)

Residential building statistics released by Statistics South Africa for the period January-July 2008 indicate a mass housing construction drive in Bloemfontein (Jacques, 2008). Passive interventions suggested by this dissertation may therefore be applied in both new constructions and renovations.

According to the recently published South Africa National Standard (SANS) 204 (2009), if increased energy efficiency, thermal insulation and high performance window systems are implemented in all residential and commercial buildings, 3500 Mega Watts (MW) electricity energy can be saved by 2020 in South Africa. This amount is twice the electricity currently produced by the only nuclear power plant in South Africa, which produces 1 800 MW.

The major proportion of environmental impact of residential buildings is as a result of the energy consumption for space heating and cooling (Shar et al., 2008). Passive techniques improve household energy efficiency, which benefits residents and the economy. These techniques bring financial and environmental rewards and improve the health and well- being of residents. Studies indicate that South Africa's contribution to the additional radiation load on the global atmosphere through emissions is roughly 1.2 % (Scholes et al., 1994). This is high, when considering that South Africa comprises a fraction of the world's economy and population.

1.2 Objectives of the research

The purpose of this dissertation is to investigate the possibility of cutting down the use of active systems in providing thermal comfort by means of passive strategies. The objective of this dissertation is to analyze the HVAC energy saving potential and thermal performance improvement of different passive strategies, applied individually as well as in combination.

1.3 Methodology

To accomplish the objective of the research, the following tasks were performed:

1. An extensive review of literature on energy efficiency, passive energy efficiency interventions and their benefits was undertaken. The focus of the review was on those interventions that are suitable for the southern hemisphere, particularly those that can be used in urban areas of Bloemfontein, South Africa.

2. The field studies were primarily done to acquire data for calibration of the Ecotect v 5.6 model. Mr. Rampai's house in Fauna, Bloemfontein, South Africa (latitude 29.1 S, longitude 26.3 E, altitude 1353 m) was chosen as the case study house after approaching various owners of households in low to high income suburbs. The field studies were conducted from 18 to 24 May 2009. The calibration process compares the results of the simulation with measured data and tunes the simulation until its results match the measured data (Yiqun et al., 2007). Calibration of simulation models is necessary for accuracy and usability of building analysis simulation software (Yiqun et al., 2007).

3. Passive strategies were incorporated on the Ecotect™ model (calibrated model) singly and in combination, then both thermal and space (HVAC) load simulations were obtained and compared to simulations from the original situation (base case) for assessing improvements in terms of thermal comfort and HVAC energy consumption.

1.4 Contribution of the research

Although various studies on passive thermal energy efficiency strategies have been done both locally and internationally, the net benefit of implementing these varies with climate differences. This dissertation is considered unique in that the suggested passive strategies will be applied in Bloemfontein urban residential areas only.

1.5 Limitations of study

The study was conducted with the following limitations in order to minimize the cost of the project and its duration:

I. The benefits of the passive techniques were quantified by simulation only (Ecotect V 5.6).

II. The study was limited to single-family detached middle to high income residential buildings of Bloemfontein only.

Chapter 2: LITERATURE REVIEW

2.1 Passive and active forms of climatic control

There are two broad methods for the regulation of internal climate: active and passive control. Active climate control requires the use of electricity, while a passive design relies on ambient energy sources, such as wind and solar energy to regulate the internal climate. Examples of active and passive climate control devices are listed in Table 2.1 below:

Table 2.1: Forms of climatic control- active and passive

Active climate control	**Passive climate control**
Refrigerative air conditioning	Thermal mass
Evaporative air conditioning	Shading
Ceiling fans	Natural ventilation
Pedestal fans	Insulation
Central heating	Glazing
Radiant heating (Bar heaters)	Radiation
Gas heating	

There is a shift towards passive climatic control for a number of reasons: reduced energy consumption, potentially lower maintenance and reduced impact on the environment. Active climatic control can consume large amounts of electricity, which may result in the generation of greenhouse gases. Passive climatic control relies on material properties and their placement and the exploitation of the external environment to achieve thermal comfort (Duell et al., 2006). Thus, the objective of passive climatic control is to achieve thermal comfort with minimal conventional energy input (Klunne, 2004).

2.2 Passive strategies in residential buildings

2.2.1 Thermal Mass

Thermal mass is basically the capacity of a material to store heat. Thermal mass is incorporated into a building as part of the walls and floor. Thermal mass absorbs heat from space. Thermal mass affects the temperature within a building by:

- Stabilising internal temperature. Thermal mass provides the heat source and heat sink surfaces for radiative, conductive and convective heat exchange processes.

- Providing bigger time-lags in equalisation of external and internal temperatures.

- Providing a reduction in extreme temperature swings between outside and inside.

A large thermal mass reduces daily temperature fluctuations (Donn and Thomas, 2007; Hastings and Wall, 2007). Thermal mass is ideal in winter to prevent temperatures from plummeting overnight. However, to improve comfort during summer, the thermal mass that has stored heat during the day needs to be cooled at night, so that it is able to absorb more heat during the following day (Chiras, 2002). Ideally, heat is not released into the house, allowing the house temperature to decrease at night, ready for heat loads the next day. This is called night cooling. However, if there is not enough ventilation or the night air is not cool enough, the thermal mass will release heat into the house.

Thermal mass provides significant benefits in shifting peak load conditions and reducing overall heat gain or loss, provided that the average outside temperature is moderate. This allows reduced heating, ventilation and air conditioning (HVAC) system size. The size reduction would result in energy and cost savings. However, these benefits depend on the configuration of the wall assembly (i.e., insulation inside or outside, thermal mass relative to the building interior) and the climatic conditions (Malhotra, 2005).

Kossecka and Kosney (1998) demonstrated that up to 11% of heating and cooling energy reduction can be achieved by optimizing the thermal mass and insulation distribution on a wall. A similar study by Kosny et al. (2001) showed whole-building energy savings of up to 8% in Minneapolis (USA), Minnesota (USA) and 18% in Bakersfield (USA), California (USA), for high R-value walls. Studies by Chulsukon (2002) and Rasisuttha and Haberl (2004) analyzed different combinations of insulation and thermal mass in houses in the hot and humid climate of Bangkok (Thailand), which were partially air-conditioned at night. Chulsukon (2002) demonstrated 4% savings from lightweight construction with R-11 insulation, and 3% savings from a 4-inch brick wall with 2-inch polystyrene insulation, as compared to an uninsulated 4-inch brick wall. Rasisuttha and Haberl (2004) demonstrated more savings from light weight concrete block walls, especially with insulation on the inside wall than from high thermal mass walls (8-inch and 12-inch brick walls).

2.2.2 Insulation

Thermal insulation is a measure that reduces energy consumption in all weather conditions, i.e. it reduces heat gains during the day and blocks the path of heat flow out of a building when the ambient temperature is lower than inside temperature (Akbari et al., 1997). Insulation is suggested to help keep the heat out during summer and keep the heat in during winter (Brandz 2005).

Lane (1986) shows that insulation reduces cooling requirements. Chiras (2002) suggests that a radiant barrier such as aluminum foil in the roof can reflect heat and stop it from entering the room. Chiras (2002) also suggests that when insulation is used in conjunction with other passive design measures, it helps in keeping the interior cool in warm weather. Hastings and Wall (2007) suggest that a high level of thermal insulation is required. However, Orme and Palmer (2003) are concerned that too much insulation traps heat inside, thus causing overheating.

Providing adequate insulation in the building envelope is critical for energy efficiency. Many studies have quantified energy savings from improved insulation. Ternes et al. (1994) showed 9% energy use reduction and 15% average peak demand reduction in Arizona (United States of America), by retrofitting an exterior masonry wall with insulation from R-3 to R-13. They showed the highest annual cooling energy savings in hot and dry climates. Matrosov and Butovsky (1994) did experiments in Russia and came to the conclusion that thermal insulation reduces energy consumption by 20-25% in residential buildings.

A study of a typical uninsulated masonry house (partially air-conditioned at night) in the hot and humid climate of Bangkok, Thailand by Chulsukon (2002) showed 3-4% annual energy savings from light-weight walls with R-11 batt insulation and from a cement tile roof with R-11 batt insulation. Another study of a similar house in Bangkok, Thailand, by Rasisutta and Haberl (2004), showed 8% of total energy reduction from light-weight concrete block walls with R-10 exterior insulation, and 9% reduction from a similar wall construction with R-10 interior insulation. A similar study of a Habitat for Humanity house in the hot-humid climate of Central Texas (United

States of America) by Kootin-Sanwu (2004) showed a small annual electricity savings, but a high cooling energy savings in the summer from improved insulation in light-weight walls.

The use of thermal insulation in buildings does not only reduce the reliance upon mechanical air-conditioning systems, but also extends the periods of indoor thermal comfort. Holm and Van Aswegen (1993) studied thermal performance of low- cost housing in South Africa. They found that the interior thermal comfort conditions in three informal houses were improved when dwellings were lined with insulation.

2.2.3 Building Configuration

Many researchers have explored the relationship between architectural form and energy use to better understand the energy consequences of basic design decisions. Brown and DeKay (2001) listed strategies for the organization, shape, orientation and location of building groups and building spaces, and the building envelope components, to obtain space heating, cooling and day-lighting benefits from the sun and wind. Watson and Labs (1983) discussed control strategies for promoting/restricting heat gain and loss through the envelope by means of wind breaks, plants and water, indoor/outdoor rooms, earth sheltering, solar walls and windows, thermal envelope, shading and natural ventilation.

Givoni (1998) discussed effects of building design features such as the layout, window orientation, shading and ventilation, on the indoor environment and energy use. He provided design guidelines for improving comfort and energy conservation in different climates (Malhotra, 2005). The work by Malhotra (2005) and that of Givoni (1998) suggest that a compact plan with a smaller exposed wall area and a reduced roof size reduces the energy demand of a mechanically conditioned building. A spread- out plan has the potential for natural ventilation and natural illumination. Compact designs, attached or clustered buildings and earth sheltering can protect from extreme temperatures, as well as from undesired winds.

Orienting the building along the east-west axis, maximizing wintertime exposure to the north, north-east and north-west sides, providing clear solar access, sunspaces on the south, buffer spaces along the north, and temperature zoning inside the building can maximize solar gain and minimize heat loss in the winter. Building envelope shading should be added to these measures, to minimize heat gain in the summer. On the other hand, for natural ventilation, orienting and planning the building for maximum contact to outdoors to capture the prevailing winds, open indoor plan, high ceiling, two storey spaces, open stairwells and elevated living spaces are recommended for maximizing air-flow indoors (Malhotra, 2005).

Friedman (2000) recommended rectangular shapes for buildings to minimize heat gain and loss through the envelope. He showed up to 15% savings by simplifying an L-shape floor plan to a rectangle, and up to 21% and 43% savings by redesigning a one-storey detached unit as a duplex and as a row house, respectively. Olgyay (1963) found that for the hot and humid climate of Miami, Florida (USA), a length-to-width ratio of 1:1.7 was the optimum that resulted in minimum heat loss in winter and minimum heat gain in summer.

2.2.4 High reflectance and high emissive coatings

Solar absorption and transmission of heat through the building envelope increases the temperature of the fabric, as well as the indoor ambient temperature. Thus, cooling needs increase, while comfort levels deteriorate. Coatings on the exterior facade of buildings presenting high reflectivity and high emissivity decrease absorption of solar radiation and increase radiation losses. Coatings presenting such a performance are known as cool materials Akbari et al. (1992). Two main types of cool coatings for roofs and exterior facades of buildings have been developed:

a) White coatings which present high reflectivity to visible part of the solar radiation (Syneffa et al. 2006).

b) Coloured coatings presenting a high reflectivity to the infrared part of the solar radiation (Levinson et al., 2006 and Syneffa et al., 2006).

Reflectance and thermal emissivity of the exterior surfaces of the building provide significant opportunity for energy savings. High solar reflectance reduces summer-time solar heating, and a high infrared (IR) emittance increases radiative cooling of the surface. The resulting reduced building surface temperature reduces the heat transfer into the building, as well as the surrounding urban air temperatures that would have increased due to convective cooling of the hot building surfaces (Malhotra 2005).

Extensive outdoor testing of cool white coatings during the summer period has shown that cool white coatings present 12° C lower surface temperatures than reflective aluminum paints, and more than 16° C than silver gray reflective coatings (Syneffa et al, 2006). In parallel, colour cool coatings tested outdoors against conventional coatings of the same colour, presented a reduction of the surface temperature by up to 10 °C (Syneffa et al, 2006).

Akbari and Konopacki (1998) showed a 10-15% cooling energy use reduction by coating roofs white, with greater opportunity of energy savings in warm climates. In their study, decreasing the roof emissivity showed a 10% net increase in the annual utility bill in hot climates, and a 3% heating energy savings in very cold climates. No savings resulted in cold climates, due to the heating energy savings being equal to the cooling energy use penalties. Akbari et al., (1993, 1997) monitored peak power and cooling energy savings from high reflective coatings on one house and found seasonal savings of 2.2kWh/day and peak demand reductions of 0.6kW. Parker et al., (1998) monitored nine homes before and after applying high reflective coatings to their roofs. They found that air conditioning energy use was reduced by 10-43% with average savings of 7.4kW/day (savings of 19%). Peak demand between 5 and 6 p.m. was reduced by 0.2-1 with an average reduction of 0.4kW (savings of 22%).

Akbari and Bretz (1994, 1997) found that increased reflectivity of many roofs in a city has the potential to create glare and visual discomfort, if not kept to a reasonable level. Extreme glare could possibly increase traffic accidents. On the other hand, high total solar reflectance with a low ratio of visibility to heat reflectance would reduce potential glare problems for a reflective roof system.

2.2.5 Glazing-fenestration

Glazing allows solar radiation to enter the house, warming the indoor air and allowing day lighting into the interior. Glazing is therefore important in both summer and winter. The orientation, the size and type of glazing affect the amount of solar heat gain entering the house. During winter solar heat gain is beneficial, but glazing also increases heat losses. So increasing the size of glazing does not always result in warmer temperatures. When the house is already warm, having solar heat gain could cause the house to overheat. Chiras (2002) suggests that it is necessary to reduce or eliminate solar heat gain to allow passive cooling. Window placement is a priority. The declination of the sun needs to be considered. Glazing facing west (where the sun sets) can lead to overheating in the evening, as the sun is low and generally not shaded by the house eaves (Donn and Thomas, 2001).

Besides allowing natural light to provide effective internal lighting (day-lighting), minimizing the unwanted heat transfer through the windows is the prime objective of efficient fenestration design in a mechanically-cooled building. For a naturally ventilated building, size and placement of windows relative to wind movement is also critical; however, this should not compromise unwanted heat gain/loss. The energy impacts of fenestration can be optimized by using:

- Day-lighting,
- Passive solar heat gain,
- Glazing with special transmission properties, and
- Insulated glazing with low air leakage (Malhotra 2005).

Windows are typically the weakest link in a building's thermal barrier. They are responsible for 10-25% of a home's winter heat loss in cold climates and approximately the same amount of solar heat gain in warmer climates (RMI, 1994). In 2002, windows accounted for 26% of the aggregate U.S. residential building heating load and 33% of the cooling loads (DOE, 2004).Therefore, considering energy-efficient options for the fenestration system is an important energy-savings strategy.

Heat flow through fenestration can be controlled by various single or multiple (insulating) glazing, interior and exterior shading, and spectrally-selective coatings and tinted glass (ASHRAE 2001). In cold climates, multiple- pane, low-emissivity and gas-filled window configurations, or super windows that combine all the above advanced features are recommended. In hot climates, less expensive glazing with low-emissivity coatings, gas fills, and shading are the most cost-effective energy-saving options (DOE, 1997).

Farrar-Nagy et al. (2000) showed a 14% reduction in afternoon peak electricity demand and a 30% reduction in daily total cooling electricity from a spectrally-selective glazing, overhang and site-shading combination, in a hot-dry climate. They demonstrated a 22% daily cooling energy savings from overhangs and site shading, as compared to an 11% savings from using spectrally selective glazing only.

Besides glazing characteristics, insulated frames and spacers, good edge seals and airtight constructions are equally important for energy-efficiency. Among the available window frame and spacer options, wood, fiberglass, and vinyl frames are better insulators than metal frames without a thermal break. Aluminum frames with a thermal break perform better than those without a thermal break. The thermal break or spacer thermal performance depends on its geometry and material composition (DOE, 1997).

A mixed climate requires consideration of both heat loss control and solar heat gain protection. Carefully designed shading devices have significant energy-saving potential by reducing direct solar gain in the summer. However, for hot and humid climates, where the diffuse radiation from the sky comprises a significant portion of the total solar heat gain due to partly cloudy skies, shading from diffuse radiation is also important (Givoni 1998).

Mayfield (2000) discussed different shading options for residences such as overhangs, decks and porches, awnings, low-e films and coatings, shade screens, solar screens and rolling shutters, and gave guidelines for choosing a shading option for different contexts.

Pletzer et al. (1987) estimated up to 32% annual cooling energy savings and 5-15% annual energy cost savings from window shading devices. He also showed higher savings from interior than from exterior shading.

RMI (1994) reported heat gain/loss reductions from different shading options for cold and warm weathers. For cold-weather, it reported heat loss reductions of 25-40% from installing plastic barriers on single-pane windows, up to 50% by storm windows and up to 40% increase in solar gain by providing clear solar access on south windows.

Other options for energy-efficient fenestration design include switchable window transmittance coatings (DOE 1997) and dynamic window controls (ASHRAE 2001), which can react to varying climatological and occupant demands. Fine and McElroy (1989) showed that the combination of switchable window transmittance and variable surface absorptance performed better than the best fixed options, with slightly more savings from switchable transmittance. However, variable thermal insulation resulted in smaller savings over the fixed super-insulation.

2.2.6 Shading/eaves

Appropriate shading of the glazing is important to prevent overheating in summer. External shading is considered to be most effective, as this prevents the heat entering the interior (Chiras 2002). Interior shading will cause a build- up of heat between the shading device and window. Much of this stored heat will eventually enter the room (Chiras 2002). Lane (1986) suggests that sun control devices are necessary during summer, to decrease the cooling load if there is sufficient glazing for passive heating during winter. Pearson (1998) suggests some options for external shading including:

- Wider roof eaves,

- Awnings,
- Shutters,
- Screens,
- Verandas,
- Blinds and low emissivity glass and
- Shading the whole structure with trees, shrubs, creepers, and earth shelter.

Shade trees intercept sunlight before it warms a building. Shade trees offer significant benefits by both reducing building air conditioning and lowering air temperature, thereby improving urban air quality by reducing smog (Akbari et al. 2001).

In one experiment, Parker, (1981) measured the cooling energy consumption of a temporary building in Florida (USA) before and after adding trees and shrubs, and found cooling electricity savings of up to 50%. Akbari et al. (1997) monitored peak power and cooling energy savings from shade trees in two houses and found cooling energy savings of 30%, corresponding to average savings of 3.6 and 4.8 kW/day. Peak demand savings for the same houses were 0.6 and 0.8 kW (about 27% savings in one house and 42% in another).

2.2.7 Air tightness of the houses

Chiras (2002) states that it is important to reduce any infiltration, as any hot air entering a house through cracks contribute to heat gains. Passively designed homes should be designed and built air tight. Hastings and Wall (2007) recommend that to achieve a high performance building, the envelope needs to be air tight and mechanical ventilation should be used to ensure adequate fresh air supply, rather than to rely on occupant controlled ventilation.

2.2.8 Ventilation

It is difficult to keep the interior of a house cool if excess heat does not have an escape path. Thus, ventilation is important for preventing overheating in summer. The traditional method of cooling is through cross ventilation (Pearson 1998). Using the prevailing winds, cool air enters the building at a low level and expels warm air through windows or vents at a high level. The thermal stack effect can be used to ventilate a house when there are no prevailing winds. The stack effect relies on a pressure difference between different openings. Again the air will enter at a low level and be expelled through a higher opening. Chiras (2002) suggests different methods for ensuring good cross ventilation such as:

- Window placement

- Open plan living

- Having a shaded court yard to cool the air before it enters the house.

- Window fans to increase air movement.

Both Chiras (2002) and Pearson (1998) recognize the benefits of night cooling to release the heat that has been stored during the day. There are other methods such as wind scoops, and earth coupling tubes, attic fans or whole house fans to increase the ventilation in warm humid or windless climates. Hastings and Wall (2007) suggest that natural ventilation needs to be designed with care, as in a very air tight building the success is user dependent.

2.2.9 Green roofs

Earth Pledge Foundation, (2002) defines a green roof as a lightweight, engineered roofing system that allows for propagation of rooftop vegetation, while protecting the integrity of the underlying roof. Becker et al., (2003) allude that green roofs have been in use for long time. Green roofed structures in Ireland date back at least five thousand years. Ancient Mesopotamians are said to have been using green roofs for at least this long as well. In Norway, grass covered roofs have been used for hundreds of years as a form of insulation. In this respect, therefore, green roof is not a new idea, but rather an ancient technology that has a number of applications for modern buildings.

The process of heat transfer into the planted roof is different when compared to a conventional bare roof of a building. Solar radiation, external temperature and relative humidity are reduced as they pass through plants that cover the roof. The plants with biological functions, such as photosynthesis, respiration, transpiration and evaporation absorb a significant proportion of solar radiation (Kruche et al., 1982).

Traditional roof construction methods and designs typically do nothing to reduce storm water runoff from a building's roof, or to reduce a building's heat gain through the roof during warm seasons. Green roof technology has demonstrated a positive effect on these, as well as other factors (Becker et al. 2003).

2.3 Energy efficiency in residential buildings of South Africa

A report by the National Association of State Energy Officials (2001), defines energy efficiency as actions that are aimed at reducing energy used by specific end-use devices and systems, without affecting the services provided. Energy efficiency is a cost- effective way of cutting carbon dioxide emissions in house holds (Abdeen, 2007). According to the recently published South Africa National Standards (SANS) 204 (2009), by implementing energy efficiency measures, i.e. thermal insulation and high performance window systems, in all residential and commercial buildings, 3500 Mega Watts (MW) electricity energy could be saved in South Africa by 2020. This amount is twice the electricity currently produced by the only nuclear power plant in South Africa, which produces 1 800 MW.

2.3.1 Regulations in terms of energy efficiency in South Africa.

2.3.1.1 South Africa Energy Policy

The energy policy of South Africa's Department of Minerals and Energy contains five key policy objectives (DME, 1998). These policies form the drivers for increasing access to affordable energy. The policy objectives are outlined below:

I. Increasing access to affordable energy services: the government will promote access to affordable energy services for disadvantaged households, small businesses, small farms and community services.

II. Improving energy governance: stakeholders will be consulted in the formulation and implementation of new energy policies.

III. Stimulating economic development: government encourages energy prices to be as cost effective as possible.

IV. Managing energy related environmental and health impacts: government will work towards the establishment and acceptance of broad national targets for the reduction of energy related emissions that are harmful to the environment and to human health and will ensure a balance between exploiting fossil fuels and the maintenance of acceptable environmental requirements.

V. Securing supply through diversity: government will pursue energy security by encouraging a diversity of both supply sources and primary energy carriers.

The above energy policy clearly alludes to affordable energy for everyone, diversity in terms of supply sources and environmentally friendly energy supply and usage. South Africa is a signatory to the United Nations Framework Convention on Climate Change (UNFCCC) and the Kyoto Protocol of Climate Change. These two agreements primarily focus on environmental friendliness and sustainability of energy sources.

2.3.1.2 SANS 204-1

SANS 204-1 sets out general requirements for achieving energy efficiency in all types of buildings. These standards will eventually form part of the National Building Regulations. Annex B of the document contains a compliance certificate which will have to be completed by the responsible person (developer or owner) and submitted together with the building plans to the local authorities for approval. This certificate also requires an energy audit to be conducted a year later, to prove compliance and measure the actual energy saved.

2.3.2 Energy efficiency objectives in South Africa

The South African government has published a draft energy efficiency strategy (DME, 2004). This strategy seeks to reduce greenhouse gas emissions, move the country towards sustainable development and minimize the adverse impact of energy use on the environment. The strategy also seeks to improve thermal efficiency in buildings for all local climatic regions.

Pretorius and Spalding (1998), state that tertiary socio-economic objectives, which are peculiar to the South African energy scenario, are also possible to attain. These include reducing air-pollution, preventing condensation on the interior of walls and ceilings of homes and therefore the development of mould growth and spore production, which is a common cause of respiratory problems in the south and western coastal (SCCPA – Southern Cape Condensation Problem Area) regions of South Africa. A further objective of introducing energy efficiency therefore is to solve the health problems caused by poor indoor air quality in homes (Winkler et al., 2002).

Objectives in response to local energy efficiency design problems have been studied. Holm (2003), found that there is unique energy and thermal design problems in South African housing. Thermal design and insulation required to achieve acceptable percentages of thermal comfort in housing units are lacking. There is need for an innovative approach.

The heating necessary in the cooler climatic regions of South Africa homes places a huge cost premium on comfort for house occupants (Simmonds and Mammon, 1996). Simmons (1997) found that a large portion of expenditure of households is on energy. By improving energy standards in houses, a significant portion of the South African community will have a better quality of life.

2.3.3 Opportunities in the residential sector of South Africa

The domestic sector is one of the largest electricity consumers in South Africa, accounting for almost 29% of municipal electricity (Surtees, 1993). South Africa is also experiencing a rapidly increasing peak demand, to which households contribute over 20% (Lane et al., 1991). To forestall the building of costly new power stations, the peak demand must be reduced. Electricity consumption in the domestic sector therefore has a significant impact.

Several studies have been conducted to determine energy saving suggestions. These suggestions attempt to reduce electricity consumption by changing people's usage patterns. However, this approach is not always successful. People are seldom prepared to put any conscious effort into saving electricity. Since electricity is relatively cheap in South Africa, it is especially difficult to motivate people to alter their wasteful habits (Mathews et al., 1999).

One of the alternatives for the reduction in domestic energy consumption is to improve the thermal performance of the building envelope. The main benefit of this strategy is that once a house is designed to be thermally efficient, no further effort is required. The energy savings are still realised, even if the house is sold to new owners (Mathews et al., 1999).

Siti (2000) found that there is a correlation between household income and electricity consumption. Figure 1.1 shows that high income households consume more electricity than low income ones. Therefore there is a greater electrical energy savings potential when higher income households are targeted.

2.3.3.1 Barriers to energy efficiency in South African residential buildings

While the more efficient use of electricity has great potential, achieving wide-spread implementation requires effort. Theoretical gains have not always been realised in practice, for either technical or economic reasons (Winkler and D van ES, 2007). Removing key barriers, such as informational, institutional, social, financial, market and technical barriers, is critical to the full realisation of energy efficiency measures (EDRC, 2003).

The key drivers for successful implementation of efficiency measures include government policy (standards, incentives, recovery of programme costs), electricity pricing mechanisms that do not penalise efficiency, and the effectiveness of demand side management delivery agencies (NER, 2002). The DME's energy efficiency strategy identified some possible barriers to implementing energy-efficiency projects (DME, 2005). The key barriers included:

- Energy pricing, with historically low unit prices of coal and electricity, and the perception that energy efficiency does not therefore make much financial sense, which still persists even in energy-intensive industries;

- Lack of knowledge and understanding of energy efficiency;

- Institutional barriers, and resistance to change, e.g. due to fears that energy efficiency might disrupt production processes;

- Lack of investment confidence, that the returns on the initial investment required will indeed materialize; and 'bounded rationality', using imperfect, or incomplete, information and less than fully rational procedures.

2.3.4 Benefits of energy efficiency

The environment will benefit from energy savings. Studies indicate that South Africa's contribution to the additional radiation load on the global atmosphere through emissions is roughly 1, 2 % (Scholes et al., 1994). This is high, when considering the South African fraction of the world's economy and population.

The major proportion of the environmental impact of residential buildings can be attributed to the energy consumption for space heating and cooling (Shar et al., 2008). Yilmaz and Kundakci (2008) in their recent research paper found that parallel to the population growth in the world, the energy demand is increasing and countries are searching for new methods of energy conservation. They go on to say that sources of energy are mostly of fossil origin which causes environmental problems and trouble in ecological cycles. Poel et al., (2007) state that European Union (EU) member states are working intensively to improve energy efficiency in all end-use sectors by increasing the exploitation of renewable energy sources (RES) in order to tackle environmental concerns deriving from energy consumption of fossil fuels and to support self-sufficiency and energy security. They go further to explain that energy efficiency plays a key role in meeting the EU target in accordance to the Kyoto Protocol commitments to reduce carbon dioxide emissions in an economic way.

Research by Pasupathy et al., (2008) indicates that passive energy provides a valuable solution for correcting the mismatch between the supply and demand of energy. Lee and Chen (2008) suggest that buildings, being the dominant energy consumers in modern cities, present a unique opportunity of cutting back energy consumption through improvement of energy efficiency.

The Draft Energy Efficiency Strategy of the Republic of South Africa (2004) reports that energy efficiency reduces the atmospheric emission of harmful substances such as oxides of sulphur, oxides of nitrogen and smoke. Such substances are known to have an adverse effect on health and are frequently primary causes of common respiratory ailments. Energy efficient homes not only improve occupant health and wellbeing, but also enable adequate provision of energy services to the community at affordable costs.

2.4 Thermal comfort and energy efficiency

Thermal comfort can be described as that temperature at which a person neither feels hot or cold, but still has enough energy to be productive (Roberts, 2001). In order to feel comfortable in a house in winter, the indoor temperature should be higher than the outdoor temperature, but in summer the indoor temperature should be lower than the outdoor temperature. The challenge for engineers and architects is to provide occupants with a comfortable indoor environment, while keeping energy costs at a low level.

(Nicol and Humphreys, 2002) list the variables which influence thermal comfort as follows

- temperature,

- air velocity,

- humidity and

- solar radiation

Air temperature and relative humidity have significant impact on thermal comfort. Data from the South African building manual, (2005), indicate that relative humidity below 30% cause dry skin, eye irritation and respiratory problems. Relative humidity above 60% provides an environment conducive to the growth of mould, mildew and dust mites that cause allergic reactions. The South African Residential Building Code (SABC) recommends an indoor temperature range of 16-28°C and a relative humidity range of 30-60%. SABC recommends an average natural infiltration rate of $0.35m^3/hm^2$ (air change rate) and an indoor carbon dioxide concentration less than 0.5% (Myers, 2004).

2.4.1 Designing buildings for thermal comfort and energy efficiency

South Africa is divided into twelve unique climatic regions, each with a different thermal comfort zone, requiring different design strategies to obtain thermal comfort in houses (Roberts, 2001). Certain design strategies can be used to achieve indoor thermal comfort within the comfort zone, but this differs for different climatic regions and different seasons. Summer and winter thermal neutrality temperatures for different climatic regions of South Africa are shown on the maps below.

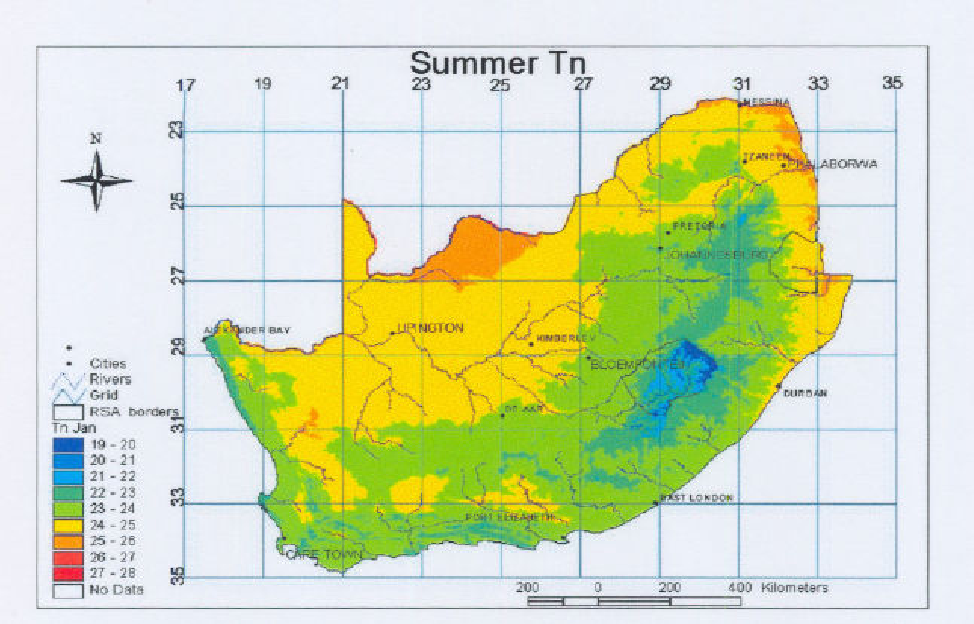


Figure 2.1 summer thermal neutrality temperatures for South Africa Adapted from (Thesis by H.C.Harris, 2003)

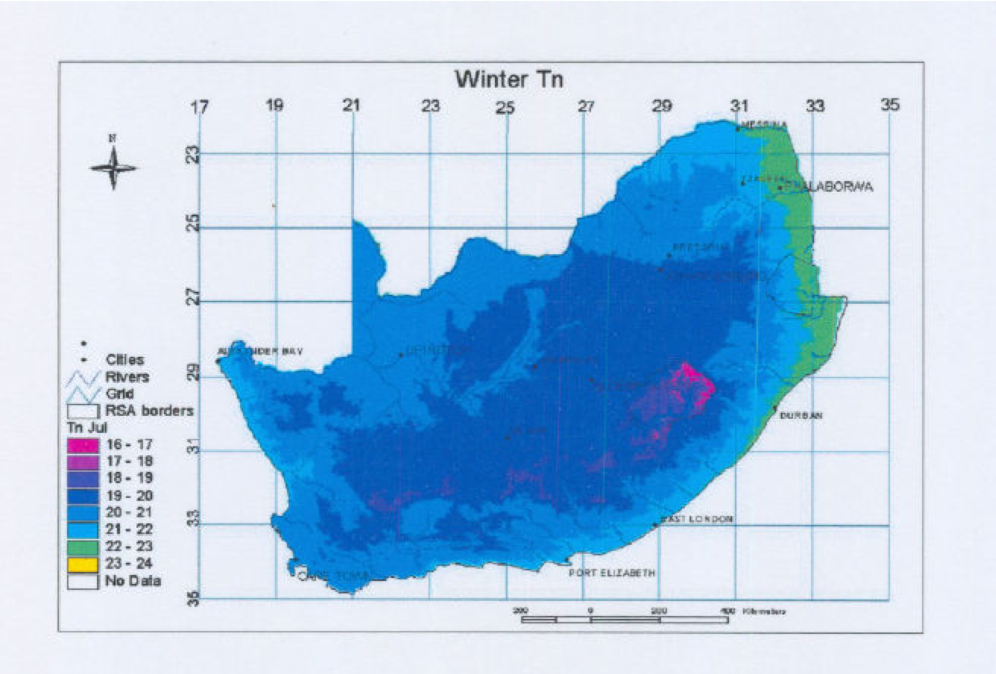


Figure 2.2Winter thermal neutrality temperatures for South Africa Adapted from (Thesis by H.C.Harris)

It is possible to model passive designs, such that winter solar gain, and summer night-time ventilation, to maintain temperatures within the range of thermal neutrality. Thus it is possible to eliminate the need for artificial heating or cooling. The South African climate is relatively mild in comparison with climates of similar latitudes, as a result of the effects of altitude and influences of the warm Indian Ocean. This mildness of climate implies that daytime fluctuations of outside temperature do, even in the extremes of summer or winter, enter the range of local thermal comfort at some hours of the day (Roberts, 2001).

2.5 Thermal simulations as design tool for residential buildings

Sustainable products and services gain an ever-widening market share in a resource limited world. For the design of buildings this has led to the application of new technologies and strategies in performance considerations, such as energy, comfort, cost, aesthetics, and environmental impact. Numerical simulation has proven itself as a valuable tool during the design stage, because it makes it easy to test ideas and see the impact of the decisions made by designers and engineers on energy consumption and the environment (Strand et al., 2004).

2.5.1 Overview of some selected building thermal simulation software

2.5.1.1 QUICK

QUICK is a thermal analysis programme that was developed by the Centre for Experimental and Numerical Thermo-flow at the University of Pretoria (Mathews et al., 1999). By means of a unique thermal model, all aspects of a building, such as the combination of building materials, ventilation and outdoor climate are taken into consideration (Richards, 1992). QUICK is flexible, it allows for separate investigation into various factors such as climate, building orientation, exterior colour, building technique, etc.

2.5.1.2 ECOTECT

Ecotect is a highly visual architectural design and analysis tool that links a comprehensive three dimensional modeler with a wide range of performance analysis functions covering thermal, energy, lighting, shading, acoustics and cost aspects. Whilst its modeling and analysis capabilities can handle geometry of any size and complexity, its main advantage is a focus on feedback at the earliest stages of the building design process.

In addition to standard graph and table-based reports, analysis results can be mapped over building surfaces or displayed directly within the spaces. This includes visualization of volumetric and spatial analysis results, including imported 3-Dimensional computational fluid dynamics (CFD) data. Real-time animation features are provided along with interactive acoustic and solar ray tracing that updates in real time with changes to building geometry and material properties (Drury et al., 2005).

2.5.1.3 TRNSYS

TRNSYS is a transient system simulation programme with a modular structure that was designed to solve complex energy system problems by breaking the problem down into a series of smaller components. TRNSYS components (referred to as "Types") may be as simple as a pump or pipe, or as complicated as a multi-zone building model (Drury et al., 2005).

The components are configured and assembled, using a fully integrated visual interface known as the TRNSYS Simulation Studio, and building input data is entered through a dedicated visual interface (TRNBuild). The simulation engine then solves the system of algebraic and differential equations that represent the whole system (Drury et al., 2005).

In building simulations, all HVAC-system components are solved simultaneously with the building envelope thermal balance and the air network at each time step. In addition to a detailed multizone building model, the TRNSYS library includes components for solar thermal and photovoltaic systems, low energy buildings and HVAC systems, renewable energy systems, cogeneration, fuel cells, etc. (Drury et al., 2005).

The modular nature of TRNSYS facilitates the addition of new mathematical models to the programme. In addition to the ability to develop new components in any programming language, the programme allows to directly embed components implemented, using other software (e.g. Mat lab/Simulink, Excel/VBA, and EES). TRNSYS can also generate executables that allow a non-expert to run parametric studies (Drury et al., 2005). A detailed comparison of some twenty building simulation programmes, as given by Drury et al., (2005), is shown in Tables 1-6 in Appendix A.

2.5.2 Status of energy efficient design tools in South Africa

There is a need for energy efficient housing design tools in South Africa, because only limited tools exist (Roberts, 2001). The author is only aware of a software package, New Quick that was developed by Prof. E.H. Matthews from the University of Pretoria, which simulates the conditions in a house, based on climate data and other inputs.

It is especially important to have energy efficient housing design tools at this stage in South Africa's history because of the big housing drive that currently exists. Not only is it less expensive to build the houses right than to retrofit, but it also implicates lifetime energy savings. The energy savings become significant in the light of an ever- increasing peak demand by the domestic energy sector for electricity and the looming shortage of capacity to supply electricity (Roberts, 2001).

2.6 Conclusion

Although passive systems are simple, their execution involves subtle complexities. The system must work in all kinds of weather, heating in the winter and cooling in the summer (Balcomb, 2006).

A report from United States' Department of Energy Electricity and Reliability (2006) reports that buildings using passive design principles do not have to cost more up front than conventionally designed buildings and when they do, the savings in energy bills quickly pay for themselves.

Research by Mathews et al., (1999), and Webber and Harris (2006), in South Africa has shown energy savings from individual interventions. However, Chiras (2002) suggests that many features make a small difference by themselves, but combined, they may make a large difference. Therefore, this dissertation develops a comprehensive survey and analysis of passive design strategies, in isolation as well as in combination, using middle to high income Ecotect- v 5.6 model for a residential building in Bloemfontein, South Africa.

Chapter 3: FIELD STUDIES

3.1 Introduction

The field studies were primarily done to acquire data for calibration of the Ecotect v 5.6 model. Mr. Rampai's house in Fauna, Bloemfontein (latitude 29.1 S, longitude 26.3 E, altitude 1353 m) was chosen as the case study house, after approaching various owners of households in low to high income suburbs. The field studies were conducted from 18 to 24 May 2009. Figure 3.1 shows the location of Fauna

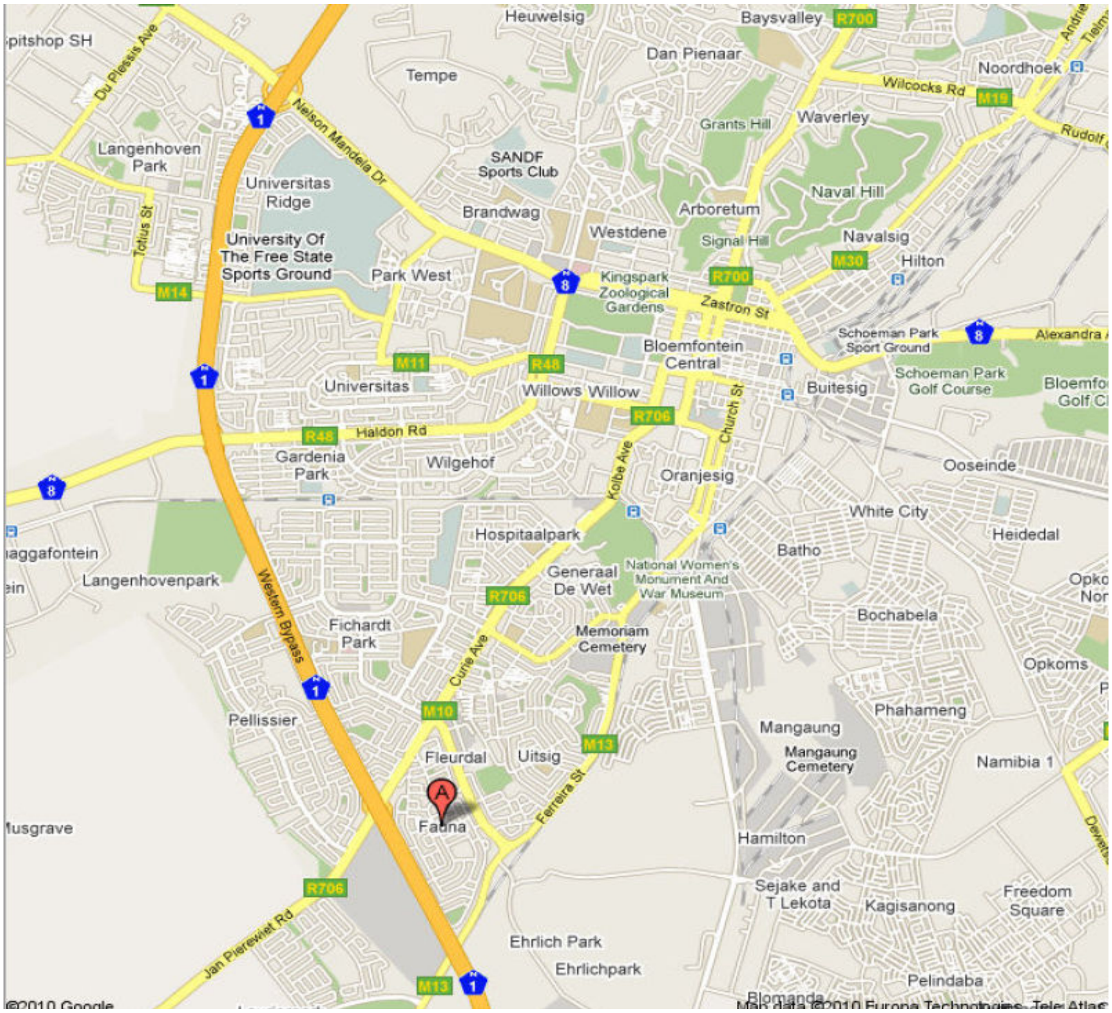


Figure 3.1: Map for Bloemfontein showing Fauna (Map from Google Maps)

3.2 Case study house

The case study house was selected according to the criteria as reviewed by Mathews et al., (1999). The most important factor in determining a typical house is the total floor area (including garage and outbuildings) (Mathews et. al., 1999). Table 3.1 below shows the typical floor areas for middle to high income residential buildings in various major cities of South Africa.

Table 3.1 Typical floor areas for the middle income house/ suburban houses (Mathews et al., 1999)

Major city	Total floor area [m^2]
Pretoria	173
Johannesburg	200
Durban	160
Bloemfontein	180-200
Cape Town	150-180
Average	180

The case study house has brick external walls and plastered single brick internal walls. The roof is of concrete tiles, supported by a timber roof structure with a timber board ceiling (see Figure 3.2 and 3.3). The western façade has the highest window area. The openings are single glazing with steel frame. The main facade has a north east orientation. The study-room and the bedrooms have carpet finishing on the floor and the dining room has tile flooring.

Figure 3.2: Case study House – main facade.

Figure 3.3 Case study House – Western facade.

Occupancy of the house was constant throughout the field study. Three adults and two children lived in the house. The parents worked normal hours, thus were not at home for most of the day. There were two school going children who were at home in the afternoons. The maid was the only one who spent most of the time at home.

3.3 General description of the field experiment

The field study primarily involved measurement of temperature and humidity in the dining room of the case study house. A temperature and humidity data logger (Ecolog TH1) was placed in an appropriate location inside the dining room, as shown in Figure 3.4. Data from the data logger is presented in Appendix B.

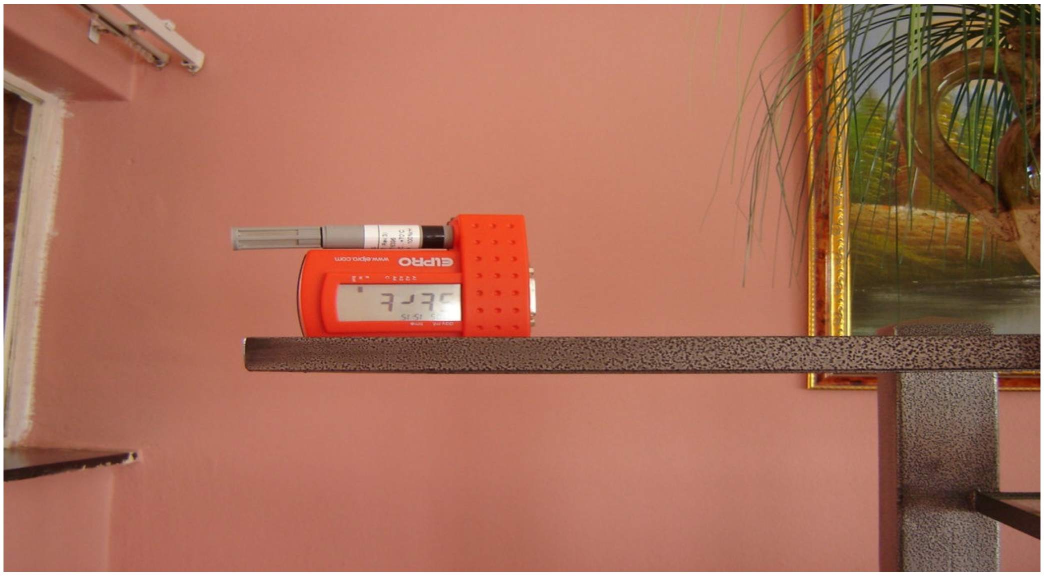


Figure 3.4 *Ecolog TH1 temperature and humidity data logger.*

Measurements were taken for seven days, from 18 May 2009 to 24 May 2009. The measurements included 24 hourly indoor temperatures and relative humidities. The temperatures and humidities are presented in Appendix B. These measurements conducted on the case study house not only provided valuable insights into its thermal performance, but also made it possible to correct the material property values for the computer model with which the dynamic thermal performance of the building was simulated with the real performance as recorded.

3.4 Results of thermal monitoring

3.4.1 Measured thermal behaviour

The thermal behaviour of the case study house was analysed both by evaluating the real time temperature and humidity readings obtained from the TH1 data logger. Results of these are discussed in the following sections. Three qualities are important when evaluating temperature and humidity charts: fluctuation, trend and time lag.

Figure 3.5 below shows the variation of indoor air temperature (measured) of the house compared to outdoor air temperature change with the time of the day. Temperature measurements of 24 hours were presented because similar variation was observed everyday (see Appendix C for Data and graphs for 18 to 24 May 2009).

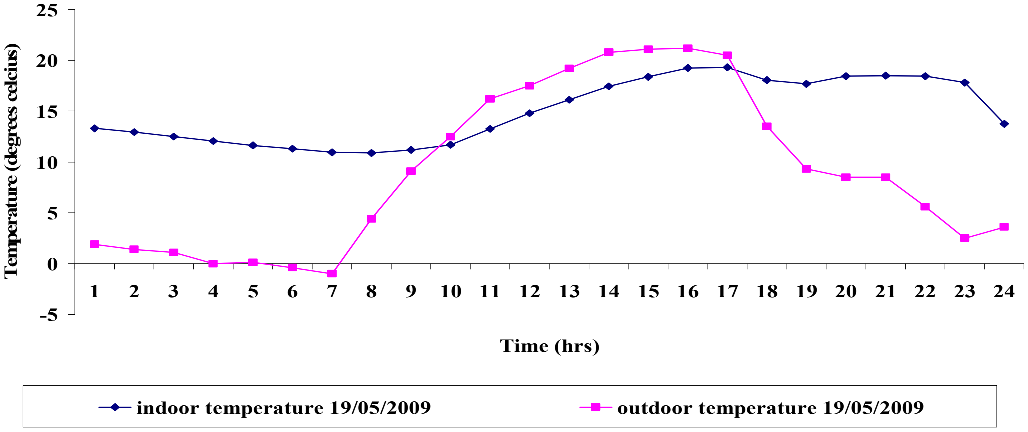


Figure 3.5: indoor temperature (shown by blue line) for the base case house plotted against outdoor air temperature (shown by pink line) for 18 May 2009

The maximum outdoor air temperature reached was 21°C (at 16:00) and a minimum of -1°C (at 07:00). The maximum indoor temperature reached was 19.31 °C (at 17:00) and a minimum of 10.88 °C (at 08:00). The indoor temperature of the house was observed to have a fast response to the outdoor temperature change, giving a temperature swing of 8.43 °C and a thermal lag of 1 hour.

The temperature data for the whole week were combined and presented in a single chart (Figure 3.6), in order to visualize the variation of indoor temperature with outdoor temperature changes.

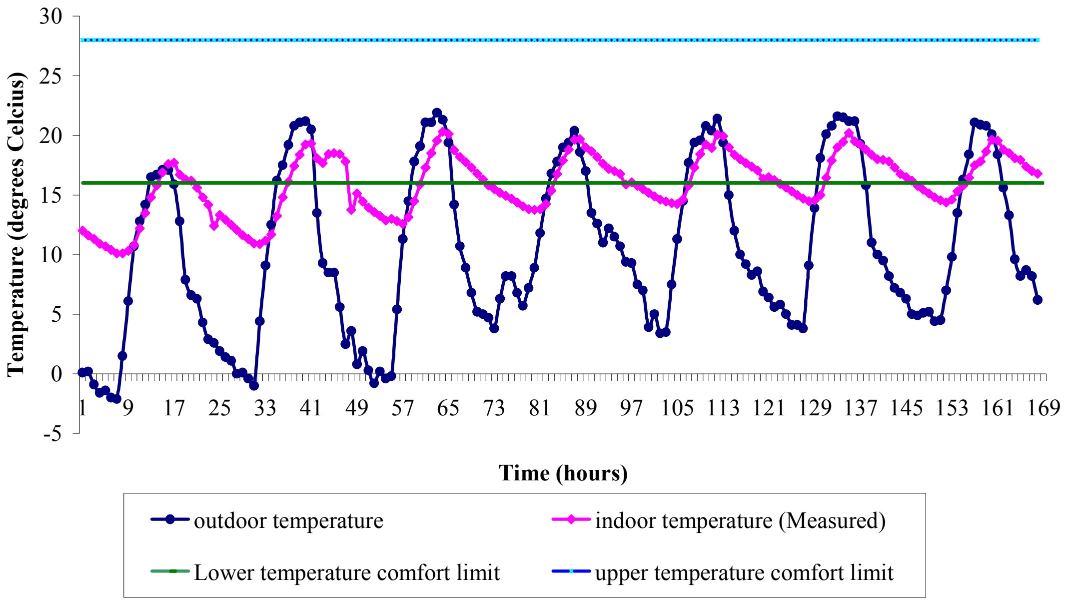


Figure 3.6 indoor temperature (shown by pink line) for the base case house plotted against outdoor air temperature (shown by blue line) for one week period between 18 May and 24 May 2009

The average temperature for the outside is 10.3 °C, whereas the average temperature for the measured indoor temperature is 15.91 °C. An observation of the general trend of the graphs in Figure 3.6 shows that the indoor temperatures dipped and peaked like the outdoor temperatures, showing the general influence of the outside temperature to the inside, without consideration of the effect of HVAC.

The temperature data for the whole week were combined and presented in a single chart (Figure 3.6) in order to visualize the variation of indoor temperature within comfort limits. A house is thermally comfortable from 16-28°C, according to the South African Building Manual (2005). According to the measured temperature variation, the house was only comfortable for 84 hours out of the 168 hours monitored.

The indoor relative humidity followed the fluctuations of the outdoor relative humidity, with the outdoor relative humidity being higher than the indoor relative humidity. Maximum relative humidity occurred in the morning at around 07:00 and minimum relative humidity occurred in the afternoon at around 15:30.

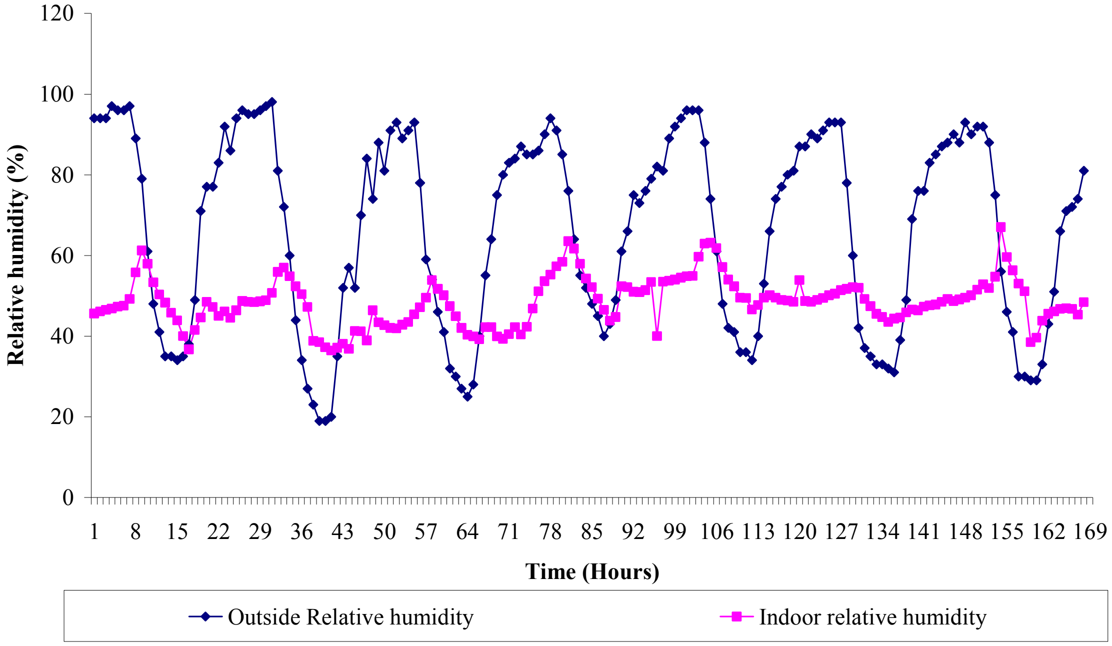


Figure 3.7 Indoor (measured) relative humidity (shown by pink line) for the base case house plotted against outdoor relative humidity (shown by blue line) for one week period between 18 May and 24 May 2009

Chapter 4: BUILDING MODELING AND CALIBRATION

4.1 Introduction

This chapter describes the development of the calibration phase of the Ecotect simulation programme. The construction details of the case study house were recorded in the programme, as well as a weather file for Bloemfontein. The results of fieldwork measurements were compared with thermal simulations from Ecotect™ thermal simulation tool (Ecotect™ v.5.6). Calibration of simulation models is necessary for accuracy and usability of building analysis simulation software. The calibration process compares the results of the simulation with measured data and tunes the simulation until its results match the measured data (Yiqun et al., 2007).

4.2 Brief description of the building thermal analysis programme Ecotect V 5.6.

Ecotect v 5.6 is the building thermal analysis programme that was used in this research for the analytical studies, including the calibration phase. Ecotect simulation software was developed by Square One Research Limited and Dr Andrew J. Marsh from the United Kingdom. The software combines a 3-Dimensional design interface with a set of performance analysis functions and interactive information displays. Ecotect is a software tool which simulates thermal performance of buildings, natural ventilation analysis and prediction of energy consumption. In this research thermal simulations and prediction of energy consumption for HVAC systems are presented.

Ecotect™ is unique in that it is capable of performing a wide range of building analysis calculations within an interactive 3D environment. Other comparable software programmes tend to rely on text-based input, or only perform a limited range of analysis calculations [1].

4.3 Weather data preparation and first calibration of the model

4.3.1 Weather Data

When weather data for the given region are available, simulations can be done for different times of the year. Thus it is possible to evaluate the effect of building materials and climatic factors on thermal comfort for any building. It is also possible to calculate the amount of energy required for space heating and cooling in order to maintain the ideal conditions for thermal comfort.

The weather file used in Ecotect consists of a group of parameters relating to the weather site and hourly values of seven climate variables: Global Radiation, Diffuse Radiation, Cloud Cover, Dry-bulb Temperature, Relative Humidity, Wind Speed and Wind Direction.

Only weather files for Cape Town and Johannesburg are in the data base for Ecotect simulation software. Hourly weather data for the whole year (2008) for Bloemfontein, South Africa were obtained from Department of Soil, Crop & Climate Sciences, Faculty of Natural and Agricultural Sciences, University of the Free State, Bloemfontein, South Africa (see Appendix D for the weather data). These data included hourly outdoor:

- relative humidities,

- temperatures,

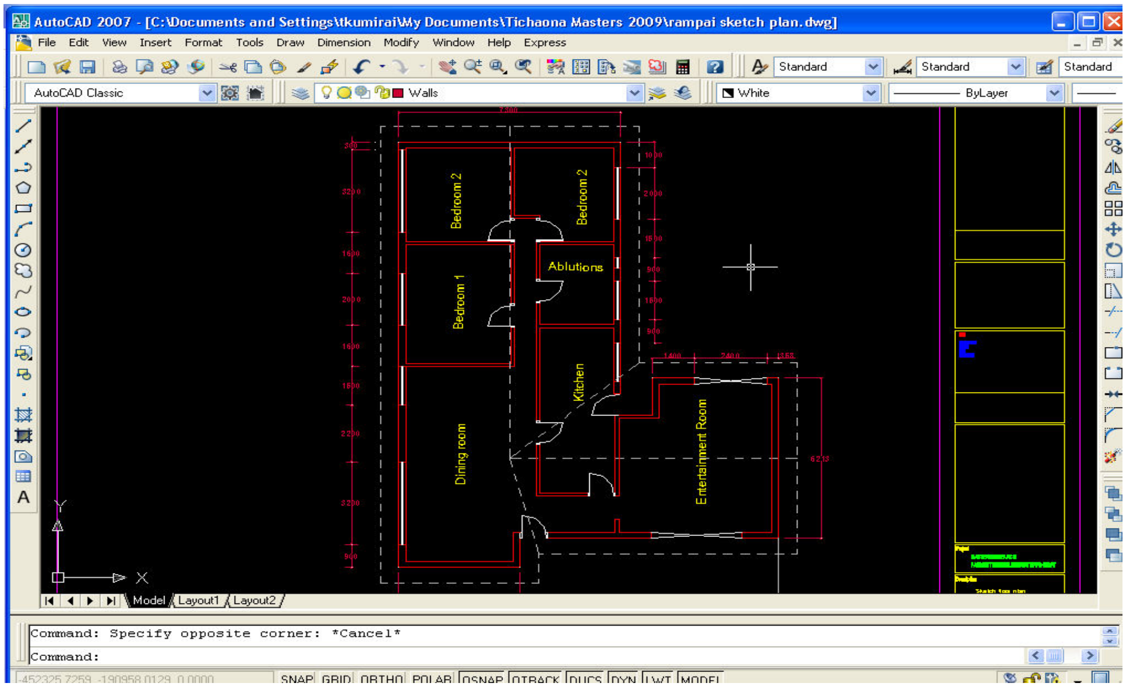
- global solar radiation and

- wind speed

These data were used because they affect the thermal comfort performance for buildings. A weather file was created for Bloemfontein so that the passive interventions suggested in this dissertation are specifically applicable in both new constructions and retrofitting residential buildings in Bloemfontein.

4.4 Measurements to come up with an as-built architectural plan

A 100 metre tape measure was used for measurements to come up with an as-built plan. This was done because the owner of the case study house did not have a plan of the house. Particular attention was in measuring widths of windows, lengths and widths for various rooms and door positions, as these are the inputs required for modelling the house in Ecotect simulation software. The as- built plan was drawn using AutoCAD 2007 software and is presented in Figure 4.1 (see Appendix E for the plotted house plan).



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Command: Specify opposite corner: *Cancel*
Command:
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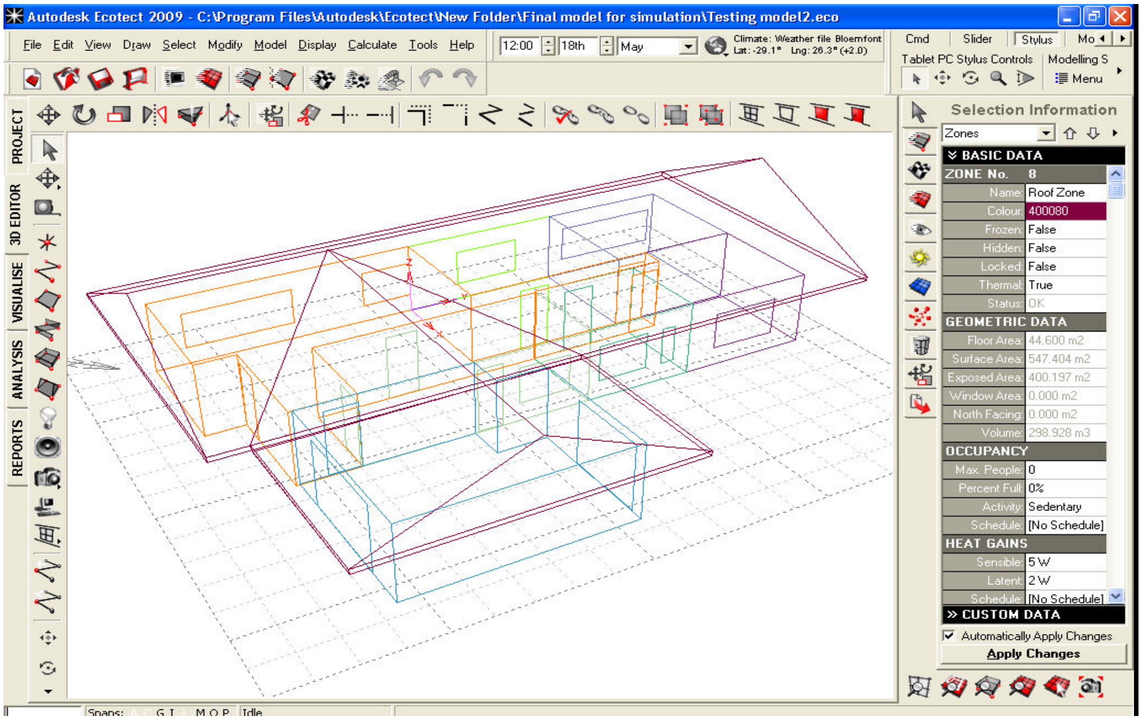
Figure 4.1: As built plan drawn in AutoCAD 2007.

4.5 Ecotect model

The model was generated in Ecotect™, using the measurements from the as built plan of the case study house. Some new materials were introduced in the materials database of Ecotect to better represent the South African materials used in the house. The thermal property values for these materials were calculated from Ecotect™ material property. The shortcoming of Ecotect™ on creating new materials is that it is not able to calculate thermal lag for new materials. Ecomat™ v 1.0 software was used for the calculation of thermal lag. Ecomat™ v 1.0 calculates thermal lag according to the standard: EN ISO 13786:2007. The standard is termed Thermal performance of building components - Dynamic thermal characteristics - Calculation method (ISO 13786:2007). This method corresponds with CIBSE Admittance Method, which is the method used by Ecotect™ for its thermal calculations [2]. Tables from Ecotect™, showing the main input data (sections and thermal properties of building materials) can be seen in Appendix F. This final Input Data represents the Base-case. Three-dimensional models of the base case house studied, generated with the simulation software Ecotect™ V5.6 are shown in the Figures 4.2 and 4.3 below.



Autodesk Ecotect 2009 - C:\Program Files\Autodesk\Ecotect\New Folder\Final model for simulation\Testing model2.eco

12:00 18th May

Climate: Weather file Bloemfont
Lat: -29.1° Lng: 26.3° (+2.0)

Selection Information

Zones

BASIC DATA

ZONE No.	8
Name	Roof Zone
Colour	400080
Frozen	False
Hidden	False
Locked	False
Thermal	True
Status	OK

GEOMETRIC DATA

Floor Area	44.600 m2
Surface Area	547.404 m2
Exposed Area	400.197 m2
Window Area	0.000 m2
North Facing	0.000 m2
Volume	298.928 m3

OCCUPANCY

Max. People	0
Percent Full	0%
Activity	Sedentary
Schedule	[No Schedule]

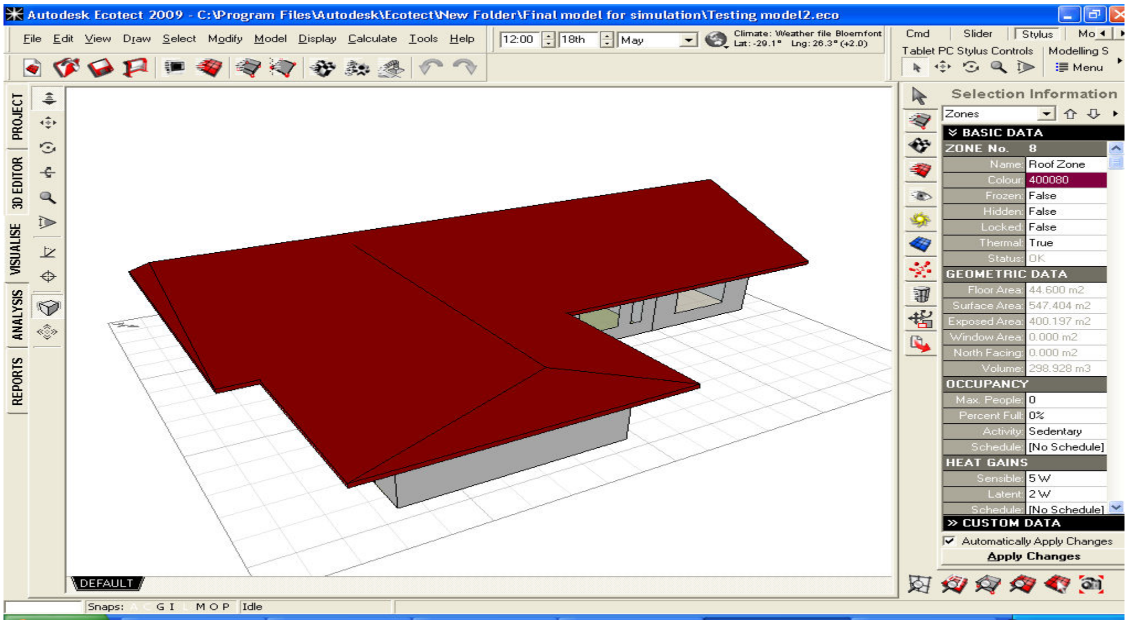
HEAT GAINS

Sensible	5 W
Latent	2 W
Schedule	[No Schedule]

CUSTOM DATA

☑ Automatically Apply Changes

Figure 4.2: Model in a perspective view.



Autodesk Ecotect 2009 - C:\Program Files\Autodesk\Ecotect\New Folder\Final model for simulation\Testing model2.eco

12:00 18th May

Climate: Weather file Bloemfont
Lat: -29.1° Lng: 26.3° (+2.0)

Selection Information

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Floor Area	44.600 m2
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Window Area	0.000 m2
North Facing	0.000 m2
Volume	298.928 m3

OCCUPANCY

Max. People	0
Percent Full	0%
Activity	Sedentary
Schedule	[No Schedule]

HEAT GAINS

Sensible	5 W
Latent	2 W
Schedule	[No Schedule]

CUSTOM DATA

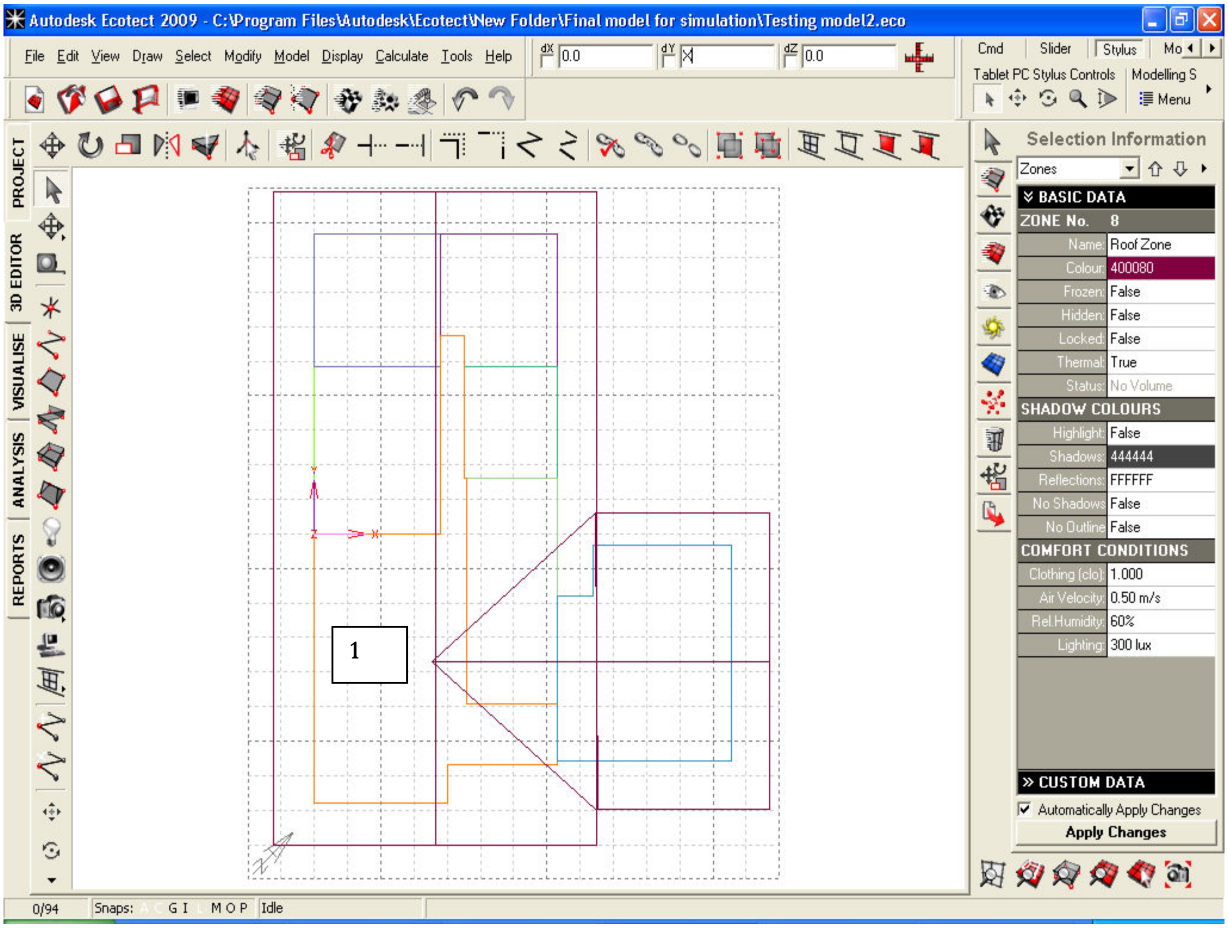
☑ Automatically Apply Changes

Figure 4.3: A 3D view of the thermal model base case house developed in Ecotect v.5.60.

4.5.1 Considerations in the Model

4.5.1.1 Zones

All rooms of the residence were considered as a different zone, to take into account the thermal exchanges between rooms. However, the interest in the results was concentrated only on one zone: Dining/passage zone, because it was the zone which was monitored in the field work. Figure 4.4 below shows a floor plan view for the model in Ecotect™. The dining/passage zone is the area enclosed by the light brown coloured line and labeled 1.



Autodesk Ecotect 2009 - C:\Program Files\Autodesk\Ecotect\New Folder\Final model for simulation\Testing model2.eco

dX 0.0
dY X
dZ 0.0

Selection Information

Zones

BASIC DATA

ZONE No. 8

Name: Roof Zone
Colour: 400080
Frozen: False
Hidden: False
Locked: False
Thermal: True
Status: No Volume

SHADOW COLOURS

Highlight: False
Shadows: 444444
Reflections: FFFFFF
No Shadows: False
No Outline: False

COMFORT CONDITIONS

Clothing (clo): 1.000
Air Velocity: 0.50 m/s
Rel.Humidity: 60%
Lighting: 300 lux

CUSTOM DATA

☑ Automatically Apply Changes

Apply Changes

0/94
Snaps: G I M O P
Idle

Figure 4.4: Floor Plan of the model showing the house rooms (zones) in different colours.

4.5.1.2 Internal Conditions

The value for equipment gains is based in ASHRAE Fundamentals (2001): Sensible heat gain per sedentary occupant is assumed to be 67 W. In single-family houses, a sensible load of 470 W should be considered for appliances divided between the kitchen and laundry areas. In the model, the gains from equipment are considered in zone 1 (dining/passage) and kitchen. The dining area is coupled to the passage, because the passage area is part of the dining area (open plan dining). The default average value of 1 air changes per hour (ach) is considered for air infiltration.

4.6 Results of first calibration

The model was simulated for the period from 18 to 24 May 2009, considering that field data was collected during this period. Figure 4.5 is the graph showing the first simulation (first calibration) for zone 1 (dining/passage). The other graphs showing simulations for the period 18 to 24 May from Ecotect ™are shown in Appendix G.

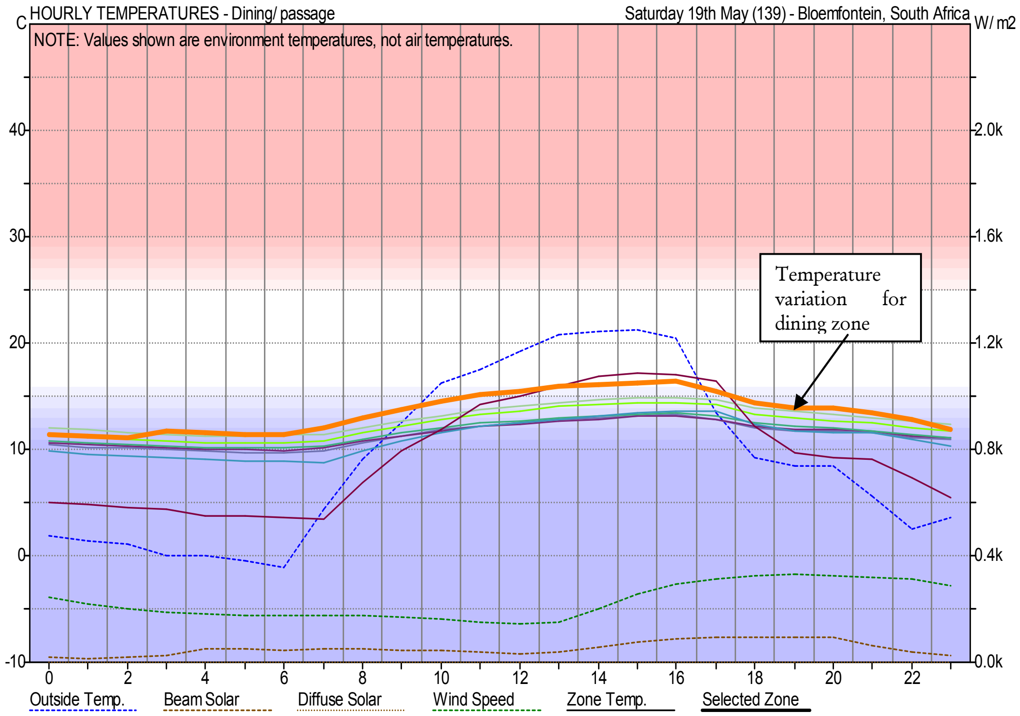


Figure 4.5: Hourly predicted temperature profile inside dining/passage zone (light brown line) on 19 May 2009, compared with 2008 weather data for Bloemfontein displayed in Ecotect v.5.60.

The results of the Ecotect™ simulations under Bloemfontein weather conditions were then transferred into Microsoft Excel format and then combined as a single data set. Simulation results were then compared to the measured data in the fieldwork. Figure 4.6 below gives a comparison between measured indoor, outdoor, and predicted temperatures.

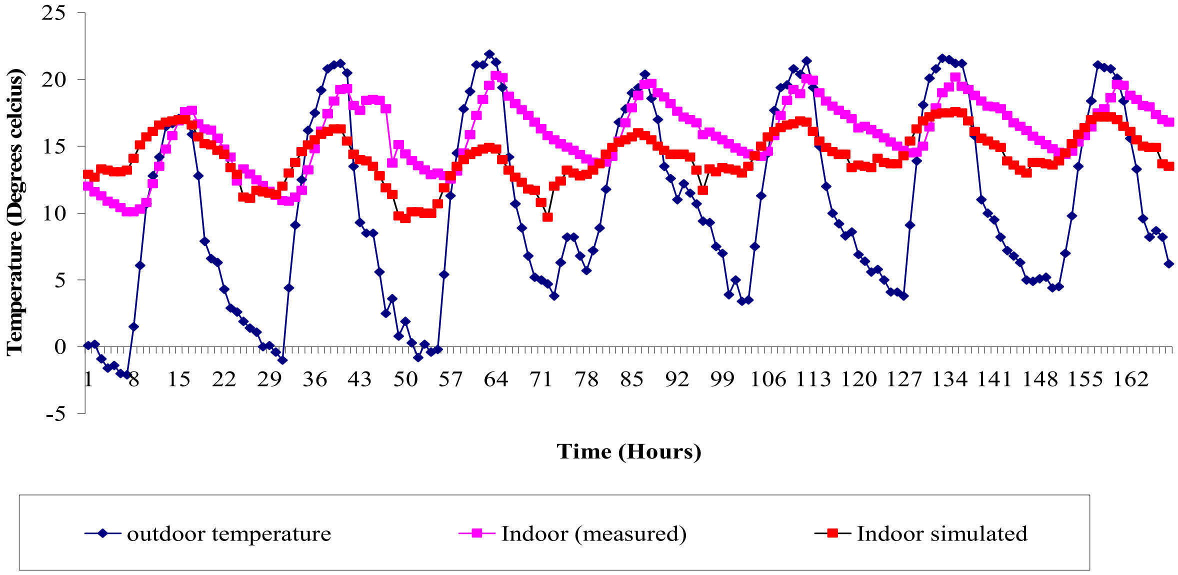


Figure 4.6: Results of first calibration for Zone 1
(Dining/passage room) compared to measurements.

In order to examine the deviations between the measured data and the simulated results, the Mean Bias Error (MBE) and the Root Mean Square Error (RMSE) were calculated. MBE indicates the mean difference of the predicted values from the measured values, whereas RMSE is a measure of deviation of the simulated values around the measured data. MBE and RMSE are calculated as follows:

$$MBE = \sum (Y_i - X_i) \div N \; = \left|-1.64\right|$$

$$RMSE = (\sum ((Y_i - X_i)^2) \div N)^{1/2} \; = 2.81964$$

Where: Y_i = Predicted value

X_i = Measured value

N = Number of observations

ε = error.

Alternatively the magnitude-error (for the means of the simulated and measured temperatures) lies between 10.3% and 11.5%, which was calculated as follows:

$$\frac{\left|\overline{Y}_i - \overline{X}_i\right|}{\left|\overline{X}_i\right|}\% \leq \varepsilon \leq \frac{\left|\overline{Y}_i - \overline{X}_i\right|}{\left|\overline{Y}_i\right|}\% \ ; \ 10.3\% \leq \varepsilon \leq 11.5\%$$

4.7 Sensitivity Analysis

The previous results of calibration were not satisfactory, as the predicted temperatures are under-estimated. Some of those differences may be due to the uncertainty in input data and the difficulty to precisely replicate reality. It is necessary to determine the sensitivity to the key uncertainties such as: climate, geometry and zoning, occupancy characteristics, airflow and control (Robinson, 2003).

In order to get a better agreement between the simulated and measured values and evaluate the sensitivity of Ecotect™ thermal simulation tool, a series of further simulations was performed. Some modifications were implemented to the model and the results were compared to the previous simulation results and against the collected experimental data. The following parameters were investigated and new simulations were performed by varying the specified parameters and keeping the rest as they were previously:

- Air infiltration values;

- Operating schedules for both equipment and occupancy;

- Material thermal properties i.e. overall heat transfer coefficients of materials and thermal lags and

- Building orientation

Air Infiltration: The value of air infiltration was increased from 0.5ach (default) to 1.92 ach (air changes per hour) in all zones. Results demonstrated that some predicted indoor air temperatures increased slightly, when compared to the previous simulation. The new predicted air temperature approximated a little more of the measured one. The value of 1.92 ach of air infiltration seems to better represent the reality.

Opening schedules: In order to evaluate the influence of the external air temperature coming in through the windows on the internal air temperature, an infiltration schedule was done. Results demonstrated that predicted indoor temperature dropped and was different from the measured one. Setting the ventilation schedule to natural ventilation better represents reality.

Sensible gain: Sensible gain values were changed in steps of ten. Results demonstrated increased predicted indoor temperature, as compared to previous simulation. The predicted air temperatures approximated more towards the measured values. The value of 60W/m^2 seems to better represent reality.

Material thermal properties: U values and thermal lags for the walls, ceilings, doors and roof were increased. Results demonstrated increased predicted indoor temperatures, as compared to the previous simulation.

Building orientation: The building orientation was changed and an increase of temperatures was observed. The orientation of 80° seemed to better represent reality.

The model was considered to be naturally ventilated and operating schedules were removed. When the HVAC system of a zone is set to Natural Ventilation, Ecotect assumes that the occupants will automatically open the windows whenever the outside air temperature is within the defined comfort band or closer to it than the current indoor zone temperature. If not, the windows are assumed closed [3].

4.8 Final Calibration

The conclusions from the sensitivity analysis led to a new simulation, taking into consideration the results highlighted above. Hourly predicted temperature profiles (see appendix H for hourly predicted temperatures from 18-24 May) inside the dining/passage zone (Light brown line) on 19 May is shown below (Figure 4.7):

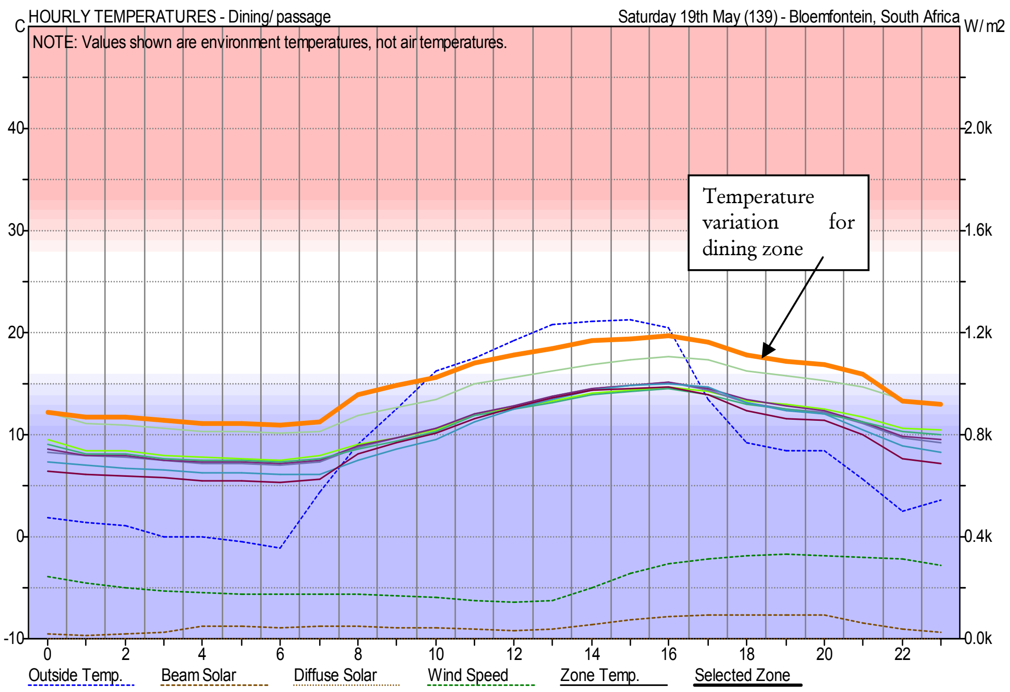


Figure 4.7: Hourly predicted temperature profile inside dining/passage zone (light brown line) on 19 May 2009, compared with 2008 weather data for Bloemfontein, displayed in Ecotect v.5.60.

The results of Ecotect simulations under Bloemfontein weather conditions were then transferred into Microsoft Excel format and then combined as a single data set. Simulation results were then compared to the measured data in the fieldwork. Figure 4.8 below gives a comparison between measured indoor, outdoor, and predicted temperatures.

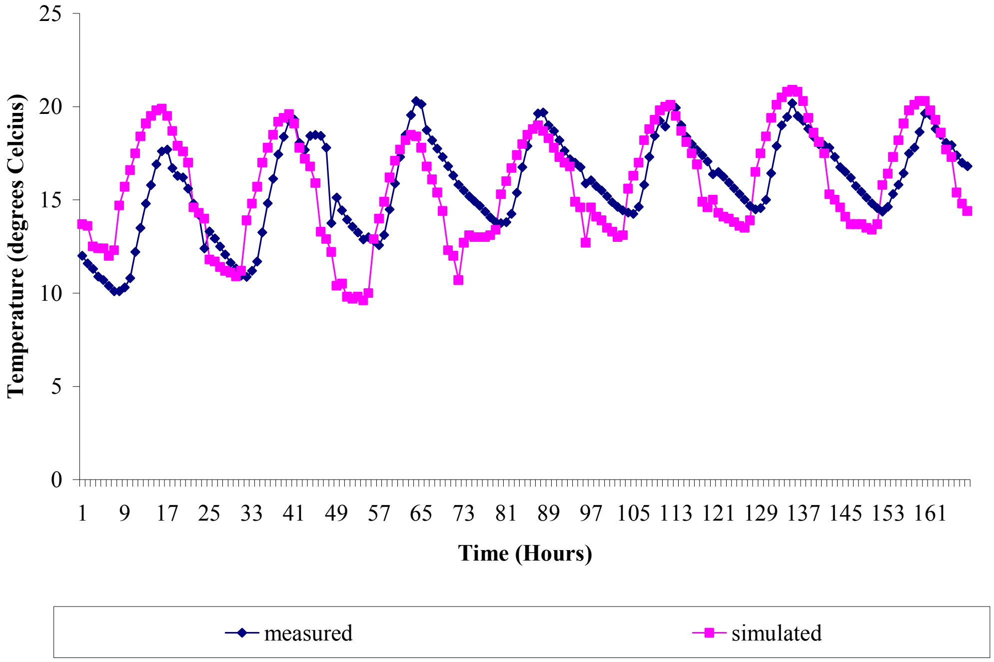


Figure 4.8: Results of final calibration simulation for Zone 1 (dining/passage room) compared to measurements.

The magnitude-error (for the means of the simulated and measured temperatures) lies between 0.364% and 0.365%, which was calculated as follows:

$$\frac{\left|\overline{Y}_i - \overline{X}_i\right|}{\left|\overline{X}_i\right|}\% \le \varepsilon \le \frac{\left|\overline{Y}_i - \overline{X}_i\right|}{\left|\overline{Y}_i\right|}\% \ ; \ 0.364\% \le \varepsilon \le 0.365\%$$

As shown (figure 4.8), the agreement between the collected experimental data (measured) and predicted results (simulated) are variable. There were days when the measurements and simulated results were close and days in which the differences between the two data were more evident. The results showed that, in general, there is an under-estimation of the model, when compared with the measurements for the same period. The reasons for differences between the measured and the simulated data can be as a result of the following factors:

Uncertainty in input data: Sensible gains, thermal properties of the building materials, building occupancy, building air change rates and wind sensitivity and infiltration schedules.

Measurement errors: Temperature sensors give a very localized spatial value, that will usually have some radiant component, whilst simulation tools typically provide spatially averaged temperatures.

Thus, some disparity between the two sets of results is to be expected. Overall, this comparison showed that predicted temperatures showed close agreement with recorded data.

4.9 Yearly predicted thermal performance of base case house.

The following graph (Figure 4.9) shows temperatures along the bottom axis and the number of hours per year spent at each temperature in the vertical axis. The data for the graph is taken from Table 4.1.

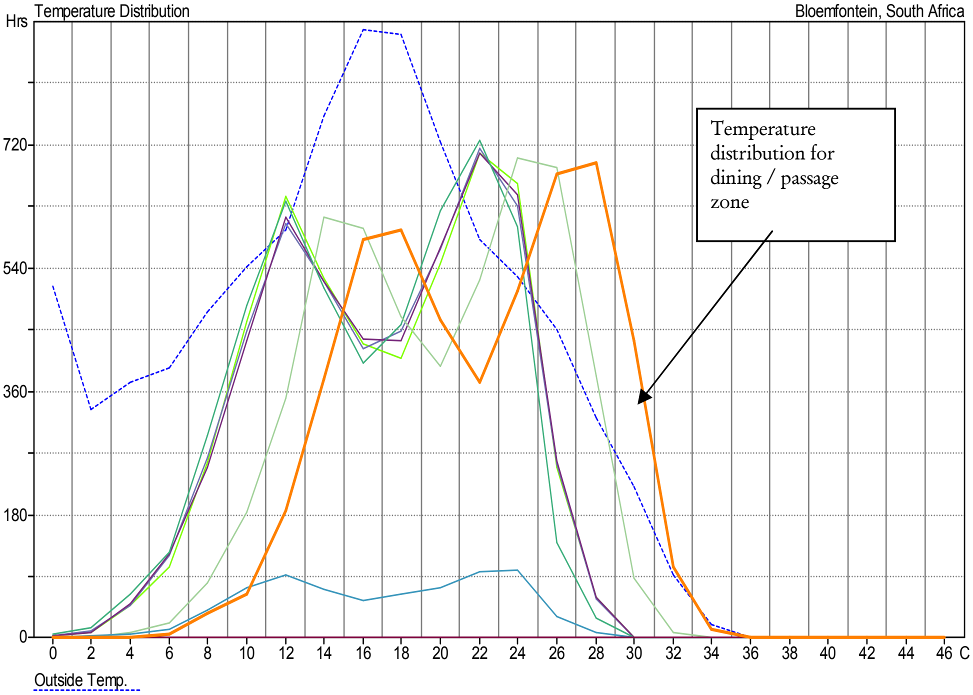


Figure 4.9: Predicted annual temperature distribution for the base case.[1]

Table 4.1 below is from Ecotect and shows specifically the number of hours spent at each temperature for the base case. These results (also plotted in Figure 4.9) were produced, considering that the dining/passage zone was occupied from 07:00 to 21:00 everyday. The thermal comfort band considered is the one prescribed in the SABC of 2005, i.e. 16 – 28 °C.

Table 4.1: Predicted annual temperature distribution for the dining / passage zone of base case

TEMP (°C).	*HOURS*	*PERCENT*
--------	--------	---------
0	0	0.00
2	0	0.00
4	0	0.00
6	6	0.10
8	37	0.70
10	65	1.30
12	185	3.60
14	377	7.40
16	582	11.40
18	594	11.60
20	464	9.10
22	374	7.30
24	506	9.90
26	676	13.20
28	693	13.60
30	434	8.50
32	105	2.10
34	12	0.20
36	0	0.00
38	0	0.00
40	0	0.00
42	0	0.00
44	0	0.00
46	0	0.00
--------	--------	---------
COMFORT	3889	76.10

Table 4.1 above shows that the base case house will be thermally comfortable for 3889 hours during the whole year, which is 76.1% of the total hours in a year.

4.10 Yearly predicted heating and cooling loads of base case house

A comparative chart for the monthly heating (red bar graphs) / cooling (blue bar graphs) loads per usable floor area of the base case house is shown below (Figure 4.10). The assumption made was that the base case house was fully air conditioned. This was done to see how much cooling or heating could be required in order to keep the base case house within the thermal comfort temperature range.

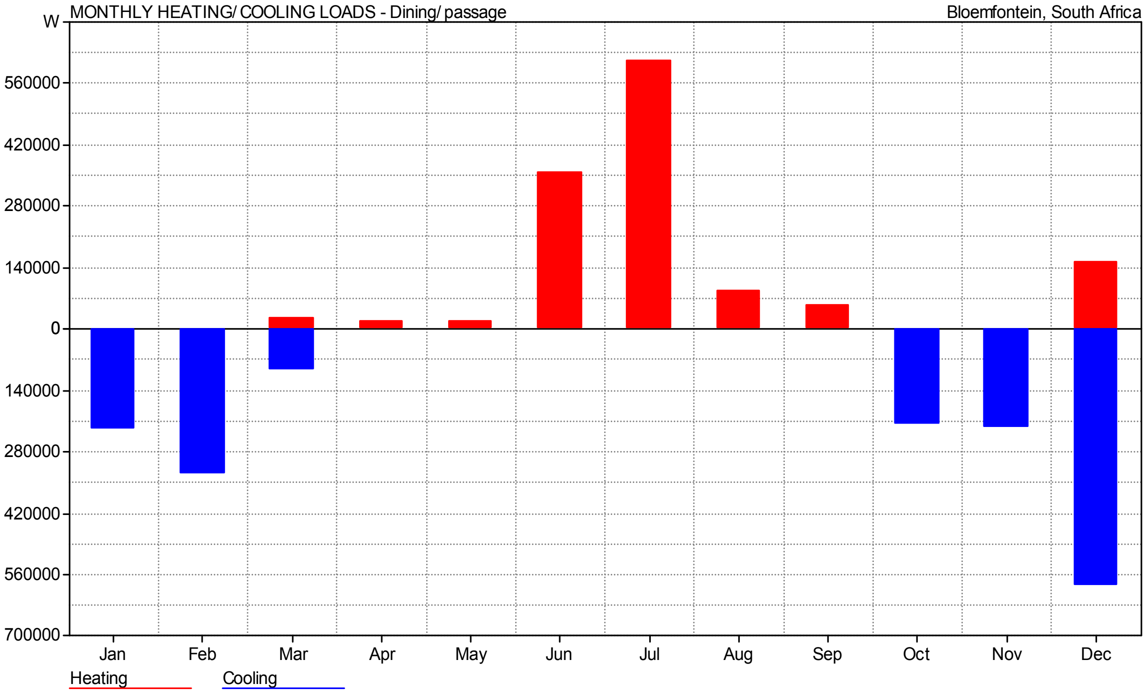


Figure 4.10: Predicted monthly heating and cooling loads for the dining / passage zone of the base case house.

Table 4.2 shows the monthly heating/cooling loads that would maintain the dining/passage zone within thermal comfort region (16-28°C). These results were produced, considering that the dining/passage zone was occupied was occupied from 07:00 to 21:00 everyday. The bar chart generated from data from Table 4.2 is shown in Figure 4.10.

Table 4.2: Predicted monthly heating and cooling loads for the dining / passage zone of the base case house.

MONTH	*HEATING (Wh)*	*COOLING (Wh)*	*TOTAL (Wh)*
Jan	0	229626	229626
Feb	0	330955	330955
Mar	25489	93152	118641
Apr	18174	0	18174
May	18879	0	18879
Jun	356000	0	356000
Jul	610652	0	610652
Aug	88753	0	88753
Sep	55798	0	55798
Oct	0	216380	216380
Nov	0	223836	223836
Dec	153416	586315	739732
-----------	--------	--------	--------
TOTAL	1327161	1680264	3007425
-----------	--------	--------	--------
PER M²	30240	38286	68526
Floor Area:	43.888 m²		

Table 4.2 above shows that the base case house will require 3 007 425 Wh (watt hours) of electricity energy annually to maintain the house within the thermal comfort range (16-28°C). A higher cooling load of 1 680 264 Wh shows that the base case house requires more cooling when compared to heating, which requires 1 327 161 Wh.

4.11 Conclusion

Higher values of MBE (mean bias error) for the predicted temperature with operating schedules have confirmed that the house was naturally ventilated in most of the days of the fieldwork. Therefore natural ventilation is representative and it will be adopted in the base case.

Despite the calibration of the model, the simulation output did not have total agreement with the measurements in the fieldwork. This difference, however, is not a problem if the purpose of simulation is to get values of relative validity, e.g., in parametric studies or for comparative evaluation of design alternatives. In the next chapter, parametric variations will be performed and compared with a base-case.

4.12 References

[1] http://www.ecotect.com/node/2077, accessed 18 January 2010

[2] http://www.ecoeficiente.es/ecomatHelp/index.htm?Features.html, accessed 25/11/2009.

[3] http://ecotect.com/node/70, accessed 24/11/2009.

Chapter 5: Parametric studies

5.1 Introduction

The aim of the parametric studies is to determine the extent to which passive strategies should be applied to improve energy efficiency and thermal performance of the base case house. The parametric analyses were performed using the Ecotect™ V 5.6 Building Analysis Programme and the results from parametric variations are shown.

Passive strategies were incorporated on the Ecotect™ model singly and in combination, then both thermal and space (HVAC) load simulations were obtained and compared to simulations from the original situation (base case) for assessing improvements in terms of thermal comfort and HVAC energy consumption. As a result of the complex interaction of energy flows through various building components, it would be inappropriate to combine results from individual components directly to determine the total energy-saving potential of a group of strategies, for making design decisions.

The analyses considered in the model are as follows:

- Roof insulation;
- Ceiling insulation;
- Outer wall plaster;
- Wall insulation,
- Double glazing;
- Combination of roof insulation, ceiling insulation, outer wall plaster, wall insulation and double glazing,
- Combining roof insulation, outer wall plaster, wall insulation and double glazing and
- Combining roof insulation, outer wall plaster, wall insulation and ceiling insulation

5.2 Effect of roof insulation on thermal performance of base case house

Figure 5.1 shows annual temperature distribution of the dining / passage zone (light brown line 5). The input to the Ecotect™ model was 65 mm wool insulation on the roof (see Appendix I Figure I 2: Roof section with insulation added). Temperature is shown along the bottom axis and the number of hours per year spent at each temperature on the vertical axis. The temperature distribution expresses the fraction of time, over the entire year, in which there is a specific inside temperature. (See Table 5.1 for data of annual temperature distribution). A comparison of the thermal performance of the base case house and the model with 65 mm thick roof insulation is shown in Table 5.3.

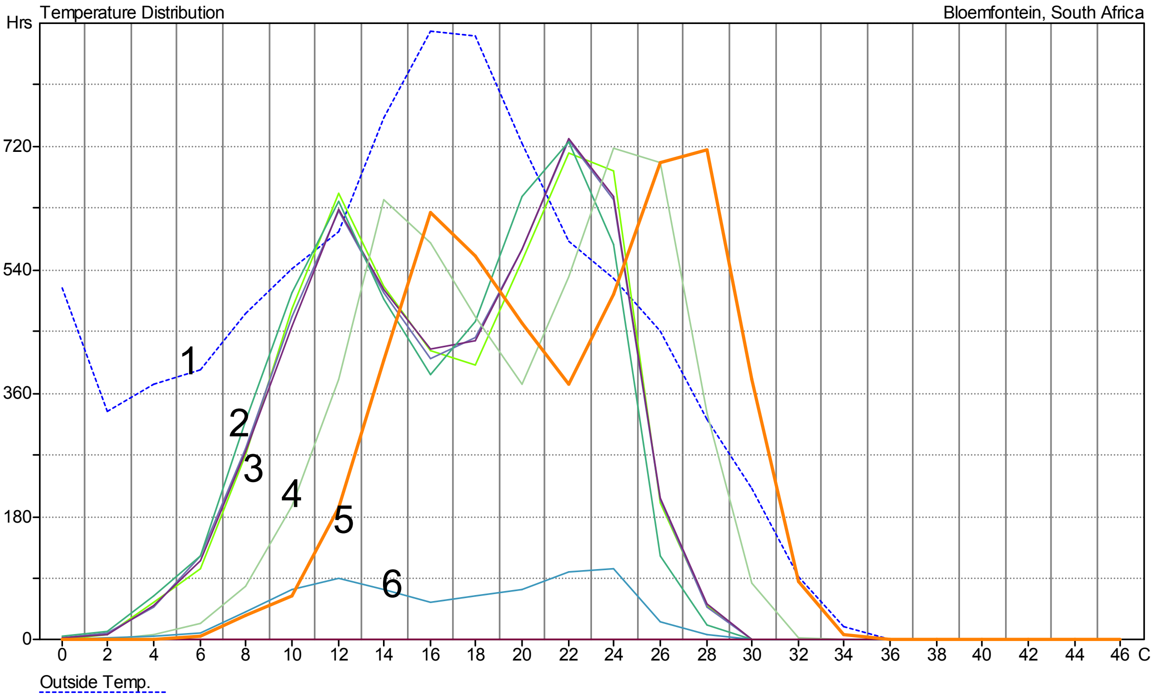


Figure 5.1: Predicted annual temperature distribution for the Ecotect model with 65mm wool insulation on roof. (1- Outside temperature, 2, 3, 4 and 6 –temperature distribution of other zones of the model, 5- temperature distribution for passage / dining zone)[1]

1

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[1] Light green colour represents bedroom 1 zone, light brown represents dining/passage, dark green represents toilet/bathroom, pale blue represents entertainment room, purple represents bedroom 3 zone.

Table 5.1 below shows that the dining / passage zone will be in thermal comfort for 3927 hours, which is 76.8 % of the total number of hours within 1 year. These results were produced considering that the dining / passage zone was occupied was occupied from 07:00 to 21:00 everyday. The thermal comfort band considered is the one prescribed in the SABC of 2005, i.e. 16 – 28 °C. The graph generated from data from Table 5.1 is the light brown line (temperature distribution for the dining / passage zone), shown in Figure 5.1.

Table 5.1: Predicted annual temperature distribution for the dining / passage zone of Ecotect model with 65 mm wool insulation on roof.

TEMP (°C).	*HOURS*	*PERCENT*
--------	--------	---------
0	0	0.00
2	0	0.00
4	0	0.00
6	7	0.10
8	37	0.70
10	64	1.30
12	192	3.80
14	408	8.00
16	622	12.20
18	560	11.00
20	461	9.00
22	372	7.30
24	503	9.80
26	695	13.60
28	714	14.00
30	381	7.50
32	86	1.70
34	8	0.20
36	0	0.00
38	0	0.00
40	0	0.00
42	0	0.00
44	0	0.00
46	0	0.00
--------	--------	---------
COMFORT	3927	76.80

Figure 5.2 below shows a graph of the annual temperature distribution of the dining / passage zone (light brown line). The input to the Ecotect™ model was 100 mm wool insulation on the roof. (See Table 5.2 for data of annual temperature distribution). A comparison of the thermal performance of the base case house and the model with 100 mm roof insulation is shown in Table 5.3.

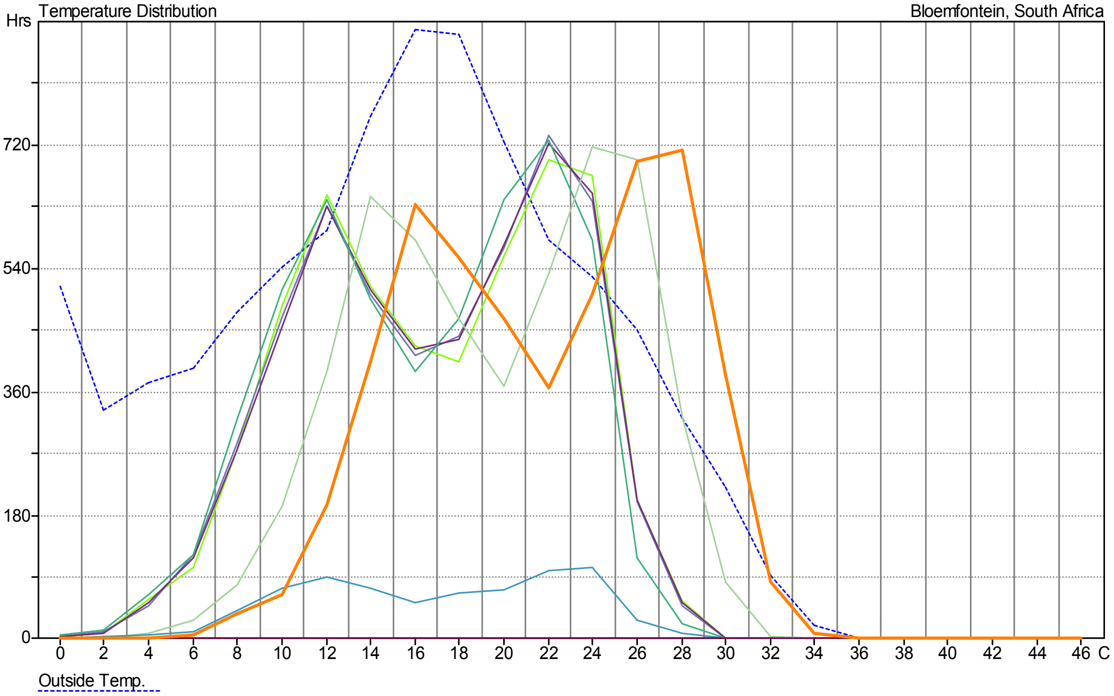

Figure 5.2: Predicted annual temperature distribution for the Ecotect model with 100 mm wool insulation on roof. [1]

Table 5.2 below shows that the dining / passage zone will be in comfort for 3928 hours, which is 76.9% of the total number of hours within 1 year. The graph generated from data from Table 5.2 is the light brown line (temperature distribution for the dining / passage zone), shown in Figure 5.2.

Table 5.2: Predicted annual temperature distribution for the dining / passage zone of Ecotect model with 100mm wool insulation on roof.

TEMP (ºC).	*HOURS*	*PERCENT*
--------	--------	---------
0	0	0.00
2	0	0.00
4	0	0.00
6	7	0.10
8	37	0.70
10	64	1.30
12	196	3.80
14	403	7.90
16	633	12.40
18	555	10.90
20	466	9.10
22	365	7.10
24	502	9.80
26	696	13.60
28	711	13.90
30	384	7.50
32	83	1.60
34	8	0.20
36	0	0.00
38	0	0.00
40	0	0.00
42	0	0.00
44	0	0.00
46	0	0.00
--------	--------	---------
COMFORT	3928	76.90

The first row of Table 5.3 shows thermal performance data for the base case, which are taken from Table 4.1 and also plotted in Figure 4.9. Data of the second row are taken from Table 5.1 and also plotted in Figure 5.1. Data of the third row are taken from Table 5.2 and also plotted in Figure 5.2. In Table 5.3, a mere 0.1 % increase in thermal comfort is shown when roof insulation thickness was increased from 65 mm to 100 mm. Results from Table 5.3 show that roof insulation alone is a measure that improved thermal performance of the case study house by 0.8%.

Table 5.3: Effect of roof insulation on the thermal performance of the dining / passage zone of base case house.

Zone 1(Dining/passage)	*Number of hours within comfort range (16°C-28°C)*	*Reduction (R) or Increasing (I) (%)*
No roof insulation (Base case)	3889	-
65 mm rock wool insulation	3927	0.7 (I)
100mm wool insulation	3928	0.8% (I)

5.3 Effect of roof insulation on HVAC energy consumption of base case house

Figure 5.3 shows the amount of heating (red bar graphs) and cooling (blue bar graphs) that will be consumed by the dining / passage zone of the base case house. The input to the Ecotect™ model was 65 mm wool insulation on the roof. (See Table 5.4 for data of monthly heating and cooling loads for the dining / passage zone). A comparison of HVAC energy consumption of the base case house and the Ecotect™ model with 65 mm roof insulation is shown in Table 5.6.

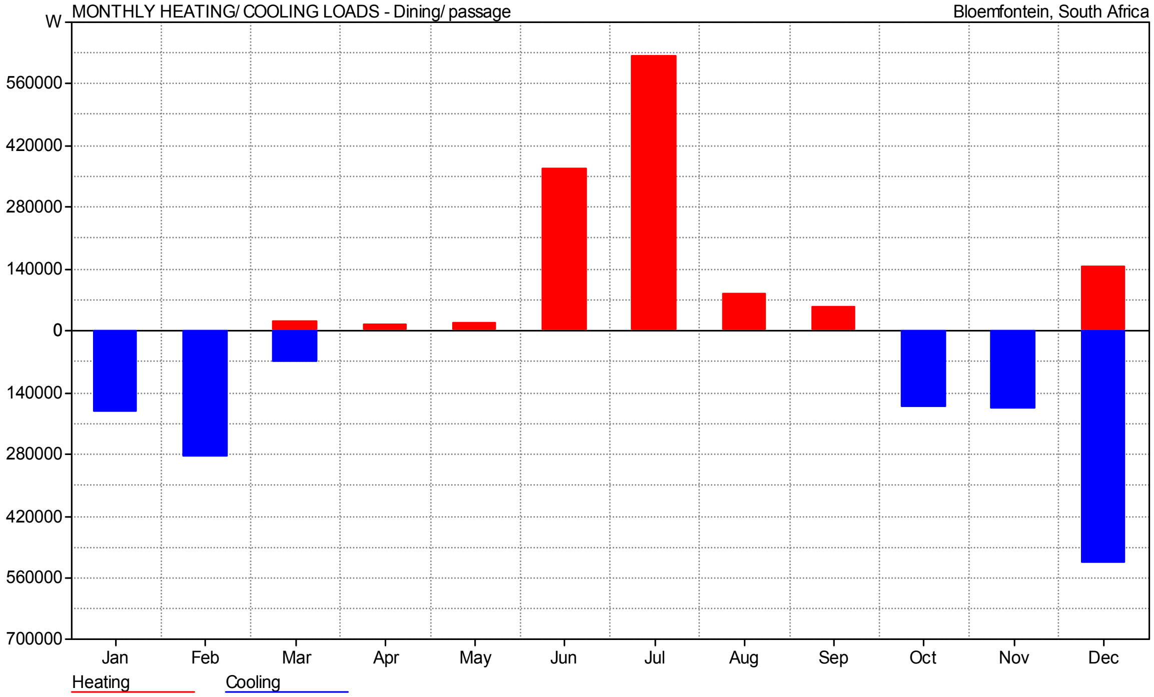

Figure 5.3: Predicted monthly heating and cooling loads for the dining / passage zone of Ecotect model with 65mm wool insulation on roof.

Table 5.4 shows the monthly heating / cooling loads that would maintain the dining / passage zone within the thermal comfort region (16 - 28°C). These results were produced, considering that the dining / passage zone was occupied was occupied from 07:00 to 21:00 everyday. The maximum heating value of 7795 W occurred at 08:00 on 13 July, while the maximum cooling value of 4458 W occurred at 16:00 on the 1st of February (this information was read directly from Ecotect™ simulation software). The bar chart generated from data from Table 5.4 is shown in Figure 5.3.

Table 5.4: Predicted monthly heating and cooling loads for the dining / passage zone of Ecotect model with 65mm wool insulation on roof.

	HEATING	*COOLING*	*TOTAL*
MONTH	*(Wh)*	*(Wh)*	*(Wh)*
-----------	--------	--------	--------
Jan	0	186754	186754
Feb	0	285689	285689
Mar	23142	73220	96362
Apr	16249	0	16249
May	18350	0	18350
Jun	367719	0	367719
Jul	623551	0	623551
Aug	83222	0	83222
Sep	55916	0	55916
Oct	0	173552	173552
Nov	0	178928	178928
Dec	143969	526356	670324
-----------	--------	--------	--------
TOTAL	1332118	1424499	2756618
-----------	--------	--------	--------
PER M^2	30353	32458	62811
Floor Area:	43.888 m^2		

Figure 5.4 shows the amount of heating (red bars) and cooling (blue bars) that will be consumed by the dining / passage zone of the case study house. The input to the Ecotect™ model was 100 mm wool insulation on the roof. (See Table 5.5 for data of monthly heating and cooling loads for the dining / passage zone). A comparison of HVAC energy consumption of base case and the Ecotect™ model with 100 mm roof insulation is shown in Table 5.6.

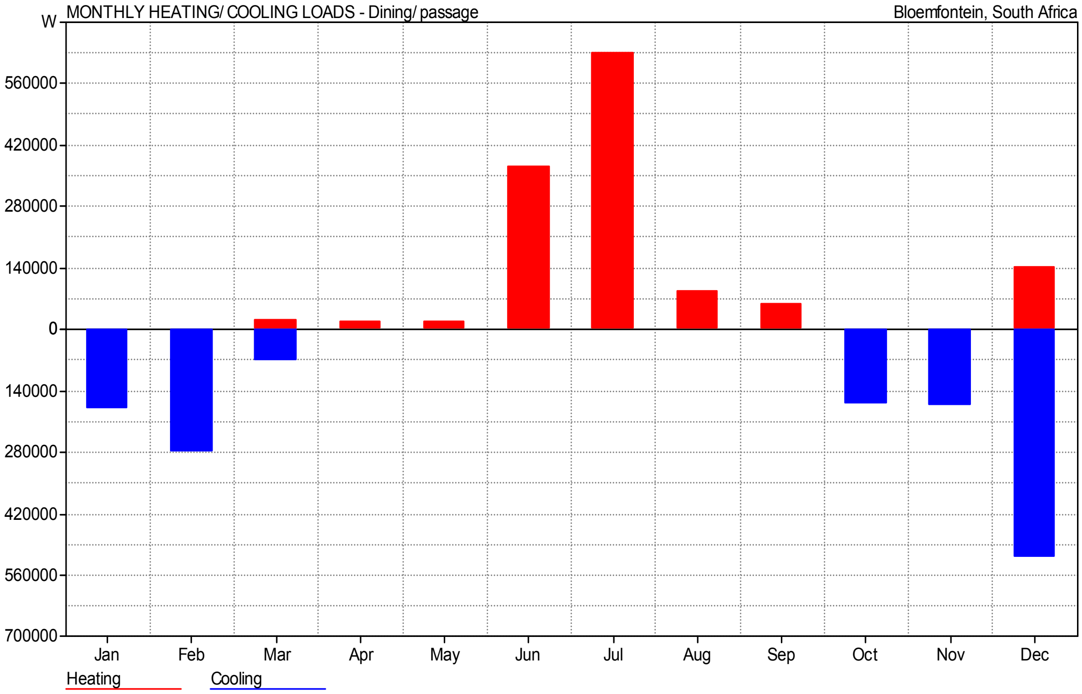

Figure 5.4: Predicted monthly heating and cooling loads for the dining / passage zone of Ecotect model with 100mm wool insulation on roof.

Table 5.5 shows monthly heating / cooling loads that would maintain the dining / passage zone within the thermal comfort region (16 - 28°C). These results were produced considering the dining / passage zone was occupied was occupied from 07:00 to 21:00 everyday. The maximum heating value of 7798 W occurred at 08:00 on 13 July, while the maximum cooling value of 4409 W occurred at 16:00 on 1 February (this information was read directly from Ecotect™ simulation software). The bar chart generated from data from Table 5.5 is shown in Figure 5.4.

Table 5.5: Predicted monthly heating and cooling loads for the dining / passage zone of Ecotect model with 100 mm wool insulation on roof.

MONTH	*HEATING (Wh)*	*COOLING (Wh)*	*TOTAL (Wh)*
Jan	0	182417	182417
Feb	0	280776	280776
Mar	22943	71459	94402
Apr	16581	0	16581
May	18528	0	18528
Jun	369345	0	369345
Jul	627591	0	627591
Aug	87846	0	87846
Sep	57960	0	57960
Oct	0	169239	169239
Nov	0	174398	174398
Dec	143162	519482	662643
------------	--------	--------	--------
TOTAL	1343956	1397771	2741728
PER M^2	30623	31849	62472
Floor Area:	43.888 m^2		

The first row of Table 5.6 shows HVAC energy consumption data (i.e. total heating and cooling loads and the total load) for the base case house which were taken from Table 4.2, which are also shown in the bar chart of Figure 4.10. Data of the second row are taken from Table 5.4 and also shown in the bar chart of Figure 5.3. Data of the third row are taken from Table 5.5 and also shown in the bar chart of Figure 5.4. From Table 5.6, it then follows that a mere 0.4% reduction in HVAC energy consumption is shown when the insulation thickness was increased from 65 mm to 100 mm. Results from Table 5.6 show that roof insulation alone is a measure that reduced the total annual HVAC energy consumption from 3 007 425 Wh to 2 741 728 Wh, which is a reduction of 8.84%.

Table 5.6: Effect of roof insulation on HVAC energy consumption of dining / passage zone of the base case.

Zone 1	*Total heating*	*Total cooling*	*Total load (Wh)*	*Energy reduction (Wh)*	*Reduction(R) or increase (I) (%)*
(Dining/Passage)	*Load (Wh)*	*Load (Wh)*	*(heating +cooling)*		
No roof insulation(Base case)	1327161	1680264	3007425	-	-
65mm wool insulation on roof	1332118	1424499	2756618	250807	8.4(R)
100mm wool insulation on roof	1343956	1397771	2741728	265697	8.84(R)

5.4 Effect of ceiling insulation on thermal performance of base case house

Figure 5.5 shows the annual temperature distribution of the dining / passage zone (light brown line). The input to the Ecotect™ model was 60 mm wool insulation on the ceiling (see section for ceiling insulation in appendix I). (See Table 5.7 for data of annual temperature distribution). A comparison of the thermal performance of the base case house and the model with 60 mm ceiling insulation (wool) is shown in Table 5.9.

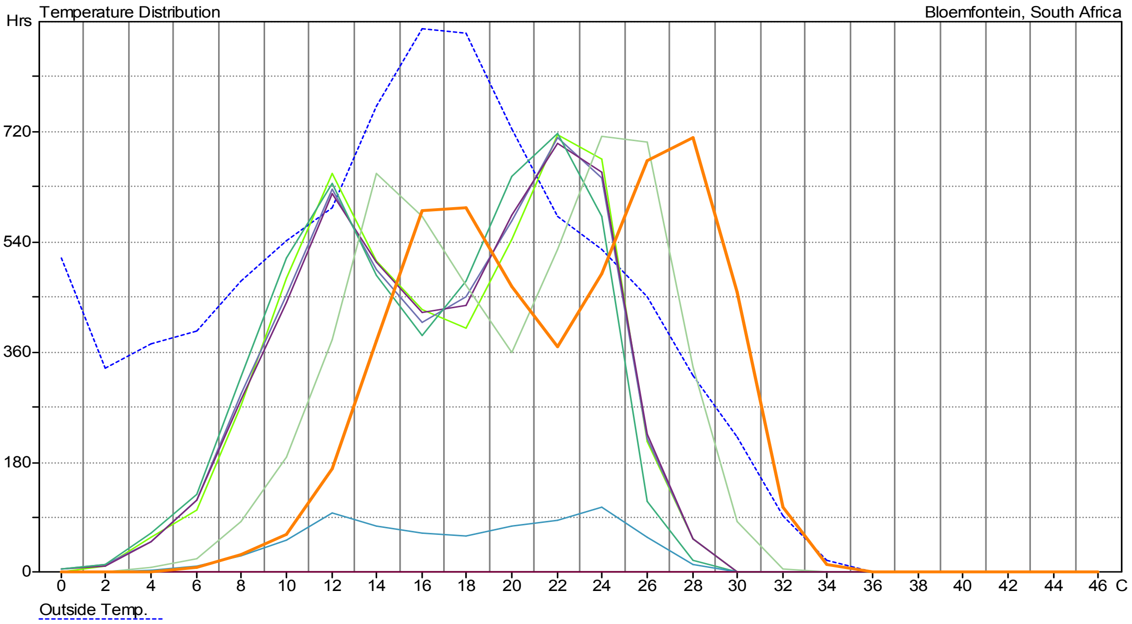

Figure 5.5 : Predicted annual temperature distribution for the Ecotect model with 60 mm wool insulation on ceiling.[1]

Table 5.7 below shows that the dining / passage zone will be in thermal comfort for 3889 hours, which is 76.1% of the total number of hours within one year. These results were produced considering that the dining / passage zone was occupied from 07:00 to 21:00 everyday. The thermal comfort band considered is the one prescribed in the SABC of 2005, i.e. 16 - 28°C. The graph generated from data from Table 5.7 is the light brown line (temperature distribution for dining / passage zone) shown in Figure 5.5.

Table 5.7: Predicted annual temperature distribution for the dining / passage of Ecotect model with 60mm wool insulation on ceiling.

TEMP (°C).	*HOURS*	*PERCENT*
--------	--------	---------
0	0	0.00
2	0	0.00
4	0	0.00
6	8	0.20
8	29	0.60
10	62	1.20
12	169	3.30
14	378	7.40
16	590	11.50
18	595	11.60
20	467	9.10
22	369	7.20
24	487	9.50
26	671	13.10
28	710	13.90
30	456	8.90
32	107	2.10
34	12	0.20
36	0	0.00
38	0	0.00
40	0	0.00
42	0	0.00
44	0	0.00
46	0	0.00
--------	--------	---------
COMFORT	3889	76.10

Figure 5.6 shows annual temperature distribution of the dining / passage zone (light brown line). The input to the Ecotect™ model was 100 mm wool insulation on the ceiling. (See Table 5.8 for data of annual temperature distribution). A comparison of thermal performance of the base case and the Ecotect™ model with 100 mm wool insulation on the ceiling is shown in Table 5.9.

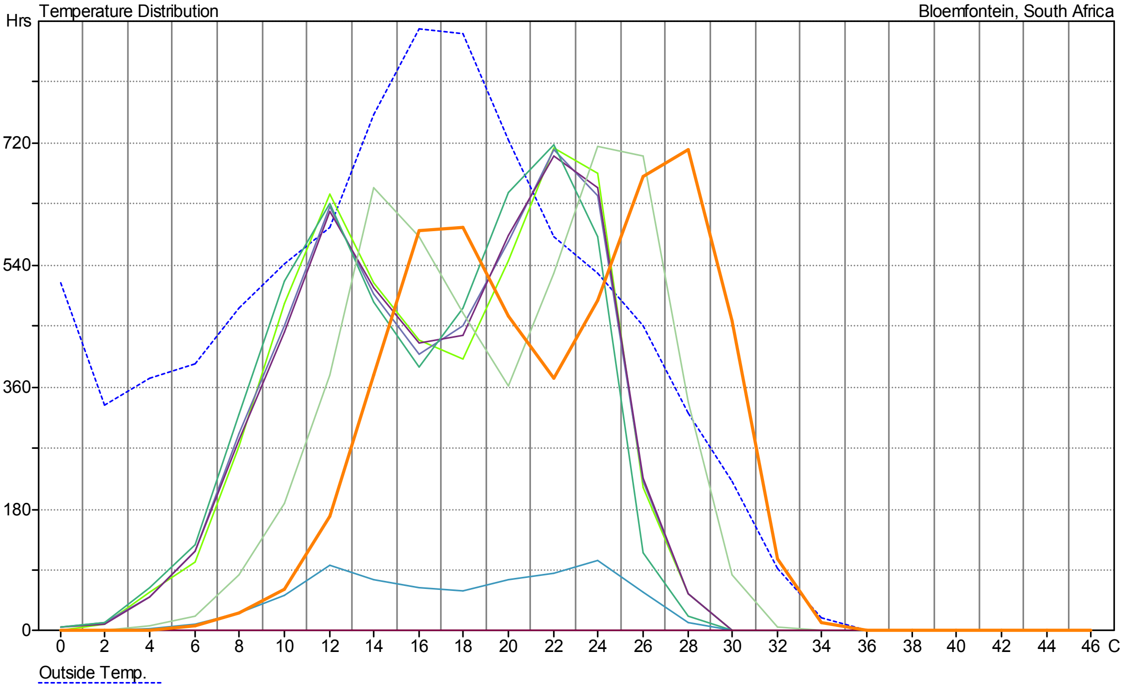

Figure 5.6: Predicted annual temperature distribution for the Ecotect model with 100mm wool insulation on ceiling.[1]

Table 5.8 shows that the dining / passage zone will be in thermal comfort for 3888 hours, which is 76.1% of the total number of hours in one year. These results were produced, considering that the dining / passage zone was occupied from 07:00 to 21:00 everyday. The thermal comfort band considered is the one prescribed in the SABC of 2005, i.e. 16 - 28°C. The graph generated from data from Table 5.8 is a light brown line (temperature distribution for dining / passage zone) shown in Figure 5.6.

Table 5.8: Predicted annual temperature distribution for the dining / passage zone of Ecotect model with 100 mm wool insulation on ceiling.

TEMP°C.	*HOURS*	*PERCENT*
--------	--------	---------
0	0	0.00
2	0	0.00
4	0	0.00
6	8	0.20
8	28	0.50
10	63	1.20
12	169	3.30
14	377	7.40
16	591	11.60
18	595	11.60
20	463	9.10
22	372	7.30
24	488	9.50
26	670	13.10
28	709	13.90
30	458	9.00
32	107	2.10
34	12	0.20
36	0	0.00
38	0	0.00
40	0	0.00
42	0	0.00
44	0	0.00
46	0	0.00
--------	--------	---------
COMFORT	3888	76.10

The first row of Table 5.9 shows thermal performance data for the base case which are taken from Table 4.1 and also plotted in Figure 4.9. Data of the second row are taken from Table 5.7 and plotted in Figure 5.5. Data of the third row are taken from Table 5.8 and plotted in Figure 5.6. From Table 5.9, it then follows that there is no change in thermal comfort when ceiling insulation thickness was increased from 60 mm to 100 mm. The results from Table 5.9 show that ceiling insulation alone is a measure that does not improve the thermal performance of the case study house, i.e. 0 % change.

Table 5.9: Effect of ceiling insulation on the thermal performance of the dining / passage zone of the base case.

Zone 1	*Number of hours*	*Reduction (R) or*
(dining/passage)	*Within comfort range*	*Increase (I) %*
	(16°C-28°C)	
Base case(no ceiling insulation)	3889	
60mm wool ceiling insulation	3889	0
100mm wool ceiling insulation	3888	0

5.5 Effect of ceiling insulation on HVAC energy consumption of base case house

Figure 5.7 shows the amount of heating (red bars) and cooling (blue bars) that will be consumed by the dining / passage zone of the base case house. The input to the Ecotect™ model was 60 mm thick rock wool insulation on the ceiling. (See Table 5.10 for data of monthly heating and cooling loads for the dining / passage zone). A comparison of HVAC energy consumption of the base case and the Ecotect™ model with 60 mm thick rock wool insulation on the ceiling is shown in Table 5.12.

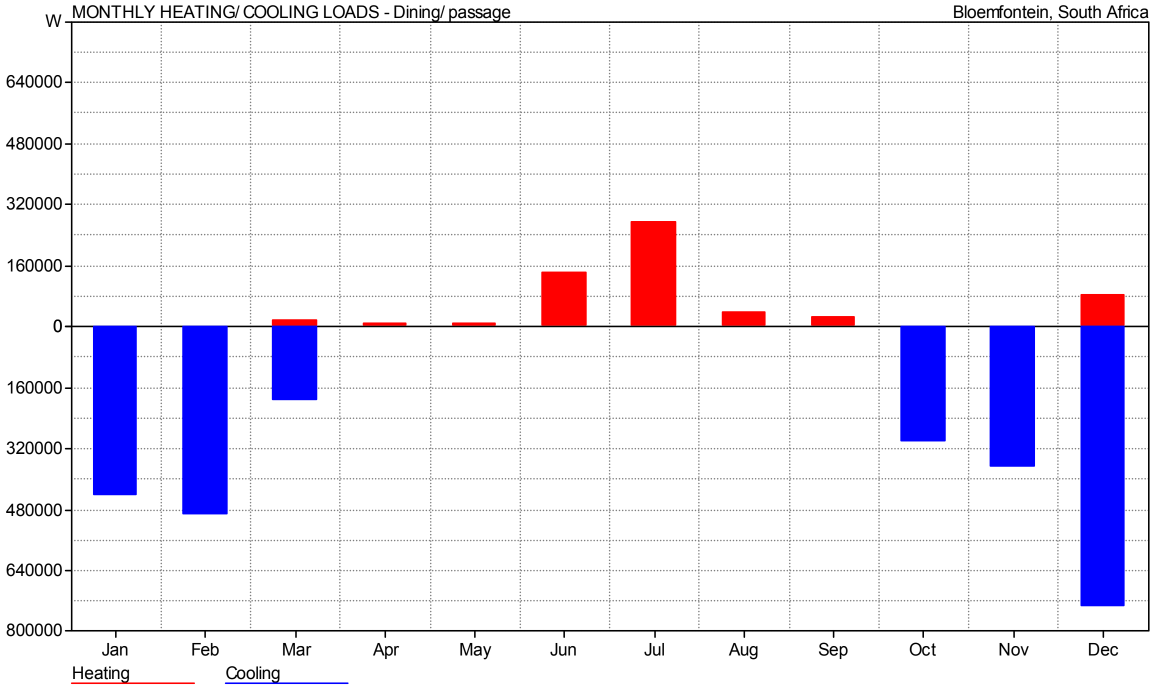

Figure 5.7: Predicted monthly heating and cooling loads for the dining / passage zone of Ecotect model with 60 mm wool insulation on ceiling.

Table 5.10 shows the monthly heating / cooling loads that would maintain the dining / passage zone within the thermal comfort region (16 - 28°C). These results were produced considering that the dining / passage zone was occupied from 07:00 to 21:00 everyday. As seen in Table 5.10, the maximum heating value of 274 308 Wh occurred in July, while the maximum cooling value of 734 742 Wh occurred in December. The bar chart generated from the data from Table 5.10 is shown in Figure 5.7.

Table 5.10: Predicted monthly heating and cooling loads for the dining /passage zone of Ecotect model with 60 mm wool insulation on ceiling.

MONTH	*HEATING (Wh)*	*COOLING (Wh)*	*TOTAL (Wh)*
Jan	0	443365	443365
Feb	0	495601	495601
Mar	16979	194726	211705
Apr	8441	0	8441
May	6291	0	6291
Jun	139673	0	139673
Jul	274308	0	274308
Aug	37086	0	37086
Sep	26327	0	26327
Oct	0	304303	304303
Nov	0	371044	371044
Dec	85011	734742	819753
-----------	--------	--------	--------
TOTAL	594115	2543780	3137895
-----------	--------	--------	--------
PER M^2	13537	57961	71499
Floor Area:	43.888 m^2		

Figure 5.8 shows the predicted amount of heating (red bars) and cooling (blue bars) that will be consumed by the dining / passage zone of the base case house. The input to the Ecotect™ model was 100 mm thick rock wool insulation on the ceiling. (See Table 5.11 for data of monthly heating and cooling loads for the dining / passage zone). A comparison of HVAC energy consumption of base case and the Ecotect™ model with 100 mm thick rock wool insulation on the ceiling is shown in Table 5.12.

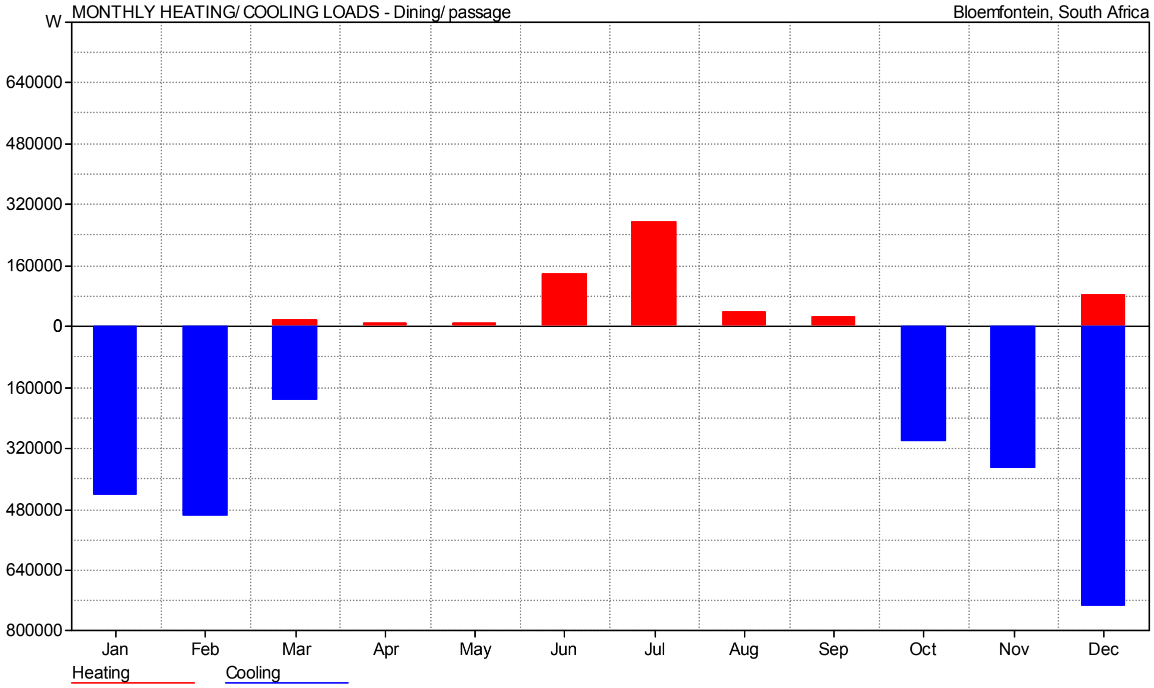

Figure 5.8: Predicted monthly heating and cooling loads for the dining / passage zone of Ecotect model with 100 mm rock wool insulation on ceiling.

Table 5.11 shows the predicted monthly heating / cooling loads that would maintain the dining / passage zone within the thermal comfort region (16 - 28°C). These results were produced considering that the dining / passage zone was occupied from 07:00 to 21:00 everyday. The maximum heating value of 4842 W occurred at 08:00 on 13 July, while the maximum cooling value of 4058 W occurred at 16:00 on 23 December (this information was read directly from Ecotect™ simulation software). The bar chart generated from the data from Table 5.11 is shown in Figure 5.8.

Table 5.11: Predicted monthly heating and cooling loads for the dining / passage zone of Ecotect model with 100 mm rock wool insulation on ceiling.

	HEATING	*COOLING*	*TOTAL*
MONTH	*(Wh)*	*(Wh)*	*(Wh)*
-----------	--------	--------	--------
Jan	0	445999	445999
Feb	0	496993	496993
Mar	16954	196370	213324
Apr	8379	0	8379
May	6248	0	6248
Jun	138630	0	138630
Jul	272453	0	272453
Aug	36836	0	36836
Sep	26168	0	26168
Oct	0	305198	305198
Nov	0	372368	372368
Dec	84696	736117	820814
------------	--------	--------	--------
TOTAL	590363	2553045	3143408
------------	--------	--------	--------
PER M^2	13452	58172	71624
Floor Area:	43.888 m^2		

The first row of Table 5.12 shows predicted HVAC energy consumption data for the base case which are taken from Table 4.2 and also shown in the bar chart of Figure 4.10. Data of the second row are taken from Table 5.10 and also shown in the bar chart of Figure 5.7. Data of the third row are taken from Table 5.11 and also shown in the bar chart of Figure 5.8. A , 0.2% increase in HVAC energy consumption is shown in Table 5.12, when ceiling insulation thickness was increased from 60 mm to 100 mm. Results from Table 5.12 show that ceiling insulation alone is a measure that increased total annual HVAC energy consumption from 3007425 Wh to 3143408 Wh, which is an increase of 4.5%. It follows that ceiling insulation applied alone is a measure that has a negative impact.

Table 5.12: Effect of ceiling insulation on HVAC energy consumption of dining / passage zone of the base case.

Zone 1	*Total heating*	*Total cooling*	*Total load (Wh)*	*Energy reduction (Wh)*	*Reduction(R) or increase (I) (%)*
(Dining/Passage)	*Load (Wh)*	*Load (Wh)*	*(heating +cooling)*		
No ceiling insulation(Base case)	1327161	1680264	3007425	-	-
60mm rock wool insulation on roof	594115	2543780	3137895	-130470	4.34(I)
100mm rock wool insulation on roof	590363	2553045	3143408	-135983	4.5(I)

5.6 Effect of cement wall plaster on thermal performance of base case house

Figure 5.9 shows annual temperature distribution of the dining / passage zone (light brown line). The input to the Ecotect™ model was 15 mm thick cement plaster on the outer wall (see Figure I 1 in Appendix I for outer wall section with added plaster on the outside). (See Table 5.13 for data of annual temperature distribution). A comparison of thermal performance of the base case house and the Ecotect model with 15 mm thick cement plaster on the outer wall is shown in Table 5.15.

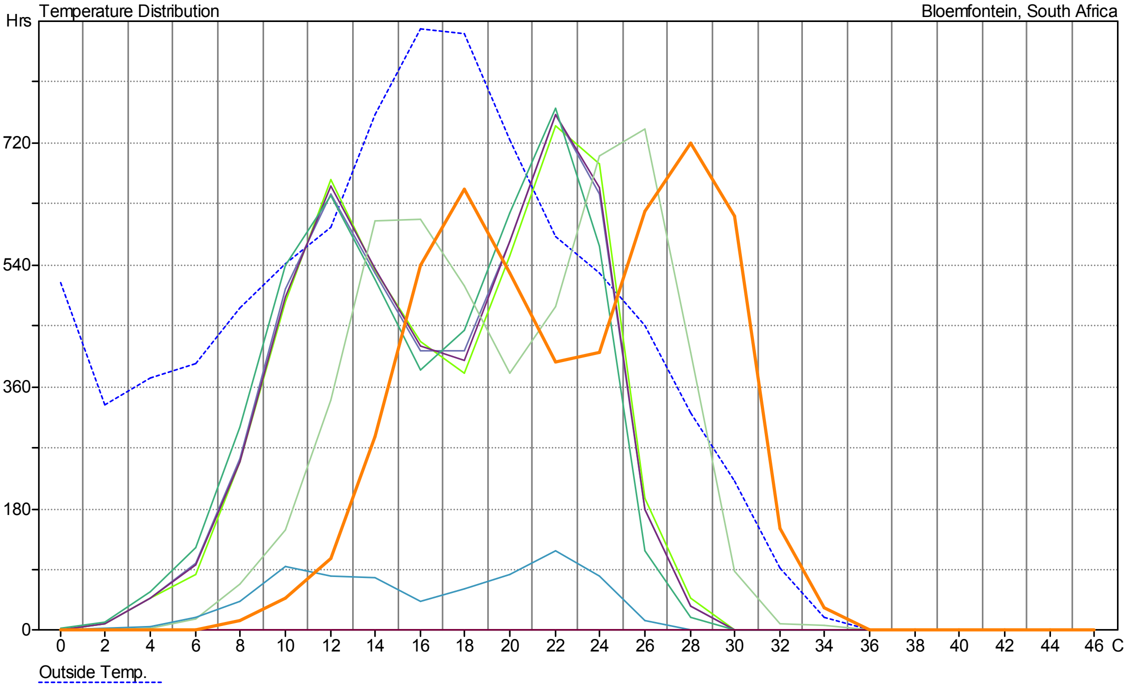

Figure 5.9: Predicted annual temperature distribution for the Ecotect model with 15 mm plaster on outer wall.[1]

Table 5.13 below shows that the dining / passage zone will be in comfort for 3860 hours, which is 75.5% of the total number of hours in one year. These results were produced considering that the dining / passage zone was occupied from 07:00 to 21:00 everyday. The thermal comfort band considered is the one prescribed in the SABC of 2005, i.e. 16 - 28°C. The graph generated by the data from Table 5.13 is the light brown line (temperature distribution for dining / passage zone) shown in Figure 5.9.

Table 5.13: Predicted annual temperature distribution for the dining / passage zone of Ecotect model with 15 mm plaster on outer wall.

TEMP°C.	*HOURS*	*PERCENT*
--------	--------	---------
0	0	0.00
2	0	0.00
4	0	0.00
6	0	0.00
8	15	0.30
10	47	0.90
12	107	2.10
14	286	5.60
16	538	10.50
18	651	12.70
20	526	10.30
22	397	7.80
24	410	8.00
26	619	12.10
28	719	14.10
30	611	12.00
32	150	2.90
34	34	0.70
36	0	0.00
38	0	0.00
40	0	0.00
42	0	0.00
44	0	0.00
46	0	0.00
--------	--------	---------
COMFORT	3860	75.50

Figure 5.10 shows annual temperature distribution of the dining / passage zone (light brown line). The input to the Ecotect model was 20 mm thick cement plaster on the outer wall (see Figure I 1 in Appendix I for outer wall section with added plaster on the outside). (See Table 5.14 for data of annual temperature distribution). A comparison of thermal performance of base case and the Ecotect model with 20 mm thick cement plaster on the outer wall is shown in Table 5.15.

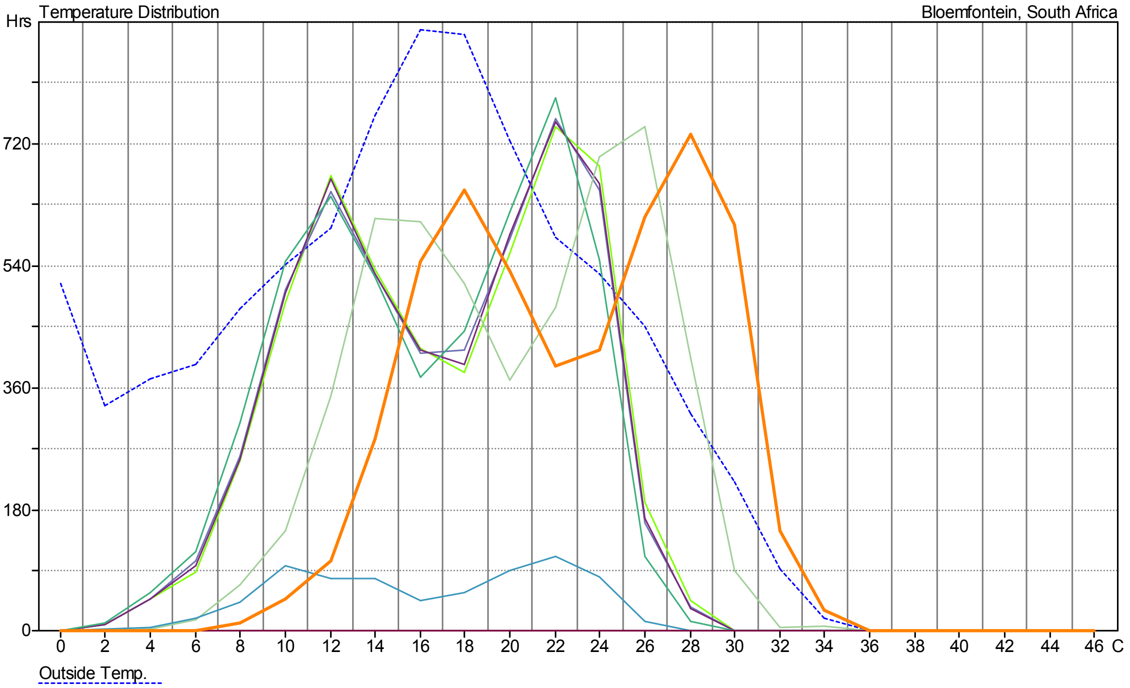

Figure 5.10: Predicted annual temperature distribution for the Ecotect model with 20 mm plaster on outer wall.[1]

Table 5.14 below shows that the dining / passage zone will be in comfort for 3879 hours, which is 75.9% of the total number of hours in one year. These results were produced considering that the dining / passage zone was occupied from 07:00 to 21:00 everyday. The thermal comfort band considered is the one prescribed in the SABC of 2005, i.e. (16 - 28°C). The graph generated from the data from Table 5.14 is light brown line (temperature distribution for the dining / passage zone) shown in Figure 5.10.

Table 5.14: Predicted annual temperature distribution for the dining / passage zone of Ecotect model with 20 mm plaster on outer wall.

TEMP°C.	*HOURS*	*PERCENT*
0	0	0.00
2	0	0.00
4	0	0.00
6	0	0.00
8	14	0.30
10	49	1.00
12	105	2.10
14	283	5.50
16	545	10.70
18	651	12.70
20	532	10.40
22	391	7.70
24	415	8.10
26	611	12.00
28	734	14.40
30	599	11.70
32	149	2.90
34	32	0.60
36	0	0.00
38	0	0.00
40	0	0.00
42	0	0.00
44	0	0.00
46	0	0.00
--------	--------	---------
COMFORT	3879	75.90

The first row of Table 5.15 shows thermal performance data for the base case which are taken from Table 4.1 and also plotted in Figure 4.9. Data of the second row are taken from Table 5.13 and plotted in Figure 5.9. Data of the third row are taken from Table 5.14 and plotted in Figure 5.10. From Table 5.15, it follows that there is a small percentage reduction in thermal comfort of 0.6% and 0.2% when 15 mm and 20 mm thick cement plaster respectively, was applied to the outer wall. It then follows that applying cement plaster to the outer wall had a small negative impact on the thermal performance of the case study house.

Table 5.15: Effect of cement plaster (on the outer wall) on thermal performance of base case.

Zone 1	*Number of hours*	*Reduction (R) or*
(dining/passage)	*Within comfort range*	*Increase (I) %*
	(16°C-28°C)	
Base case(no plaster on outer wall)	3889	-
15mm cement plaster on outer wall	3860	0.6(R)
20mm cement plaster on outer wall	3879	0.2(R)

5.7 Effect of cement wall plaster on HVAC energy consumption of base case house

Figure 5.11 shows the predicted amount of heating (red bars) and cooling (blue bars) that would be consumed by the dining / passage zone of the base case house. The input to the Ecotect™ model was 15 mm thick cement plaster on the outer wall. (See Table 5.16 for data of predicted monthly heating and cooling loads for the dining / passage zone). A comparison of HVAC energy consumption of the base case and the Ecotect™ model with 15 mm thick cement plaster on the outer wall is shown in Table 5.18.

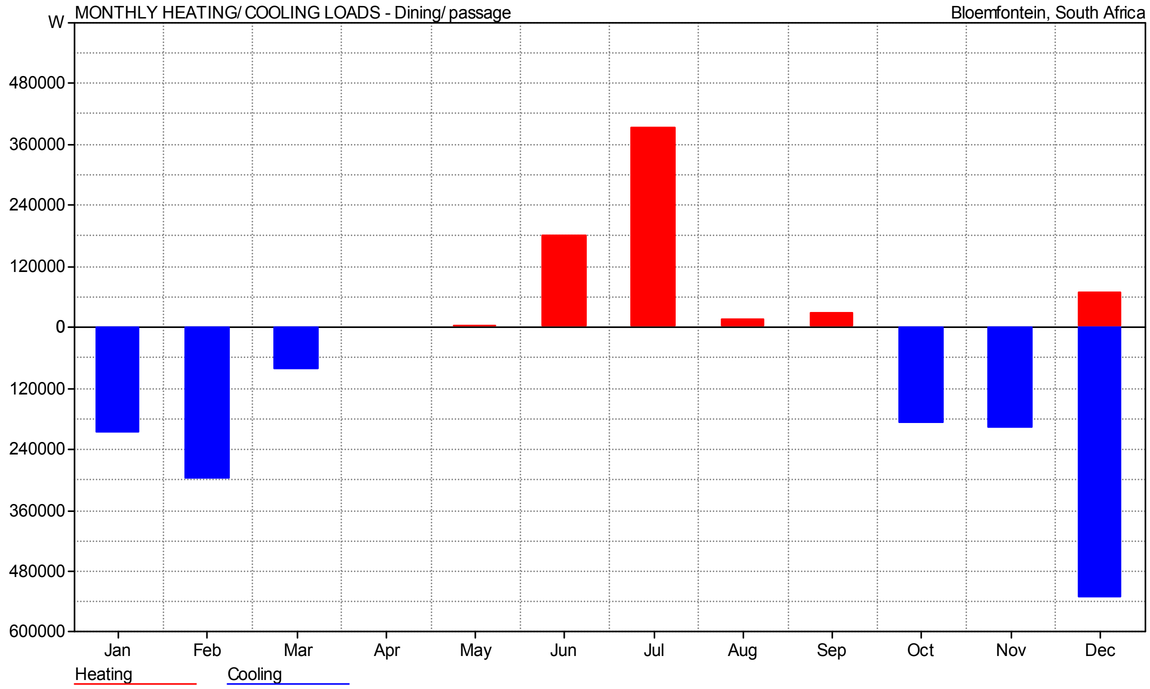

Figure 5.11: Predicted monthly heating and cooling loads for the dining / passage zone of Ecotect model with 15 mm plaster on outer wall.

Table 5.16 shows predicted monthly heating / cooling loads that would maintain the dining / passage zone within the thermal comfort region (16 - 28°C). These results were produced considering that the dining / passage zone was occupied from 07:00 to 21:00 everyday. The maximum heating value of 6186 W occurred at 08:00 on 13 July, while the maximum cooling value of 4293 W occurred at 16:00 on 1 February (this information was read directly from Ecotect simulation software).

Table 5.16: Predicted monthly heating and cooling loads for the dining / passage of Ecotect model with 15 mm plaster on outer wall.

MONTH	*HEATING (Wh)*	*COOLING (Wh)*	*TOTAL (Wh)*
-----------	--------	-------	-------
Jan	0	209492	209492
Feb	0	300497	300497
Mar	0	84443	84443
Apr	0	0	0
May	2563	0	2563
Jun	180203	0	180203
Jul	391330	0	391330
Aug	14892	0	14892
Sep	27982	0	27982
Oct	0	188883	188883
Nov	0	200655	200655
Dec	69617	532352	601969
------------	--------	--------	--------
TOTAL	686586	1516322	2202908
------------	--------	--------	--------
PER M^2	15644	34550	50194
Floor Area:	43.888 m^2		

Figure 5.12 shows the predicted amount of heating (red bars) and cooling (blue bars) that would be consumed by the dining / passage zone of the base case house. The input to the Ecotect™ model was 20 mm thick cement plaster on the outer wall. (See Table 5.17 for data of predicted monthly heating and cooling loads for the dining / passage zone). A comparison of HVAC energy consumption of the base case and the Ecotect™ model with 20 mm thick cement plaster on the outer wall is shown in Table 5.18

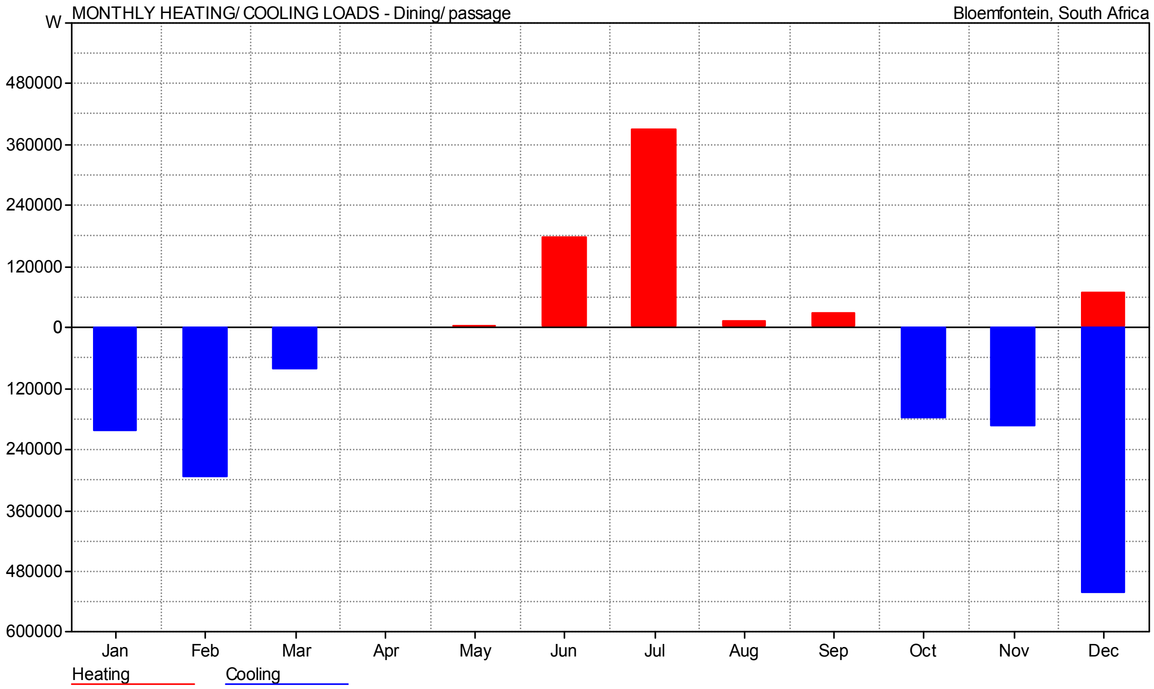

Figure 5.12: Predicted monthly heating and cooling loads for the dining / passage zone of Ecotect model with 20 mm plaster on outer wall.

Table 5.17 shows predicted monthly heating / cooling loads that would maintain the dining / passage zone within the thermal comfort region (16 - 28°C). These results were produced considering that the dining / passage zone was occupied from 07:00 to 21:00 everyday. The maximum heating value of 5930 W occurred at 08:00 on 13 July while the maximum cooling value of 4204 W occurred at 16:00 on 1 February (this information was read directly from Ecotect simulation software).

Table 5.17: Predicted monthly heating and cooling loads for the dining / passage zone of Ecotect model with 20 mm plaster on outer wall.

	HEATING	*COOLING*	*TOTAL*
MONTH	*(Wh)*	*(Wh)*	*(Wh)*
-----------	--------	--------	--------
Jan	0	206369	206369
Feb	0	295142	295142
Mar	0	82636	82636
Apr	0	0	0
May	2499	0	2499
Jun	178842	0	178842
Jul	388683	0	388683
Aug	11770	0	11770
Sep	29034	0	29034
Oct	0	182141	182141
Nov	0	195451	195451
Dec	69208	524287	593495
-----------	--------	--------	--------
TOTAL	680037	1486024	2166061
-----------	--------	--------	--------
PER M^2	15495	33860	49355
Floor Area:	43.888 m^2		

The first row of Table 5.18 shows predicted HVAC energy consumption data for the base case which are taken from Table 4.2 and also shown in the bar chart of Figure 4.10. Data of the second row are taken from Table 5.16 and also shown in the bar chart of Figure 5.11. Data of the third row are taken from Table 5.17 and also shown in the bar chart of Figure 5.12. From Table 5.18, 1% reduction in HVAC energy consumption is shown when the outer wall cement plaster thickness was increased from 15 mm to 20 mm. Results from Table 5.18 show that outer wall cement plaster alone is a measure that significantly reduced the total annual HVAC energy consumption from 3007425 Wh to 2166061 Wh, which is a reduction of 28%. It follows that outer wall cement plaster applied alone is a measure that has a positive effect. Results from Table 5.18 show that outer wall cement plaster greatly reduces the amount of heating (by 49%) when compared to reducing the amount of cooling (by 11.6%). It therefore follows that outer wall plaster is a measure that is most effective during winter and moderately effective during summer time in Bloemfontein, South Africa.

Table 5.18: Effect of cement plaster (on outer wall) on the HVAC energy consumption of base case.

				Energy reduction (Wh)	*Reduction(R) or increase (I) (%)*
Zone 1 (Dining/Passage)	*Total heating Load (Wh)*	*Total cooling Load (Wh)*	*Total load (Wh) (heating +cooling)*		
No plaster on outer wall (Base case)	1327161	1680264	3007425	-	-
15mm cement plaster on outer wall	686586	1516322	2202908	804517	27(R)
20mm cement plaster on outer wall	680037	1486024	2166061	841364	28(R)

5.8 Effect of wall insulation on thermal performance of base case house

Figure 5.13 shows annual temperature distribution of the dining/passage zone (light brown line). The input to the Ecotect™ model was 20 mm thick fibrous wool insulation on the wall (see Figure I 1 in appendix I for the section). (See Table 5.19 for data of annual temperature distribution). A comparison of the thermal performance of the base case house and the Ecotect™ model with 20 mm thick fibrous wool insulation on the wall is shown in Table 5.20.

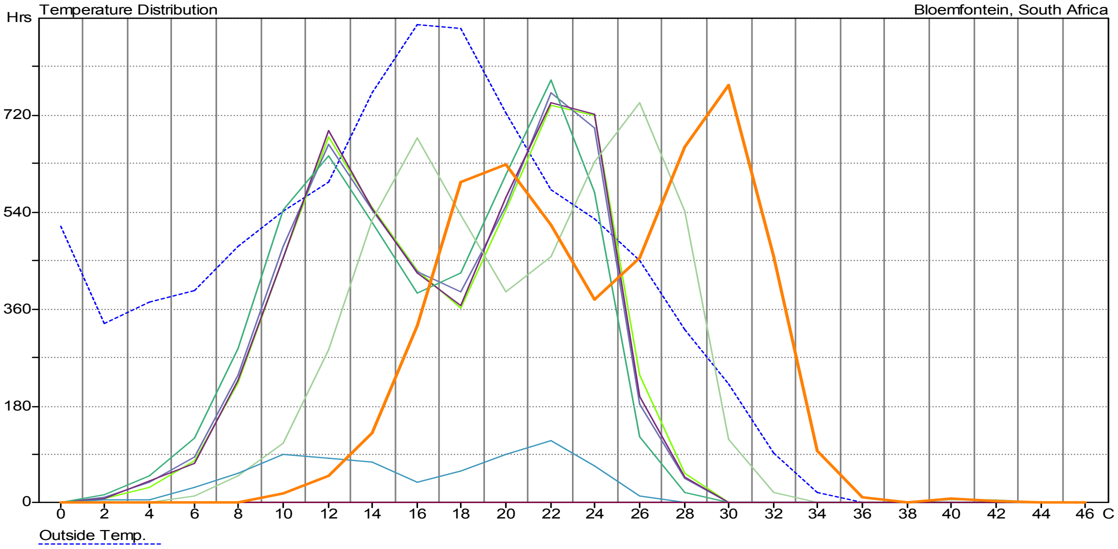

Figure 5.13: Predicted annual temperature distribution for the Ecotect model with 20 mm fibrous wool insulation on the wall.[1]

Table 5.19 below shows that the dining / passage zone will be in thermal comfort for 3556 hours, which is 69.6% of the total number of hours in one year. These results were produced considering that the dining / passage zone was occupied from 07:00 to 21:00 everyday. The thermal comfort band considered is the one prescribed in the SABC of 2005, i.e. 16 - 28°C. The graph generated by the data from Table 5.19 is a light brown line (temperature distribution of the dining / passage zone) shown in Figure 5.13.

Table 5.19 : Predicted annual temperature distribution for the dining / passage zone of Ecotect model with 20 mm fibrous wool insulation on the wall.

TEMP (°C).	*HOURS*	*PERCENT*
0	0	0.00
2	0	0.00
4	0	0.00
6	0	0.00
8	1	0.00
10	17	0.30
12	51	1.00
14	130	2.50
16	328	6.40
18	594	11.60
20	627	12.30
22	515	10.10
24	377	7.40
26	455	8.90
28	660	12.90
30	776	15.20
32	458	9.00
34	98	1.90
36	11	0.20
38	1	0.00
40	8	0.20
42	3	0.10
44	0	0.00
46	0	0.00
COMFORT	3556	69.60

The first row of Table 5.20 shows thermal performance data for the base case which are taken from Table 4.1 and also plotted in Figure 4.9. Data of the second row are taken from Table 5.19 and plotted in Figure 5.13. From the Table 5.20, it follows that applying fibrous wool insulation to the wall significantly reduced the thermal performance of the case study house by 6.5%.

Table 5.20: Effect of fibrous wool insulation on the thermal performance of the base case.

Zone 1 (dining/passage)	*Number of hours Within comfort range*(16°C-28°C)	*Reduction (R) or Increase (I) %*
Base case(no plaster on outer wall)	3889	-
20mm cement plaster and 20mm fibrous wool insulation on outer wall on outer wall	3556	6.5 (R)

5.9 Effect of wall insulation on HVAC energy consumption of base case house

Figure 5.14 shows the predicted amount of heating (red bars) and cooling (blue bars) that would be consumed by the dining / passage zone of the base case house. The input to the Ecotect™ model was 20 mm thick fibrous wool insulation on the wall. (See Table 5.21 for data of monthly heating and cooling loads for the dining / passage zone). A comparison of HVAC energy consumption of the base case and the Ecotect™ model with 20 mm thick fibrous wool insulation on the wall is shown in Table 5.22.

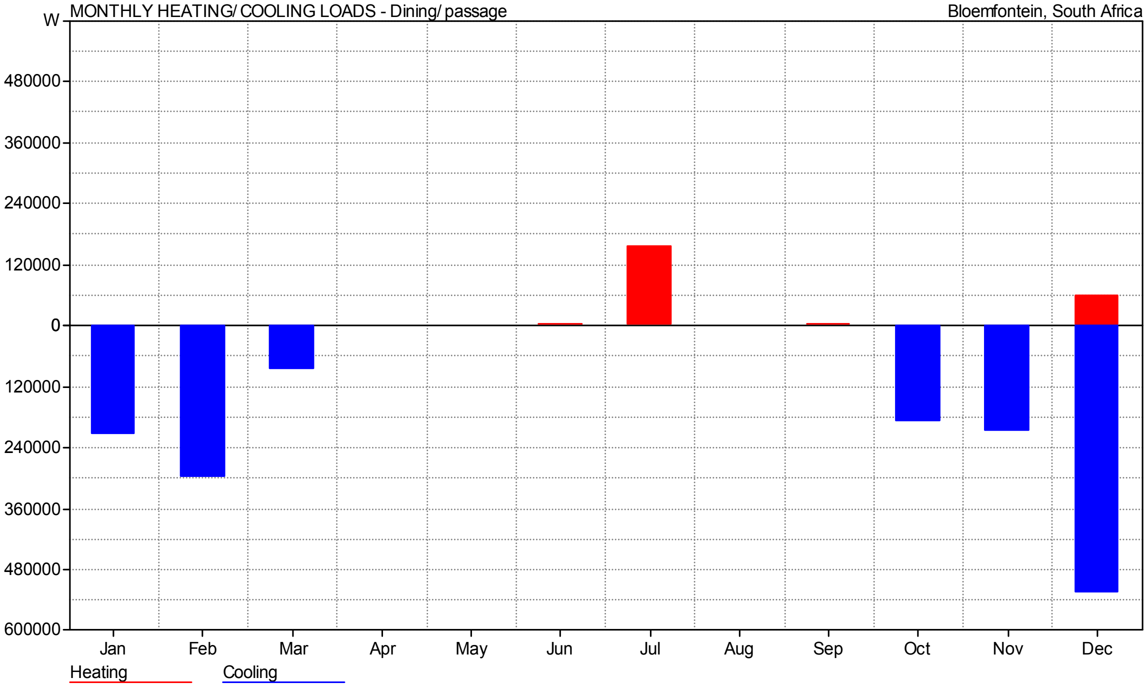

Figure 5.14: Predicted monthly heating and cooling loads for the dining / passage zone of Ecotect model with 20 mm thick fibrous wool insulation on wall.

Table 5.21 shows the predicted monthly heating / cooling loads that will maintain the dining / passage zone within thermal comfort (16 - 28°C). These results were produced considering that the dining / passage zone was occupied from 07:00 to 21:00 everyday. The maximum heating value of 5121 W occurred at 08:00 on 13 July while the maximum cooling value of 4238 W occurred at 16:00 on 1 February (this information was read directly from Ecotect simulation software). The bar chart generated by the data from Table 5.21 is shown in Figure 5.14.

Table 5.21: Predicted monthly heating and cooling loads for the dining / passage zone of Ecotect model with 20mm wool fibrous insulation on outer wall.

	HEATING	*COOLING*	*TOTAL*
MONTH	*(Wh)*	*(Wh)*	*(Wh)*
-----------	--------	--------	--------
Jan	0	213778	213778
Feb	0	300483	300483
Mar	0	86636	86636
Apr	0	0	0
May	0	0	0
Jun	4391	0	4391
Jul	156476	0	156476
Aug	0	0	0
Sep	4272	0	4272
Oct	0	190555	190555
Nov	0	209756	209756
Dec	58532	526995	585527
-----------	--------	--------	--------
TOTAL	223671	1528205	1751876
-----------	--------	--------	--------
PER M^2	5096	34821	39917
Floor Area:	43.888 m^2		

The first row of Table 5.22 shows HVAC energy consumption data for the base case which are taken from Table 4.2 and shown in the bar chart of Figure 4.10. Data of the second row are taken from Table 5.21 and also shown in the bar chart of Figure 5.14. From Table 5.22, it follows that applying fibrous wool insulation to the wall significantly reduced the HVAC energy consumption of the case study house by 42%.

Table 5.22: Effect of fibrous wool insulation (on wall) on the HVAC energy consumption of the base case.

Zone 1	*Total heating*	*Total cooling*	*Total load (Wh)*	*Energy reduction (Wh)*	*Reduction(R) or increase (I) (%)*
(Dining/Passage)	*Load (Wh)*	*Load (Wh)*	*(heating +cooling)*		
No plaster on outer wall (Base case)	1327161	1680264	3007425	-	-
20mm cement plaster and 20mm fibrous wool insulation on outer wall	223671	1528205	1751876	1255549	42(R)

5.10 Effect of double glazing on thermal performance of base case house

Figure 5.15 shows the annual temperature distribution of the dining/passage zone (light brown line). The input to the Ecotect™ model was double glazed windows. (See Table 5.23 for data of annual temperature distribution). A comparison of thermal performance of the base case and the Ecotect™ model with double glazing is shown in Table 5.24.

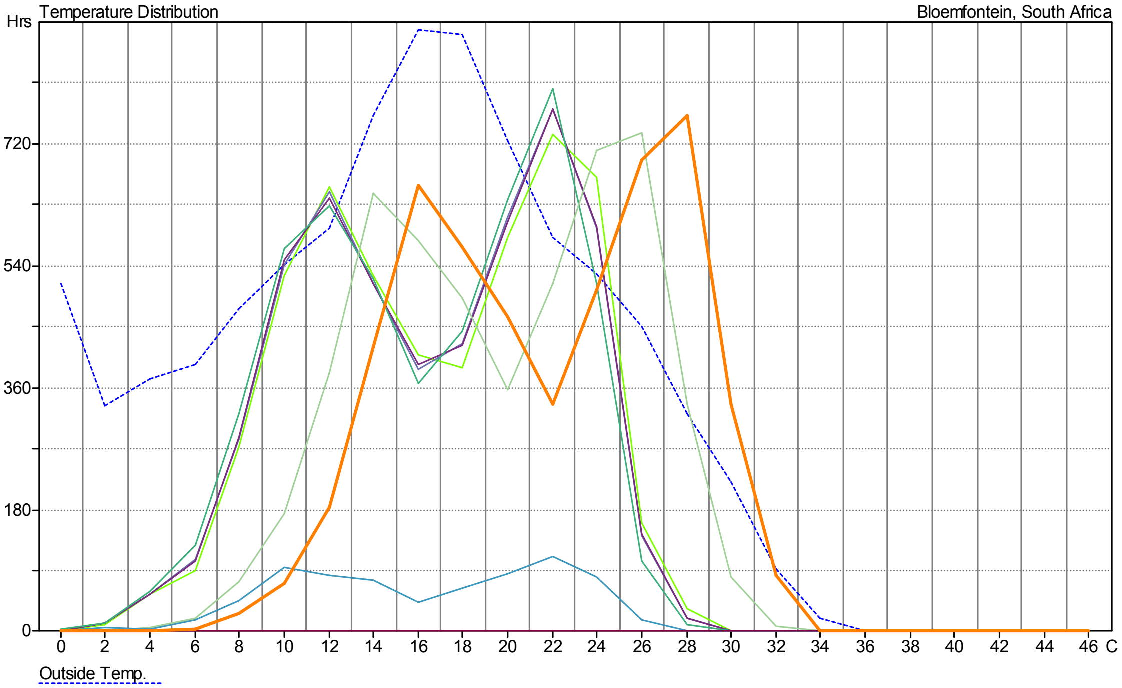

Figure 5.15: Predicted annual temperature distribution for the Ecotect model with double glazing.[1]

Table 5.23 below shows that the dining / passage zone will be in comfort for 3985 hours, which is 78% of the total number of hours in one year. These results were produced considering that the dining / passage zone was occupied from 07:00 to 21:00 everyday. The thermal comfort band considered is the one prescribed in the SABC of 2005, i.e. 16 - 28°C. The graph generated by the data from Table 5.23 is the light brown line (temperature distribution of the dining / passage zone) shown in Figure 5.15.

Table 5.23: Predicted annual temperature distribution for the dining / passage zone of Ecotect model with double glazing

TEMP (°C).	*HOURS*	*PERCENT*
--------	--------	---------
0	0	0.00
2	0	0.00
4	0	0.00
6	4	0.10
8	28	0.50
10	71	1.40
12	183	3.60
14	420	8.20
16	658	12.90
18	567	11.10
20	464	9.10
22	336	6.60
24	503	9.80
26	696	13.60
28	761	14.90
30	335	6.60
32	82	1.60
34	2	0.00
36	0	0.00
38	0	0.00
40	0	0.00
42	0	0.00
44	0	0.00
46	0	0.00
--------	--------	---------
COMFORT	3985	78.00

The first row of Table 5.24 shows thermal performance data for the base case which are taken from Table 4.1 and also plotted in Figure 4.9. Data of the second row are taken from Table 5.23 and plotted in Figure 5.15. From Table 5.24, it then follows that the thermal performance of the case study house can be improved by replacing single glazing with double glazing. An increase of 2 % is shown in Table 5.24.

Table 5.24: Effect of double glazing on the thermal performance of the base case.

Zone 1	***Number of hours***	***Reduction (R) or***
(dining/passage)	***Within comfort range***	***Increase (I) %***
	(16°C-28°C)	
Base case(single glazed)	3889	-
Double glazed	3985	2 (I)

5.11 Effect of combination of roof insulation, ceiling insulation, outer wall plaster, wall insulation and double glazing on thermal performance of base case house

Figure 5.16 shows the annual temperature distribution of the dining/passage zone (light brown line). The inputs to the Ecotect™ model were double glazing, roof insulation, cement plaster on the outer wall, wall insulation and ceiling insulation. (See Table 5.25 for the annual temperature distribution). A comparison of thermal performance of the base case and the Ecotect™ model with double glazing, roof insulation, cement plaster on the outer wall, wall insulation and ceiling insulation is shown in Table 5.26.

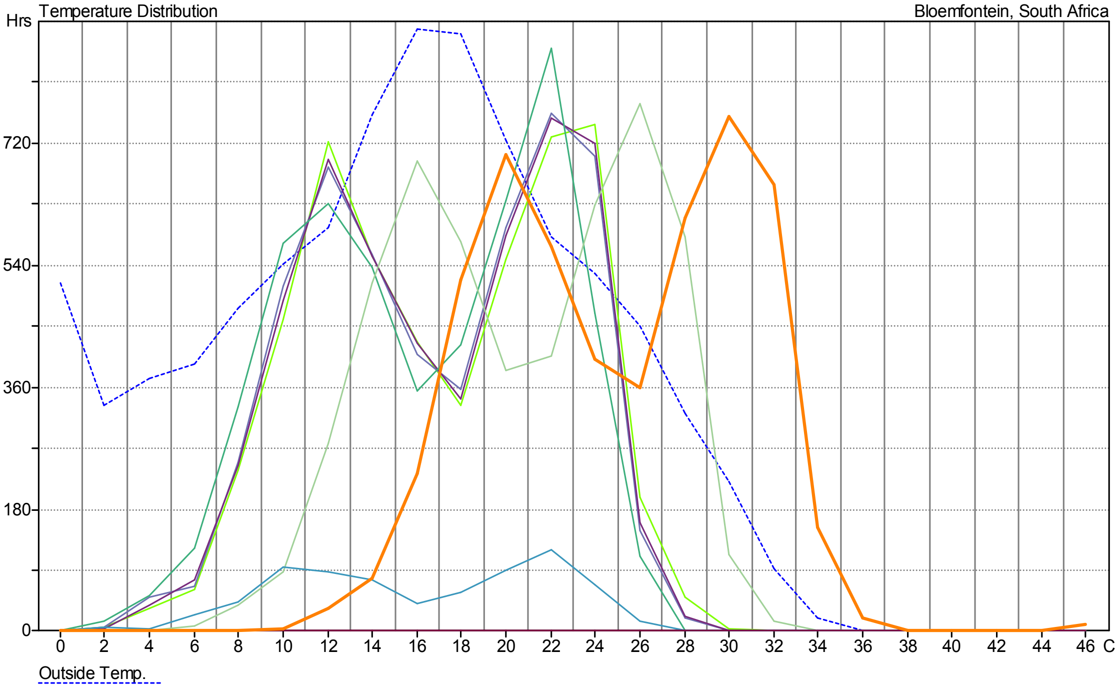

Figure 5.16: Predicted annual temperature distribution for the Ecotect model with a combination of double glazing, roof insulation, cement plaster on the outer wall, wall insulation and ceiling insulation[1]

Table 5.25 below shows that the dining/passage zone will be in comfort for 3389 hours, which is 66.3% of the total number of hours in one year. These results were produced considering that the dining / passage zone was occupied from 07:00 to 21:00 everyday. The thermal comfort band considered is the one prescribed in the SABC of 2005, i.e. 16 - 28°C. The graph generated by the data from Table 5.25 is the light brown line (temperature distribution for the dining / passage zone) shown in Figure 5.16.

Table 5.25: Predicted annual temperature distribution for the Ecotect model with a combination of double glazing, roof insulation, cement plaster on the outer wall, wall insulation and ceiling insulation

TEMP (°C).	*HOURS*	*PERCENT*
--------	--------	---------
0	0	0.00
2	0	0.00
4	0	0.00
6	0	0.00
8	0	0.00
10	4	0.10
12	35	0.70
14	78	1.50
16	233	4.60
18	518	10.10
20	702	13.70
22	566	11.10
24	402	7.90
26	358	7.00
28	610	11.90
30	759	14.90
32	658	12.90
34	153	3.00
36	21	0.40
38	1	0.00
40	0	0.00
42	0	0.00
44	1	0.00
46	11	0.20
--------	--------	---------
COMFORT	3389	66.30

The first row of Table 5.26 shows the data for the thermal performance of the base case which are taken from Table 4.1 and also plotted in Figure 4.9. Data of the second row are taken from Table 5.25 and plotted in Figure 5.16. From Table 5.26 it then follows that the application of interventions in combination i.e. double glazing, roof insulation, cement plaster on the outer wall, wall insulation and ceiling insulation, reduced the thermal performance of the house by 9.8%.

Table 5.26: Effect of a combination of double glazing, roof insulation, cement plaster on the outer wall, wall insulation and ceiling insulation on thermal performance of base case.

Zone 1	*Number of hours*	*Reduction (R) or*
(dining/passage)	*Within comfort range*	*Increase (I) %*
	(16°C-28°C)	
Base case	3889	-
Combination of Double glazing, roof insulation, wall plaster plus insulation, ceiling insulation.	3389	9.8 (R)

5.12 Effect of combination of roof insulation, ceiling insulation, outer wall plaster, outer wall insulation and double glazing on HVAC energy consumption of base case house

Figure 5.17 shows the predicted amount of heating (red bars) and cooling (blue bars) that would be consumed by the dining / passage zone of the base case house. The inputs to the Ecotect™ model were double glazing, roof insulation, cement plaster on the outer wall, wall insulation and ceiling insulation. See Table 5.27 for data of monthly heating and cooling loads for the dining / passage zone. A comparison of HVAC energy consumption of base case and the Ecotect™ model with double glazing, roof insulation, cement plaster on the outer wall, wall insulation and ceiling insulation is shown in Table 5.28.

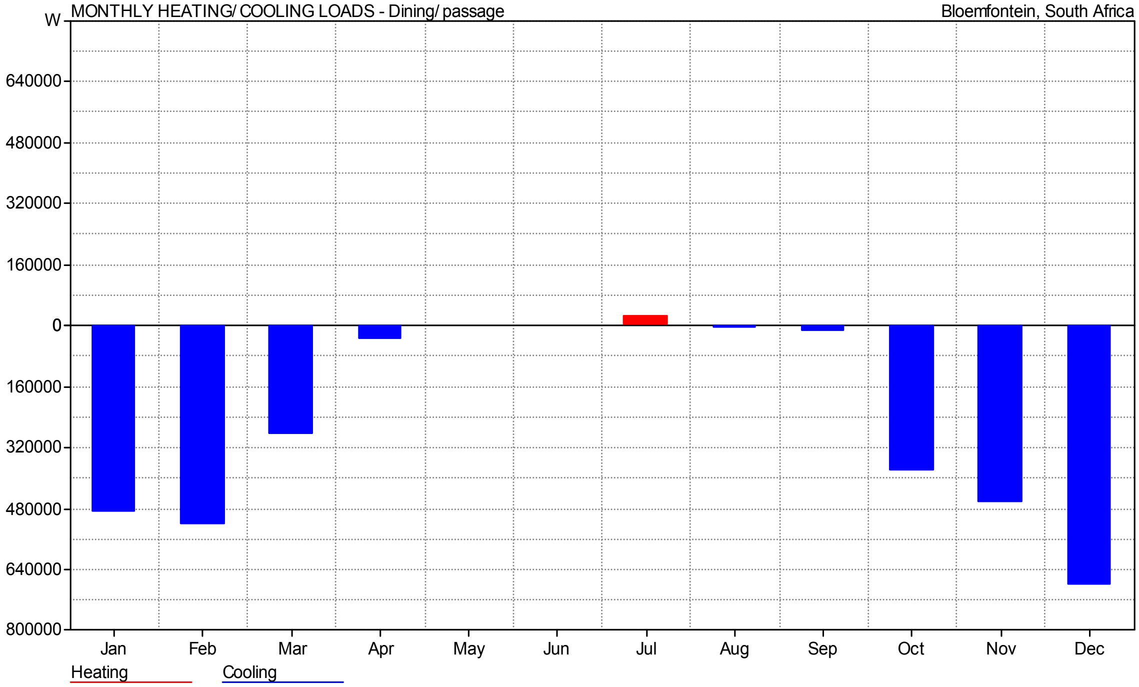

Figure 5.17: Predicted monthly heating and cooling loads for the dining / passage zone of Ecotect model with combined roof insulation, ceiling insulation, outer wall plaster, wall insulation and double glazing.

Table 5.27 shows the predicted monthly heating / cooling loads that would maintain the dining / passage zone within thermal comfort (16 – 28 °C). These results were produced, considering that the dining / passage zone was occupied from 07:00 to 21:00 everyday. The maximum heating value of 1723 W occurred at 08:00 on 12 July while the maximum cooling value of 4115 W occurred at 15:00 on 17 November (this information was read directly from Ecotect simulation software). The bar chart generated by data from Table 5.27 is shown in Figure 5.17.

Table 5.27: Predicted monthly heating and cooling loads for the dining / passage zone of Ecotect model with combination of roof insulation, ceiling insulation, outer wall plaster, wall insulation and double glazing.

	HEATING	*COOLING*	*TOTAL*
MONTH	*(Wh)*	*(Wh)*	*(Wh)*
-----------	--------	--------	--------
Jan	0	491063	491063
Feb	0	522182	522182
Mar	0	286290	286290
Apr	0	37416	37416
May	0	1154	1154
Jun	0	0	0
Jul	25424	0	25424
Aug	0	9092	9092
Sep	0	16123	16123
Oct	0	381967	381967
Nov	0	467103	467103
Dec	0	680534	680534
-----------	--------	--------	--------
TOTAL	25424	2892924	2918348
-----------	--------	--------	--------
PER M²	579	65917	66496
Floor Area:	43.888 m²		

From Table 5.28, the base case information is taken from Table 4.2, whereas the data for the combination (row 2) are taken from Table 5.27 (which is also shown in the bar chart of Figure 5.17). The results from Table 5.28 show that applying the interventions in combination i.e. combining roof insulation, ceiling insulation, outer wall plaster, wall insulation and double glazing, results in a small annual electricity savings (2.96%), but a high heating energy savings in the winter months of 98%.

Table 5.28: Effect of combined strategies (roof insulation, ceiling insulation, outer wall plaster, outer wall insulation and double glazing) on the HVAC energy consumption of base case.

Zone 1	*Total heating*	*Total cooling*	*Total load (Wh)*	*Energy reduction (Wh)*	*Reduction(R) or increase (I) (%)*
(Dining/Passage)	*Load (Wh)*	*Load (Wh)*	*(heating +cooling)*		
Base case	1327161	1680264	3007425	-	-
Combination of Double glazing, roof insulation, wall plaster plus insulation, ceiling insulation.	25424	2892924	2918348	89077	2.96(R)

5.13 Effect of roof insulation, outer wall plaster, outer wall insulation and double glazing on HVAC energy consumption of base case

Figure 5.18 shows the predicted amount of heating (red bars) and cooling (blue bars) that would be consumed by the dining / passage zone of the base case house. The inputs to the Ecotect™ model were roof insulation, outer wall plaster, wall insulation and double glazing. See Table 5.29 for data of monthly heating and cooling loads for the dining / passage zone. A comparison of HVAC energy consumption of base case and the Ecotect™ model with roof insulation, outer wall plaster, wall insulation and double glazing is shown in Table 5.30.

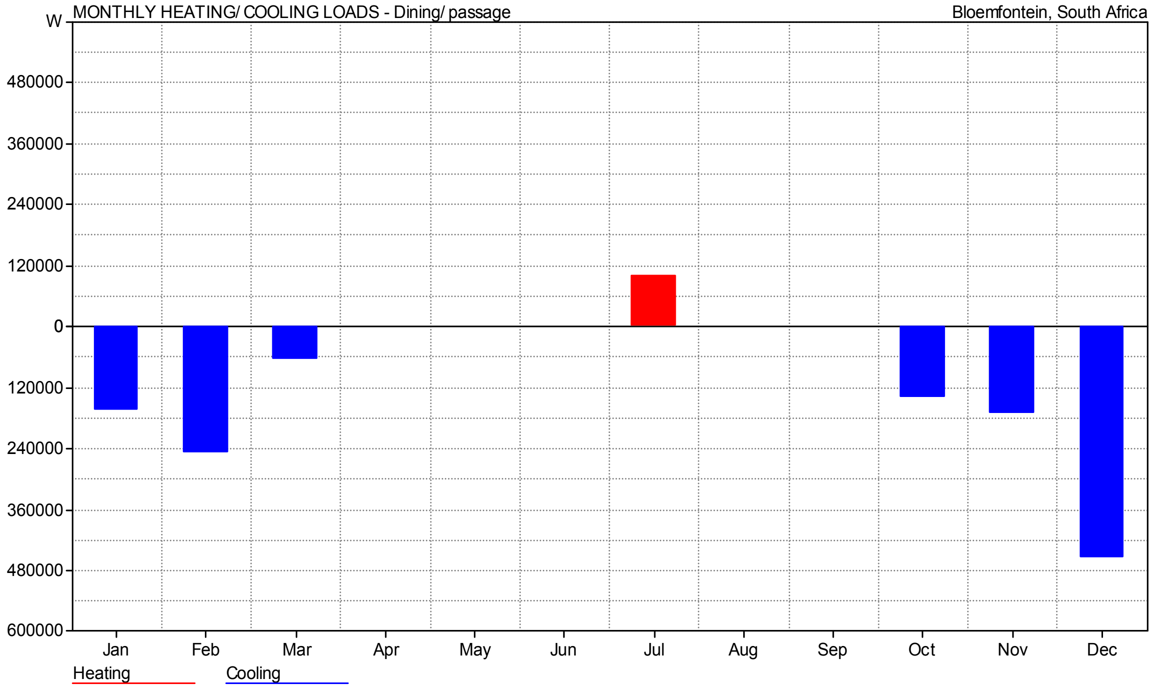

Figure 5.18: Predicted monthly heating and cooling loads for the dining / passage zone of Ecotect model with a combination of roof insulation, outer wall plaster, wall insulation and double glazing.

Table 5.29 shows the predicted monthly heating / cooling loads that would maintain the dining / passage zone within thermal comfort (16 – 28 °C). These results were produced considering that the dining / passage zone was occupied from 07:00 to 21:00 everyday. The maximum heating value of 99067 W occurred in July, while the maximum cooling value of 455557 W occurred in December. The bar chart generated by data from Table 5.29 is shown in Figure 5.18.

Table 5.29: Predicted monthly heating and cooling loads for the dining / passage zone of Ecotect model with combination of roof insulation, outer wall plaster, wall insulation and double glazing.

	HEATING	*COOLING*	*TOTAL*
MONTH	*(Wh)*	*(Wh)*	*(Wh)*
-----------	--------	--------	--------
Jan	0	165037	165037
Feb	0	249935	249935
Mar	0	64046	64046
Apr	0	0	0
May	0	0	0
Jun	0	0	0
Jul	99067	0	99067
Aug	0	0	0
Sep	0	0	0
Oct	0	141251	141251
Nov	0	172060	172060
Dec	0	455557	455557
-----------	--------	--------	--------
TOTAL	99067	1247886	1346953
-----------	--------	--------	--------
PER M^2	2257	28434	30691
Floor Area:	43.888 m^2		

The first row of Table 5.30 shows HVAC energy consumption data for the base case which are taken from Table 4.2 and shown in the bar chart of Figure 4.10. Data of the second row are taken from Table 5.29 and also shown in the bar chart off Figure 5.18. From Table 5.30 it follows that combining roof insulation, outer wall plaster, wall insulation and double glazing yields a considerably high reduction of HVAC energy consumption by as much as 55.2%.

Table 5.30: Effect of combining roof insulation, outer wall plaster, wall insulation and double glazing on the HVAC energy consumption of the base case.

Zone 1 (Dining/Passage)	*Total heating Load (Wh)*	*Total cooling Load (Wh)*	*Total load (Wh) (heating + cooling)*	*Energy reduction (Wh)*	*Reduction(R) or increase (I) (%)*
Base case	1327161	1680264	3007425	-	-
Combination of Double glazing, roof insulation, wall plaster plus insulation	99067	1247886	1346953	1660472	55.2(R)

5.14 Effect of combining roof insulation, outer wall plaster, wall insulation and double glazing on thermal performance of base case

Figure 5.19 shows the annual temperature distribution of the dining/passage zone (light brown line). The inputs to the Ecotect™ model were double glazing, roof insulation, cement plaster on the outer wall and wall insulation. (See Table 5.31 for the annual temperature distribution). A comparison of thermal performance of base case and the Ecotect™ model with double glazing, roof insulation, cement plaster on the outer wall and wall insulation is shown Table 5.32.

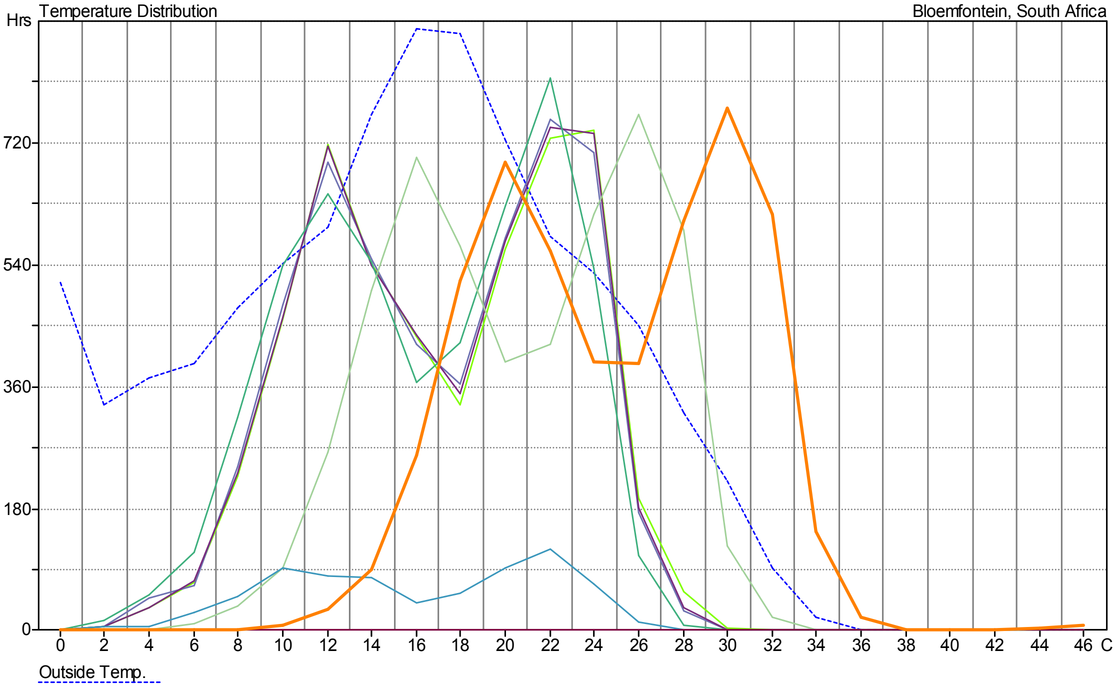

Figure 5.19: Predicted annual temperature distribution for the Ecotect model with a combination of roof insulation, outer wall plaster, wall insulation and double glazing.[1]

Table 5.31 below shows that the dining/passage zone will be in comfort for 3420 hours, which is 66.9% of the total number of hours in one year. These results were produced considering that the dining / passage zone was occupied from 07:00 to 21:00 everyday. The thermal comfort band considered is the one prescribed in the SABC of 2005, i.e. 16 - 28°C. The graph generated by the data from Table 5.31 is the light brown line (temperature distribution for the dining / passage zone) shown in Figure 5.19.

Table 5.31: Predicted annual temperature distribution for the dining / passage zone of Ecotect model with a combination of roof insulation, outer wall plaster, wall insulation and double glazing

TEMP (°C).	*HOURS*	*PERCENT*
--------	--------	---------
0	0	0.00
2	0	0.00
4	0	0.00
6	0	0.00
8	0	0.00
10	8	0.20
12	31	0.60
14	90	1.80
16	259	5.10
18	515	10.10
20	691	13.50
22	559	10.90
24	397	7.80
26	395	7.70
28	604	11.80
30	770	15.10
32	613	12.00
34	145	2.80
36	20	0.40
38	1	0.00
40	0	0.00
42	0	0.00
44	4	0.10
46	8	0.20
--------	--------	---------
COMFORT	3420	66.90

The first row of Table 5.32 shows the data for the thermal performance of the base case which are taken from Table 4.1 and also plotted in Figure 4.9. Data of the second row are taken from Table 5.31 and plotted in Figure 5.19. From Table 5.32 it then follows that application of interventions in combination i.e. double glazing, roof insulation, cement plaster on the outer wall and wall insulation reduced the thermal performance of the house by 9.2 %.

Table 5.32: Effect of combining roof insulation, outer wall plaster, wall insulation and double glazing on the thermal performance of base case.

Zone 1	***Number of hours***	***Reduction (R) or***
(dining/passage)	***Within comfort range***	***Increase (I) %***
	(16°C-28°C)	
Base case	3889	-
Combination of Double glazing, roof insulation, wall plaster plus insulation	3420	9.2(R)

5.15 Effect of combining roof insulation, outer wall plaster, wall insulation and ceiling insulation on thermal performance of base case

Figure 5.20 shows annual temperature distribution of the dining/passage zone (light brown line). The inputs to the Ecotect™ model were roof insulation, cement plaster on the outer wall and wall insulation. (See Table 5.33 for the annual temperature distribution). A comparison of thermal performance of the base case and the Ecotect™ model with roof insulation, cement plaster on the outer wall and wall insulation is shown Table 5.34.

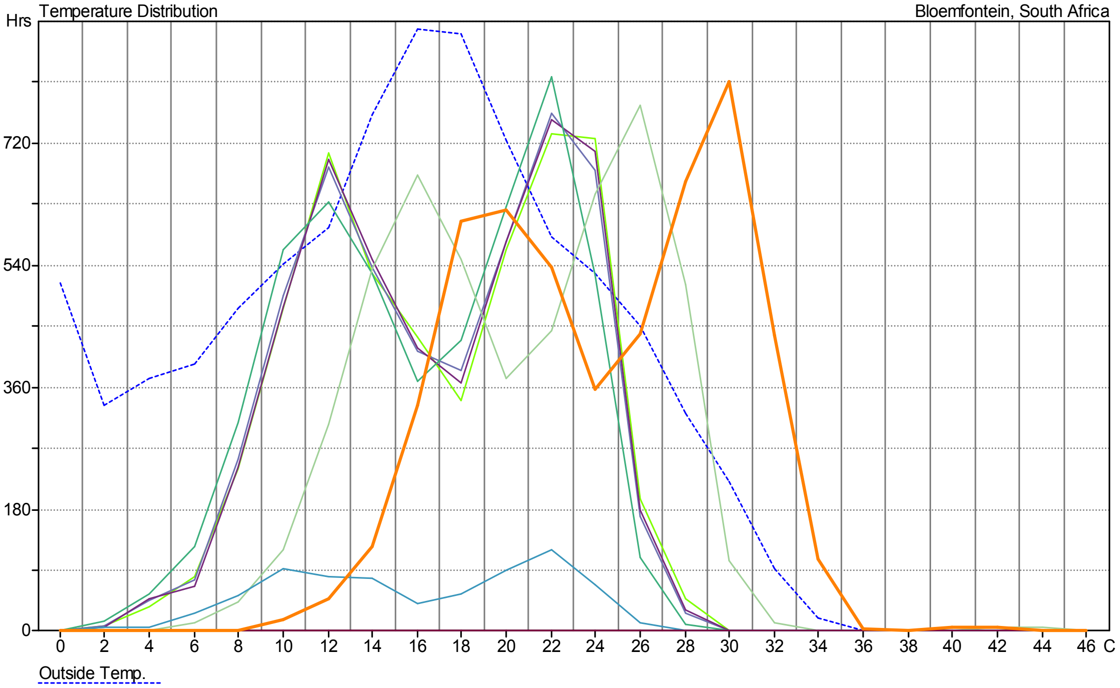

Figure 5.20: Predicted annual temperature distribution for the Ecotect model with a combination of roof insulation, outer wall plaster, wall insulation and ceiling insulation[1]

Table 5.33 below shows that the dining/passage zone will be in comfort for 3552 hours, which is 69.5% of the total number of hours in one year. These results were produced considering that the dining / passage zone was occupied from 07:00 to 21:00 everyday. The thermal comfort band considered is the one prescribed in the SABC of 2005, i.e. 16 - 28°C. The graph generated by the data from Table 5.33 is the light brown line (temperature distribution for the dining / passage zone) shown in Figure 5.20.

Table 5.33: Predicted annual temperature distribution for the dining / passage zone of Ecotect model with a combination of roof insulation, outer wall plaster, wall insulation and ceiling insulation

TEMP (°C).	*HOURS*	*PERCENT*
0	0	0.00
2	0	0.00
4	0	0.00
6	0	0.00
8	0	0.00
10	18	0.40
12	48	0.90
14	125	2.40
16	334	6.50
18	604	11.80
20	620	12.10
22	536	10.50
24	357	7.00
26	439	8.60
28	662	13.00
30	809	15.80
32	435	8.50
34	107	2.10
36	4	0.10
38	0	0.00
40	5	0.10
42	7	0.10
44	0	0.00
46	0	0.00
--------	--------	---------
COMFORT	3552	69.50

The first row of Table 5.34 shows the data for the thermal performance of the base case which are taken from Table 4.1 and also plotted in Figure 4.9. Data of the second row are taken from Table 5.33 and plotted in Figure 5.20. From Table 5.34 it then follows that the application of interventions in combination i.e. roof insulation, cement plaster on the outer wall, wall insulation and ceiling insulation reduced the thermal performance of the house by 6.6 %.

Table 5.34: Effect of combining roof insulation, outer wall plaster, wall insulation and ceiling insulation on the thermal performance of the base case.

Zone 1	*Number of hours*	*Reduction (R) or*
(dining/passage)	*Within comfort range*	*Increase (I) %*
	(16°C-28°C)	
Base case	3889	-
Combination of ceiling insulation, roof insulation, wall plaster plus insulation	3552	6.6 (R)

5.16 Effect of combining roof insulation, outer wall plaster, wall insulation and ceiling insulation on HVAC energy consumption of base case

Figure 5.21 shows the predicted amount of heating (red bars) and cooling (blue bars) that would be consumed by the dining / passage zone of the base case house. The inputs to the Ecotect™ model were roof insulation, outer wall plaster, wall insulation and ceiling insulation. (See Table 5.35 for data of monthly heating and cooling loads for the dining / passage zone). A comparison of HVAC energy consumption of the base case and the Ecotect™ model with roof insulation, outer wall plaster, wall insulation and ceiling insulation is shown in Table 5.36.

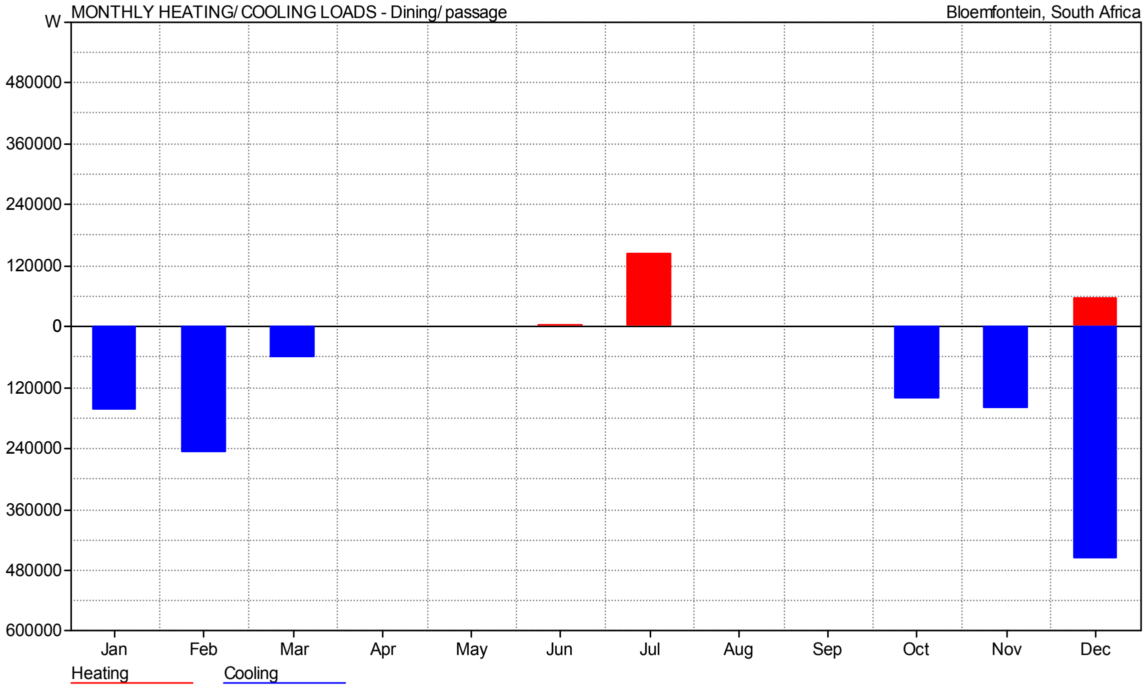

Figure 5.21: Predicted monthly heating and cooling loads for the dining / passage zone of Ecotect model with a combination of roof insulation, outer wall plaster, wall insulation and ceiling insulation.

Table 5.35 shows the predicted monthly heating / cooling loads that would maintain the dining / passage zone within thermal comfort (16 – 28 °C). These results were produced considering that the dining / passage zone was occupied from 07:00 to 21:00 everyday. The maximum heating value of 4889W occurred on 12 July at 08:00, while the maximum cooling value of 3791 W occurred at 16:00 on 1 October. The bar chart generated by data from Table 5.35 is shown in Figure 5.21.

Table 5.35: Predicted monthly heating and cooling loads for the dining / passage zone of Ecotect model with a combination of roof insulation, outer wall plaster, wall insulation and ceiling insulation.

	HEATING	*COOLING*	*TOTAL*
MONTH	*(Wh)*	*(Wh)*	*(Wh)*
-----------	--------	--------	--------
Jan	0	164584	164584
Feb	0	250031	250031
Mar	0	63669	63669
Apr	0	0	0
May	0	0	0
Jun	4182	0	4182
Jul	142440	0	142440
Aug	0	0	0
Sep	0	0	0
Oct	0	142380	142380
Nov	0	161578	161578
Dec	54602	458881	513483
-----------	--------	--------	--------
TOTAL	201224	1241124	1442348
-----------	--------	--------	--------
PER M^2	4585	28280	32865
Floor Area:	43.888 m^2		

The first row of Table 5.36 shows HVAC energy consumption data for the base case which are taken from Table 4.2 and shown in the bar chart of Figure 4.10. Data of the second row are taken from Table 5.35 and also shown in the bar chart off Figure 5.21. From Table 5.36 it follows that combining roof insulation, outer wall plaster, wall insulation and ceiling insulation yields a considerably high reduction of HVAC energy consumption by as much as 52%.

Table 5.36: Effect of combining roof insulation, outer wall plaster, wall insulation and ceiling insulation on the HVAC energy consumption of base case.

Zone 1	*Total heating*	*Total cooling*	*Total load (Wh)*	*Energy reduction (Wh)*	*Reduction(R) or increase (I) (%)*
(Dining/Passage)	*Load (Wh)*	*Load (Wh)*	*(heating +cooling)*		
Base case	1327161	1680264	3007425	-	-
Combination of ceiling insulation, roof insulation, wall plaster plus insulation	201224	1241124	1442348	1565077	52(R)

Chapter 6: Discussion of results

6.1 Introduction

A matrix for the parametric results (Table 6.1) was organised to indicate the effectiveness of each measure studied. The number of hours that the zone temperature was within comfort range (16-28°C) and the HVAC energy consumption was compared to the base-case. See Tables 5.3, 5.6, 5.9, 5.12, 5.15, 5.18, 5.20, 5.22, 5.26, 5.28, 5.30, 5.32, 5.34 and 5.36.

Table 6.1: Summary of results from parametric studies.

Intervention	**Effect on HVAC energy Consumption.**	**Effect on thermal performance**
Roof insulation	8.84% (R) (see Table 5.6)	0.8% (I) (see Table 5.3)
Ceiling insulation	4.5% (I) (see Table 5.12)	0% (see Table 5.9)
Outer wall plaster	28% (R) (see Table 5.18)	0.6% (R) (see Table 5.15)
Wall insulation	42% (R) (see Table 5.22)	6.5% (R) (see Table 5.20)
Roof insulation, ceiling insulation, outer wall plaster, double glazing and wall insulation	2.96% (R) (see Table 5.28)	9.8% (R) (see Table 5.26)
Roof insulation, outer wall plaster, double glazing and wall insulation	55.2% (R) (see Table 5.30)	9.2% (R) (see Table 5.32)
Roof insulation, ceiling insulation, outer wall plaster, and wall insulation	52% (R) (see Table 5.36)	6.6% (R) (see Table 5.34)

Key

R: reduction

I: increase

6.2 Roof insulation

Roof insulation moderately reduces HVAC energy consumption: a reduction of 8.84 % is shown in Table 6.1. However, the intervention does not present a significant improvement in thermal performance. The increase is only 0.8 %. As shown in Table 5.3, the reductions do not differ much if we used 65 mm wool or 100 mm wool. Roof insulation with 65 mm wool is therefore reasonable. Roof insulation is a measure that can be difficult or costly to implement during retrofitting, as compared to installing it in a new building.

6.3 Ceiling insulation

Table 6.1 shows that ceiling insulation alone increases HVAC energy consumption by only 4.5 %. This is unusual when compared to studies by other researchers. Investigation by Mathews et al., (1999) has shown that ceiling insulation reduces energy consumption of HVAC systems by as much as 36 %. This apparent discrepancy would be due to the differences in the climate of the two case study houses.

Mathews et al., (1999) looked at a house which was situated in Pretoria, South Africa. Pretoria has a different weather pattern from Bloemfontein, South Africa. Pretoria is warmer in summer (average summer temperature 27°C to 28°C) than Bloemfontein (average summer temperature +/-23°C). Pretoria is also warmer in winter (winter average temperature 18 °C) than Bloemfontein (winter average temperature +/-8°C) [1, 2].

Passive strategies depend upon the climate of a particular area, therefore the interventions studied in this dissertation are considered unique to Bloemfontein urban residential areas. For single family detached middle to high income houses of Bloemfontein, ceiling insulation is therefore not considered a viable measure to reduce energy consumption of HVAC systems.

6.4 Outer wall plaster

Table 6.1 shows that outer wall plaster has a significant impact on energy consumption, accounting for as much as a 28 % reduction in the energy consumed by HVAC systems. A mere 0.6 % reduction in the thermal performance of the house was observed. This small reduction in thermal performance can easily be offset by an HVAC system. As shown in Tables 5.15 and 5.18, the reductions in thermal performance and HVAC energy consumption do not differ much whether we used 15 mm plaster or 20 mm plaster. Thus 15 mm plaster is reasonable.

Plaster is a form of wall insulation. Plaster does not improve the thermal performance of a house as there was a 0.6 % change in our case study, as plaster shifts the entire temperature profile slightly upwards. Therefore some of the temperature distribution that was within the comfort range, moved out of it. For generally warm climates like Bloemfontein, some of the benefits accrued in winter are offset by the hotter indoor temperatures in summer.

Applying outer wall plaster is an intervention which can easily be incorporated when retrofitting the house. However, plastering the outer wall is a matter of preference, as some house owners value the aesthetic appearance of face brick. Perhaps other forms of wall insulation need to be investigated. Wall insulation, in general, is an effective energy conservation tool.

6.5 Wall insulation

Table 6.1 shows that applying wall insulation (fibrous wool) alone contributes to a 42% reduction in energy consumed by HVAC systems. This percentage reduction is the highest for a single intervention. Table 6.1 shows that increasing the thermal resistance of the outer wall alone, results in big HVAC energy savings of 28 % and 42 %. This shows that the weak element in terms of heat transfer on the base case is its outer walls.

Theoretically, insulation can be lined on the outside of wall masonry, in-between bricks and on the inside surface. Outer wall insulation is not practical, as it negatively affects the aesthetics of the house. The most feasible option is to have wall insulation embedded within the brick wall. However, this can only be done for new buildings. Wall insulation also presents the largest reduction in the thermal performance for a single intervention, as a 6.5 % reduction was seen. This reduction in thermal performance can easily be offset by an HVAC system. Therefore wall insulation is a measure that can be effected on new buildings rather than retrofitting, because of cost implications and practical considerations.

6.6 Combination of roof insulation, ceiling insulation, outer wall plaster, double glazing and outer wall insulation.

The findings from investigating the effects of individual strategies have been combined to formulate a building envelope design that has the minimum annual required HVAC energy consumption. Table 6.1 shows that combining roof insulation, ceiling insulation, outer wall plaster and wall insulation, contributes to a 2.96 % reduction in energy consumed by HVAC system. This percentage reduction is very low when compared with reductions from incorporating single interventions (e.g. roof insulation, outer wall insulation and outer wall plaster). This shows that the effect of individual interventions cannot be summed together to give the desired overall reduction in energy consumption. Combining all passive interventions at once works against one another. Some individual interventions have been seen to have greater impact on both HVAC energy consumption and thermal performance when compared to a combination of interventions. A reduction of 9.8% in the thermal performance of the house is also seen.

6.7 Roof insulation, outer wall plaster, double glazing and wall insulation

The combination of roof insulation, outer wall plaster, double glazing and outer wall insulation has the highest reduction of HVAC energy consumption, as a reduction of 55.2% is shown in Table 6.1. This mix of interventions has the same limitations as shown in paragraph 6.6. However, the removal of ceiling insulation accounts for the huge increase in energy saving. Table 5.30 shows that this combination of passive strategies yields a very high percentage reduction in the heating load, i.e. 99.9 % and 25.7 % reduction in the cooling load. It follows that a combination of these passive strategies is most effective in reducing the heating load in winter and moderately effective in reducing the cooling load during summer.

6.8 Roof insulation, ceiling insulation, outer wall plaster, and wall insulation

The combination of roof insulation, ceiling insulation, outer wall plaster, and wall insulation is the second most effective intervention in terms of HVAC energy consumption, as a reduction of 52% is evident in Table 6.1. The inclusion of ceiling insulation in the mix of interventions accounts for the decrease in energy savings when compared to paragraph 6.7.

6.9 References

[1] http://www.sa-venues.com/weather/freestate.htm accesed 26/01/2010

[2] http://www.sanbi.org/pretoria/summer.htm accessed 26/01/2010

Chapter 7: CONCLUSION AND RECOMMENDATIONS

7.1 Conclusion

This research has investigated the effect of passive strategies in cutting down on energy used for HVAC purposes in single-family detached middle to high income residential buildings in Bloemfontein. The thermal performance of the case study house was evaluated first through field work. After incorporating passive strategies, an analysis of these strategies was undertaken through the use of numerical simulations (Ecotect™ simulation software). The findings provided useful information which can be used by building designers in Bloemfontein.

Results from this dissertation have demonstrated higher energy savings when interventions are considered in combination. The results show that a saving of 55.2 % in annual HVAC energy consumption for the base case can be achieved. It can be seen that the combined effect of roof insulation, outer wall plaster, double glazing and outer wall insulation achieved the highest saving of 55.2%, followed by a 52% from using a combination of roof insulation, ceiling insulation, outer wall plaster, and outer wall insulation, followed by a saving of 42% from using outer wall insulation only. The combined effect of roof insulation, outer wall plaster, double glazing and outer wall insulation reduced the thermal performance of the dining / passage zone by 9.2 % and a combination of roof insulation, ceiling insulation, outer wall plaster, and outer wall insulation reduced the thermal performance of the dining / passage zone by 6.6 %.

Generally, the passive interventions investigated have been seen to have a great impact on reducing HVAC energy consumption, as compared to improving the thermal performance of the house.

The profile of internal temperatures, obtained from field studies shows poor thermal performance of the case study house. The temperature swing of 8.43°C is high, which shows that the outdoor environment greatly influences the environment within the house. This might be interpreted as lack of consideration of energy efficiency during the design and construction of the case study house.

7.2 Recommendations

1. Further research must focus on optimization of the passive strategies.

2. The case study simulations can be improved to match reality by gathering detailed operation schedules for the house for at least one year.
3. Building of a case study house and monitoring variables to validate interventions that promote energy efficiency and implications on funding should be considered.

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APPENDIXES

APPENDIX A

This Appendix presents the comparison of twenty building simulation programmes.

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Table A1: Comparison of twenty building simulation programmes

Table 1 ***Zone Loads*** (11 of the 21 rows from Table 2 of the report)	BLAST	BSim	DeST	DOE-2.1E	ECOTECT	Ener-Win	Energy Express	Energy-10	EnergyPlus	eQUEST	ESP-r	IDA ICE	IES <VE>	HAP	HEED	PowerDomus	SUNREL	Tas	TRACE	TRNSYS
Interior surface convection																				
▪ Dependent on temperature	X	X					P		X		X	X	X		X	X	X	X		X
▪ Dependent on air flow	X						X		P		X		X		X			X		E
▪ Dependent on surface heat coefficient from CFD									E		E		X							
▪ User-defined coefficients (constants, equations or correlations)		X	X	X	X				X		E	R	X		X	X	X	X		X
Internal thermal mass	X	X	X	X	X	X	X	X	X	X	X	X	X		X	X	X	X	X	X
Automatic design day calculations for sizing																				
▪ Dry bulb temperature	X	X	X	X	X	X	X	X	X	X		X	X	X	X	P		X	X	
▪ Dew point temperature or relative humidity			X	X		X	X		X	X		X	X	X				X	X	
▪ User-specified minimum and maximum			X	X		X	X		X	X		X	X	X	X			X	X	
▪ User-specified steady-state, steady-periodic or fully dynamic design conditions			X									X	X	X				X	X	X

Table 2 ***Building Envelope, Daylighting and Solar*** (9 of the 52 rows from Table 3 in the report)	BLAST	BSim	DeST	DOE-2.1E	ECOTECT	Ener-Win	Energy Express	Energy-10	EnergyPlus	eQUEST	ESP-r	IDA ICE	IES <VE>	HAP	HEED	PowerDomus	SUNREL	Tas	TRACE	TRNSYS
Outside surface convection algorithm																				
▪ BLAST/TARP	X								X										X	
▪ DOE-2				X					X	X									X	
▪ MoWiTT									X		X								X	
▪ ASHRAE simple	X					X		X	X				X		X			X	X	
▪ Ito, Kimura, and Oka correlation											X	X								
▪ User-selectable			X						X		X	X	X			X		X	X	X
Inside radiation view factors		X	X						X		X	X	X				P	X		
Radiation-to-air component separate from detailed convection (exterior)		X	X						X	X	X	X	X				X	X	P	X
Solar gain and daylighting calculations account for inter-reflections from external building components and other buildings		P			X				X		X		X			P				X

Table 4 ***Infiltration, Ventilation, Room Air and Multizone Airflow***	BLAST	BSim	DeST	DOE-2.1E	ECOTECT	Ener-Win	Energy Express	Energy-10	EnergyPlus	eQUEST	ESP-r	IDA ICE	IES <VE>	HAP	HEED	PowerDomus	SUNREL	Tas	TRACE	TRNSYS
Single zone infiltration	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Automatic calculation of wind pressure coefficients		X	P						P				X				X	X		
Natural ventilation (pressure, buoyancy driven)		X	P						X	P	X	X	X			X	X	X		O
Multizone airflow (via pressure network model)		X	P						X		X	X	X				X	X		O
Hybrid natural and mechanical ventilation		X	P			X					I	X	X			X		X		O
Control window opening based on zone or external conditions			X			X			X		X		X			P	X			O
Displacement ventilation									X		X	X	X					X		O
Mix of flow networks and CFD domains			X								E									
Contaminants, mycotoxins (mold growth)		P									R					P				

Table 5 ***HVAC Systems/Components & Renewable Energy Systems*** [summary from report Tables 5, 7 & 8 (9 pages)]	BLAST	BSim	DeST	DOE-2.1E	ECOTECT	Ener-Win	Energy Express	Energy-10	EnergyPlus	eQUEST	ESP-r	IDA ICE	IES <VE>	HAP	HEED	PowerDomus	SUNREL	Tas	TRACE	TRNSYS
Renewable Energy Systems (12 identified, X+O)	1	2	2	1	4	0	0	2	4	2	7	1	3	0	0	1	2	2	0	12
Idealized HVAC systems	X		X		X	X			X		X	X	X				X			X
User-configurable HVAC systems		X	X				P		X		X	X	X	X	X	X	R	X	X	X
Pre-configured systems (among 34 identified, X+O)	14	14	20	16	0	16	5	7	28	24	23	32	28	28	10	8	1	23	26	20
Discrete HVAC components (98 identified, X+O)	51	24	34	39	0	24	8	15	66	61	40	52	38	43	7	15	3	26	63	82

Table 6 ***Economic Evaluation*** (energy costs portion of Table 11 of the report)	BLAST	BSim	DeST	DOE-2.1E	ECOTECT	Ener-Win	Energy Express	Energy-10	EnergyPlus	eQUEST	ESP-r	IDA ICE	IES <VE>	HAP	HEED	PowerDomus	SUNREL	Tas	TRACE	TRNSYS
Simple energy and demand charges		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X		X	X	X
Complex energy tariffs including fixed charges, block charges, demand charges, ratchets		X	X	X			X		X	X			X	X	X	P			X	E
Scheduled variation in all rate components		X	X	X					X	X		X	X	X	X	P		X	X	X
User selectable billing dates				X					X	X					X	P			X	E

APPENDIX B: HOURLY TEMPERATURE AND HUMIDITY VALUES FROM 18 MAY 2009 TO 24 MAY 2009.

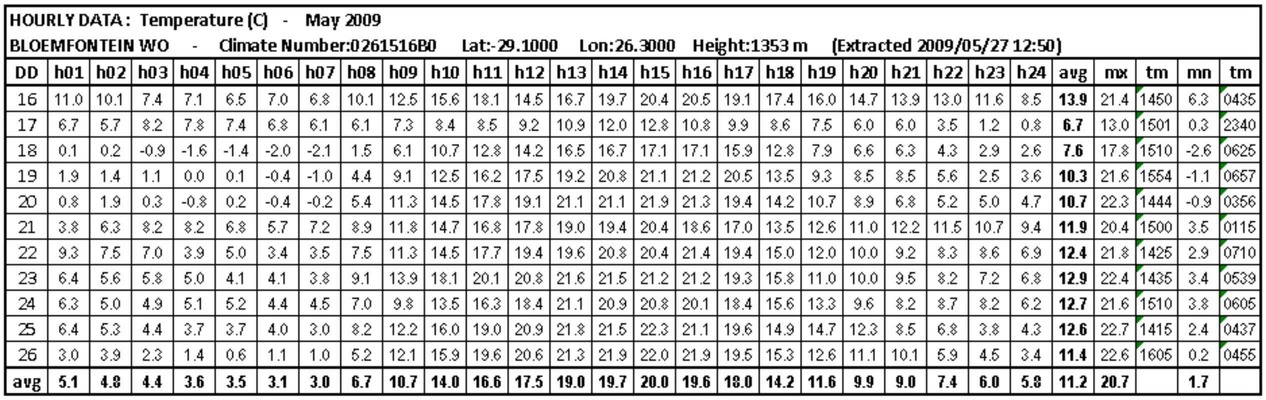
This appendix presents measured data for temperature and humidity used for thermal comfort assessment of the case study house. Sample measured data from Ecolog TH1 are presented in the table B 1 below. All the data from the Ecolog TH1 data logger are recorded on the CD attached on the inner back cover under the folder 'Data from Ecolog TH1'. Tables B 2 and B 3 show hourly outdoor measured temperature and hourly outdoor relative humidity data (for 18 May 2009 to 24 May 2009 respectively), from the Bloemfontein Metrological office.

Table B 1: Sample indoor measured data from Ecolog TH1 data logger (18 May 2009 to 24 May 2009)

18.05.2009	00:00:47	12.38	44.5
18.05.2009	00:01:47	12.38	44.8
18.05.2009	00:02:47	12.38	44.8
18.05.2009	00:03:47	12.38	44.8
18.05.2009	00:04:47	12.38	44.9
18.05.2009	00:05:47	12.38	44.9
18.05.2009	00:06:47	12.38	45
18.05.2009	00:07:47	12.31	45
18.05.2009	00:08:47	12.31	44.9
18.05.2009	00:09:47	12.31	45
18.05.2009	00:10:47	12.31	45
18.05.2009	00:11:47	12.31	45
18.05.2009	00:12:47	12.31	45
18.05.2009	00:13:47	12.31	45.1
18.05.2009	00:14:47	12.31	45.1
18.05.2009	00:15:47	12.31	45.1
18.05.2009	00:16:47	12.25	45
18.05.2009	00:17:47	12.25	45.1
18.05.2009	00:18:47	12.25	45.2
18.05.2009	00:19:47	12.25	45.1
18.05.2009	00:20:47	12.25	45.1
18.05.2009	00:21:47	12.25	45.1
18.05.2009	00:22:47	12.25	45.1
18.05.2009	00:23:47	12.19	45.2
18.05.2009	00:24:47	12.19	45.2
18.05.2009	00:25:47	12.19	45.2
18.05.2009	00:26:47	12.19	45.2
18.05.2009	00:27:47	12.19	45.2

The columns above represent the following:
1. Date
2. Time
3. Indoor temperature
4. Indoor relative humidity

Table B 2: hourly measured temperature data from Bloemfontein Metrological office (18 May 2009 to 24 May 2009)

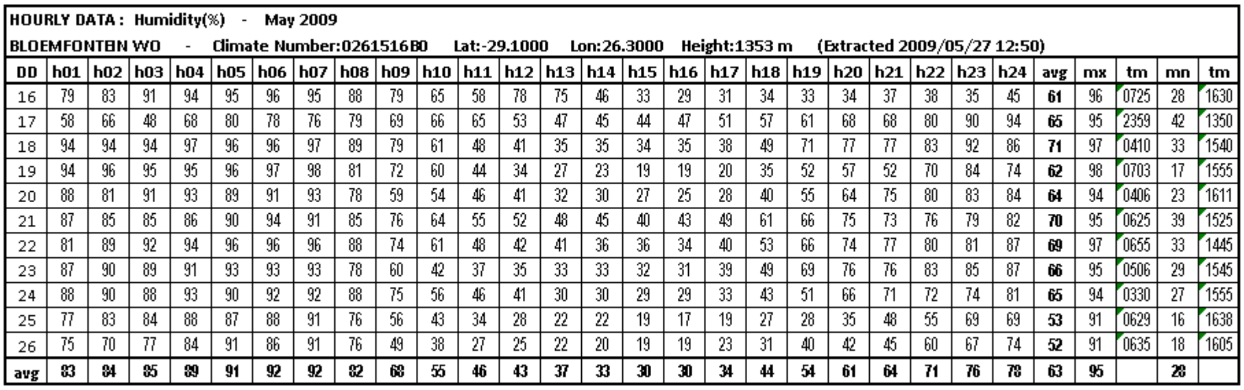


HOURLY DATA : Temperature (C) - May 2009

BLOEMFONTEIN WO - Climate Number:0261516B0 Lat:-29.1000 Lon:26.3000 Height:1353 m (Extracted 2009/05/27 12:50)

DD	h01	h02	h03	h04	h05	h06	h07	h08	h09	h10	h11	h12	h13	h14	h15	h16	h17	h18	h19	h20	h21	h22	h23	h24	avg	mx	tm	mn	tm
16	11.0	10.1	7.4	7.1	6.5	7.0	6.8	10.1	12.5	15.6	18.1	14.5	16.7	19.7	20.4	20.5	19.1	17.4	16.0	14.7	13.9	13.0	11.6	8.5	**13.9**	21.4	1450	6.3	0435
17	6.7	5.7	8.2	7.8	7.4	6.8	6.1	6.1	7.3	8.4	8.5	9.2	10.9	12.0	12.8	10.8	9.9	8.6	7.5	6.0	6.0	3.5	1.2	0.8	**6.7**	13.0	1501	0.3	2340
18	0.1	0.2	-0.9	-1.6	-1.4	-2.0	-2.1	1.5	6.1	10.7	12.8	14.2	16.5	16.7	17.1	17.1	15.9	12.8	7.9	6.6	6.3	4.3	2.9	2.6	**7.6**	17.8	1510	-2.6	0625
19	1.9	1.4	1.1	0.0	0.1	-0.4	-1.0	4.4	9.1	12.5	16.2	17.5	19.2	20.8	21.1	21.2	20.5	13.5	9.3	8.5	8.5	5.6	2.5	3.6	**10.3**	21.6	1554	-1.1	0657
20	0.8	1.9	0.3	-0.8	0.2	-0.4	-0.2	5.4	11.3	14.5	17.8	19.1	21.1	21.1	21.9	21.3	19.4	14.2	10.7	8.9	6.8	5.2	5.0	4.7	**10.7**	22.3	1444	-0.9	0356
21	3.8	6.3	8.2	8.2	6.8	5.7	7.2	8.9	11.8	14.7	16.8	17.8	19.0	19.4	20.4	18.6	17.0	13.5	12.6	11.0	12.2	11.5	10.7	9.4	**11.9**	20.4	1500	3.5	0115
22	9.3	7.5	7.0	3.9	5.0	3.4	3.5	7.5	11.3	14.5	17.7	19.4	19.6	20.8	20.4	21.4	19.4	15.0	12.0	10.0	9.2	8.3	8.6	6.9	**12.4**	21.8	1425	2.9	0710
23	6.4	5.6	5.8	5.0	4.1	4.1	3.8	9.1	13.9	18.1	20.1	20.8	21.6	21.5	21.2	21.2	19.3	15.8	11.0	10.0	9.5	8.2	7.2	6.8	**12.9**	22.4	1435	3.4	0539
24	6.3	5.0	4.9	5.1	5.2	4.4	4.5	7.0	9.8	13.5	16.3	18.4	21.1	20.9	20.8	20.1	18.4	15.6	13.3	9.6	8.2	8.7	8.2	6.2	**12.7**	21.6	1510	3.8	0605
25	6.4	5.3	4.4	3.7	3.7	4.0	3.0	8.2	12.2	16.0	19.0	20.9	21.8	21.5	22.3	21.1	19.6	14.9	14.7	12.3	8.5	6.8	3.8	4.3	**12.6**	22.7	1415	2.4	0437
26	3.0	3.9	2.3	1.4	0.6	1.1	1.0	5.2	12.1	15.9	19.6	20.6	21.3	21.9	22.0	21.9	19.5	15.3	12.6	11.1	10.1	5.9	4.5	3.4	**11.4**	22.6	1605	0.2	0455
avg	**5.1**	**4.8**	**4.4**	**3.6**	**3.5**	**3.1**	**3.0**	**6.7**	**10.7**	**14.0**	**16.6**	**17.5**	**19.0**	**19.7**	**20.0**	**19.6**	**18.0**	**14.2**	**11.6**	**9.9**	**9.0**	**7.4**	**6.0**	**5.8**	**11.2**	**20.7**		**1.7**	

Table B 3: *hourly measured outdoor relative humidity data from Bloemfontein Metrological office (18 May 2009 to 24 May 2009)*



HOURLY DATA : Humidity(%) - May 2009

BLOEMFONTBN WO - Climate Number:0261516B0 Lat:-29.1000 Lon:26.3000 Height:1353 m (Extracted 2009/05/27 12:50)

DD	h01	h02	h03	h04	h05	h06	h07	h08	h09	h10	h11	h12	h13	h14	h15	h16	h17	h18	h19	h20	h21	h22	h23	h24	avg	mx	tm	mn	tm
16	79	83	91	94	95	96	95	88	79	65	58	78	75	46	33	29	31	34	33	34	37	38	35	45	**61**	96	0725	28	1630
17	58	66	48	68	80	78	76	79	69	66	65	53	47	45	44	47	51	57	61	68	68	80	90	94	**65**	95	2359	42	1350
18	94	94	94	97	96	96	97	89	79	61	48	41	35	35	34	35	38	49	71	77	77	83	92	86	**71**	97	0410	33	1540
19	94	96	95	95	96	97	98	81	72	60	44	34	27	23	19	19	20	35	52	57	52	70	84	74	**62**	98	0703	17	1555
20	88	81	91	93	89	91	93	78	59	54	46	41	32	30	27	25	28	40	55	64	75	80	83	84	**64**	94	0406	23	1611
21	87	85	85	86	90	94	91	85	76	64	55	52	48	45	40	43	49	61	66	75	73	76	79	82	**70**	95	0625	39	1525
22	81	89	92	94	96	96	96	88	74	61	48	42	41	36	36	34	40	53	66	74	77	80	81	87	**69**	97	0655	33	1445
23	87	90	89	91	93	93	93	78	60	42	37	35	33	33	32	31	39	49	69	76	76	83	85	87	**66**	95	0506	29	1545
24	88	90	88	93	90	92	92	88	75	56	46	41	30	30	29	29	33	43	51	66	71	72	74	81	**65**	94	0330	27	1555
25	77	83	84	88	87	88	91	76	56	43	34	28	22	22	19	17	19	27	28	35	48	55	69	69	**53**	91	0629	16	1638
26	75	70	77	84	91	86	91	76	49	38	27	25	22	20	19	19	23	31	40	42	45	60	67	74	**52**	91	0635	18	1605
avg	**83**	**84**	**85**	**89**	**91**	**92**	**92**	**82**	**68**	**55**	**46**	**43**	**37**	**33**	**30**	**30**	**34**	**44**	**54**	**61**	**64**	**71**	**76**	**78**	**63**	**95**		**28**	

APPENDIX C:

This appendix presents the following:

- Graphical Comparison of indoor to outdoor temperatures.
- Graphical Comparison of indoor to outdoor relative humidities.

All the hourly data which were used to plot the graphs Figure C1 to C 14 are recorded on the CD attached on the inner back cover under the folder 'Hourly data extracted from Ecolog TH1'.

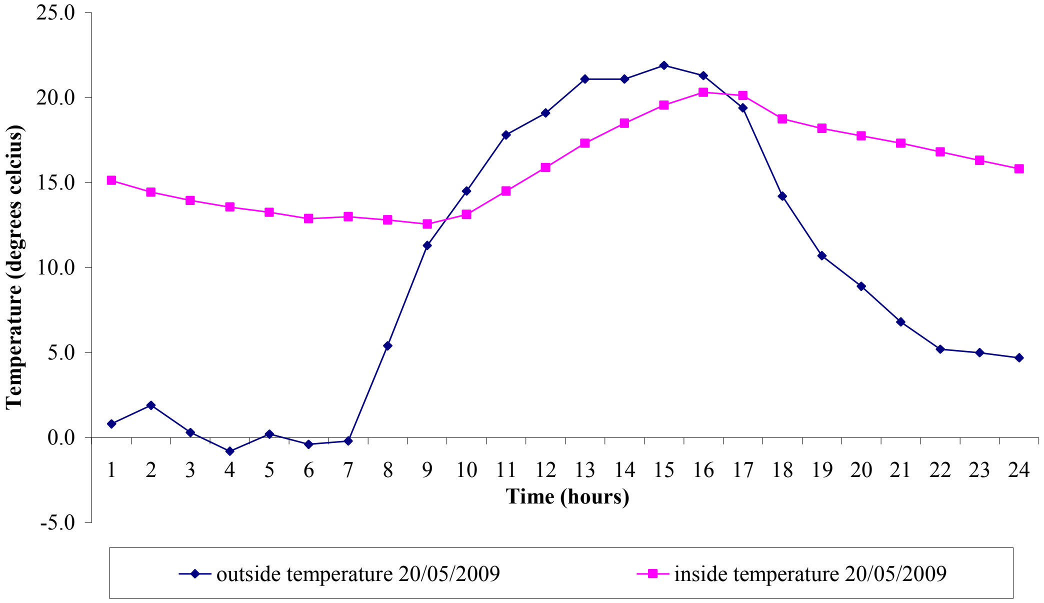


Figure C 1: indoor temperature (shown by pink line) for the case study house plotted against outdoor air temperature (shown by blue line) for 20 May 2009

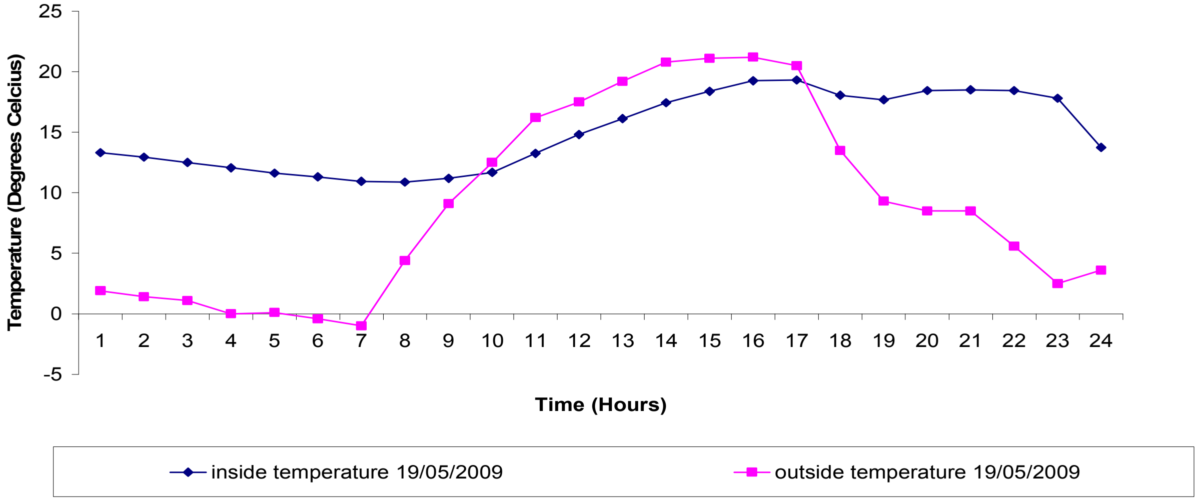


Figure C 2: indoor temperature (shown by blue line) for the case study house plotted against outdoor air temperature (shown by pink line) for 19 May 2009

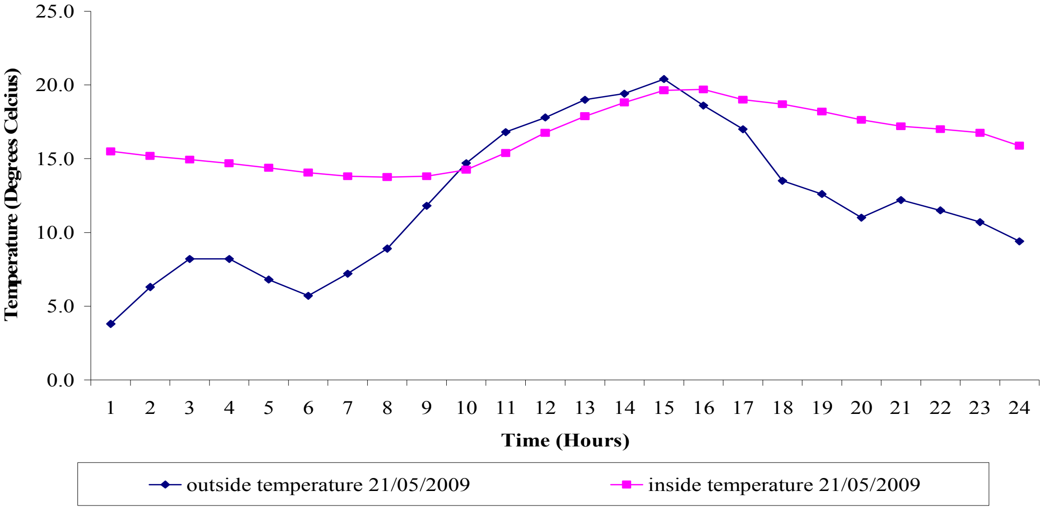


Figure C 3: indoor temperature (shown by pink line) for the case study house plotted against outdoor air temperature (shown by blue line) for 21 May 2009

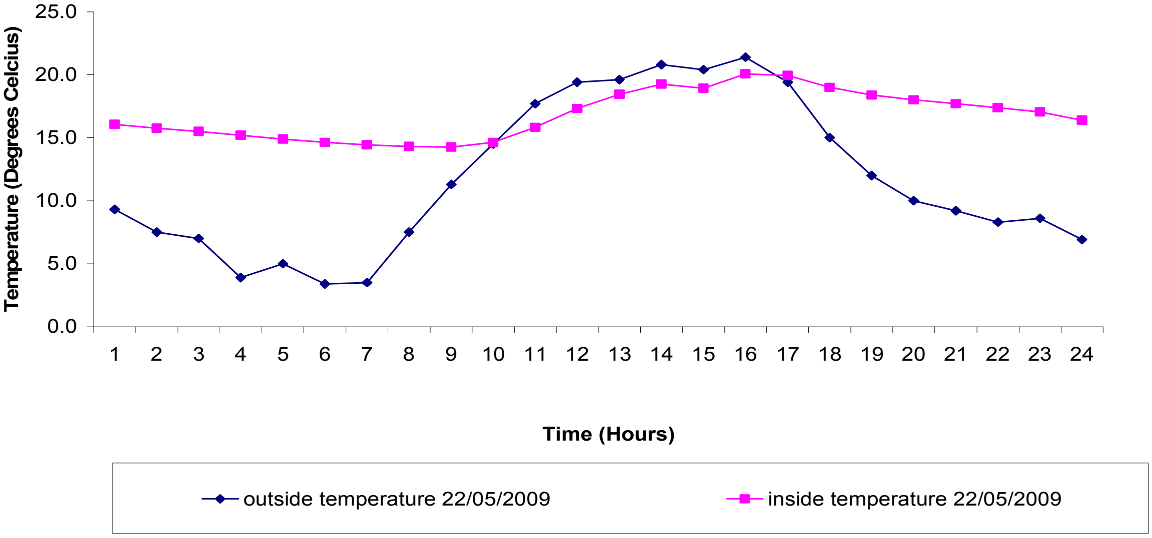


Figure C 4: indoor temperature (shown by pink line) for the case study house plotted against outdoor air temperature (shown by blue line) for 22 May 2009

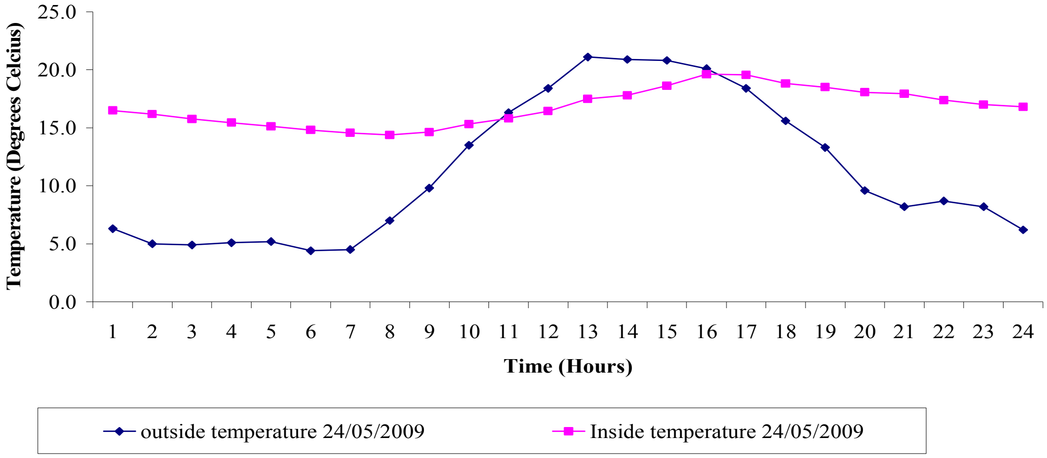


Figure C 5: indoor temperature (shown by pink line) for the case study house plotted against outdoor air temperature (shown by blue line) for 24 May 2009

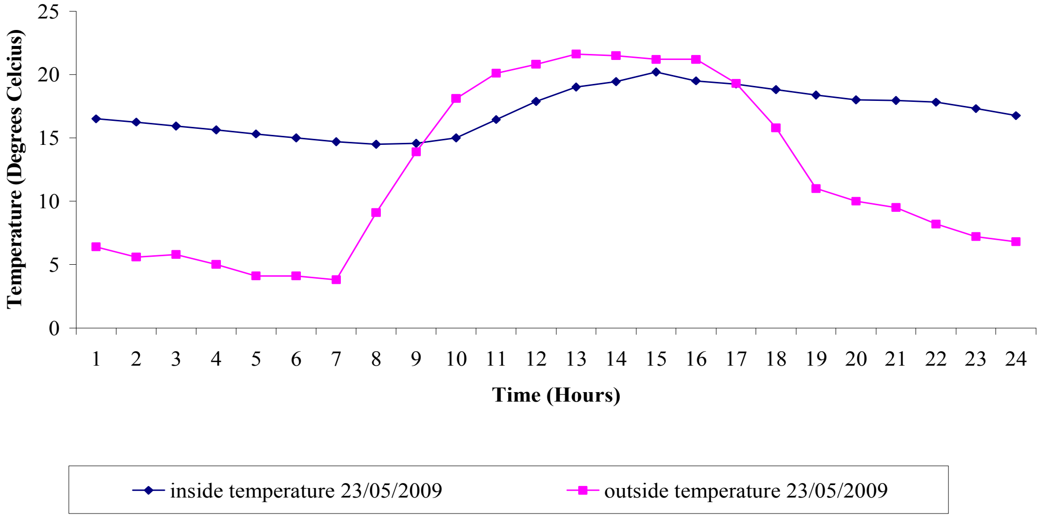


Figure C 6: indoor temperature (shown by pink line) for the case study house plotted against outdoor air temperature (shown by blue line) for 23 May 2009

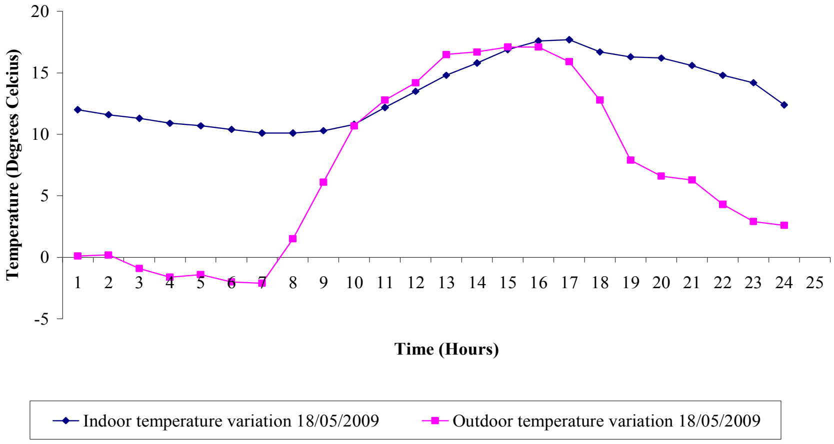


Figure C 7: indoor temperature (shown by blue line) for the case study house plotted against outdoor air temperature (shown by pink line) for 18 May 2009

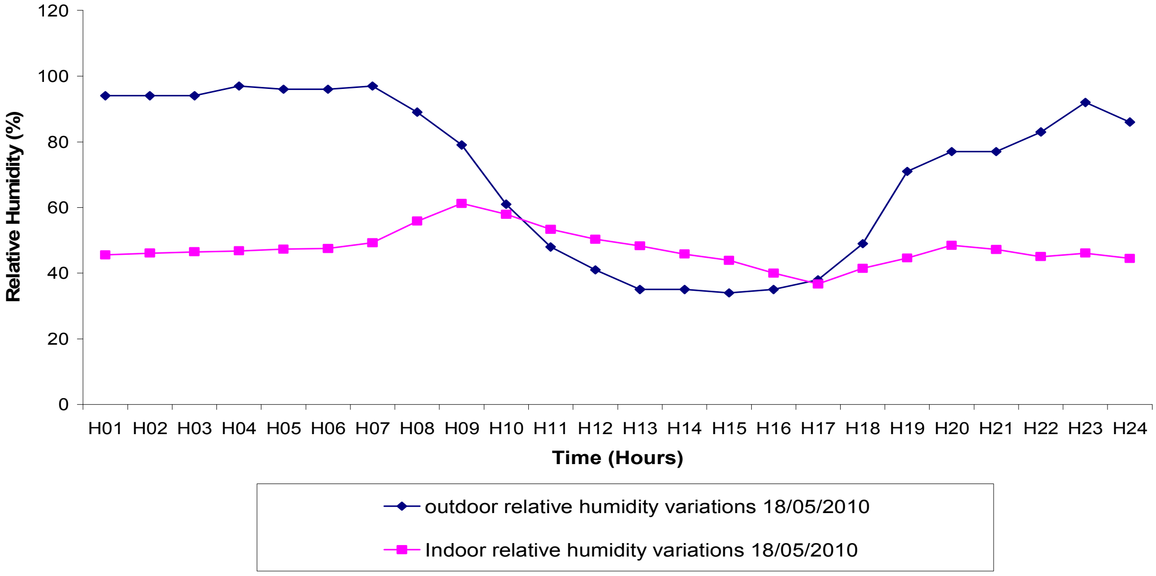


Figure C 8: indoor (measured) relative humidity (shown by pink line) for the case study house plotted against outdoor relative humidity (shown by blue line) for 18 May 2009

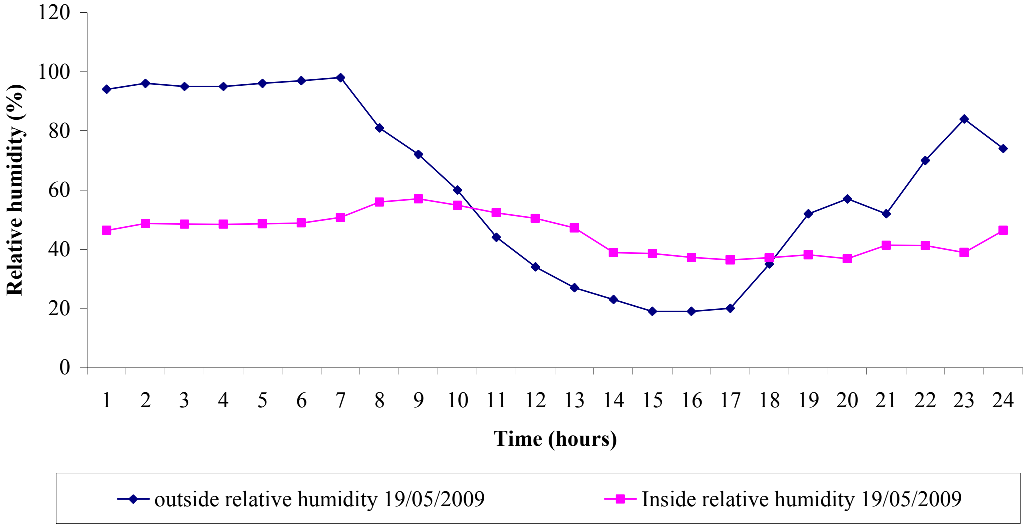


Figure C 9: indoor (measured) relative humidity (shown by pink line) for the base case house plotted against outdoor relative humidity (shown by blue line) for 19 May 2009

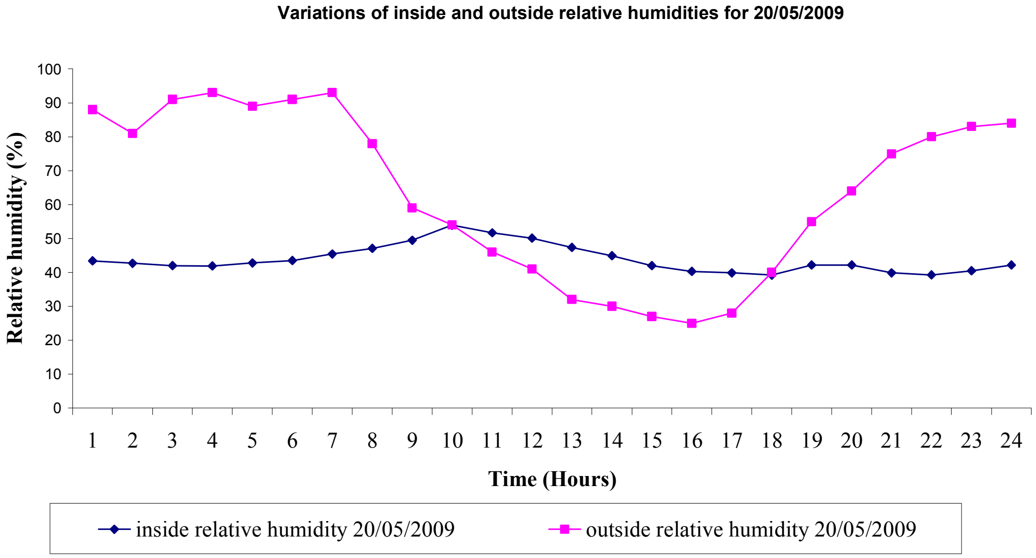
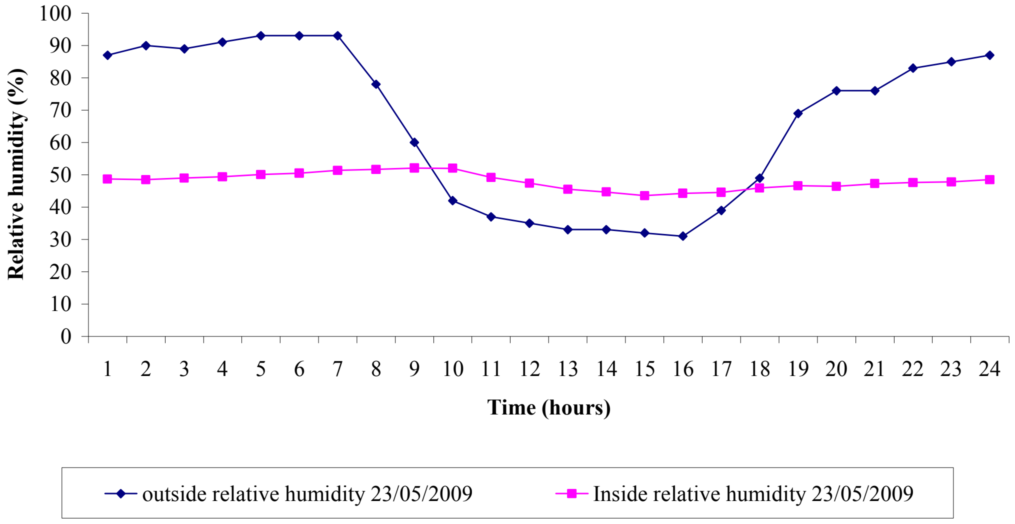


Figure C 10: indoor (measured) relative humidity (shown by Blue line) for the base case house plotted against outdoor relative humidity (shown by pink line) for 20 May 2009



]

Figure C 11: indoor (measured) relative humidity (shown by pink line) for the base case house plotted against outdoor relative humidity (shown by blue line) for 23 May 2009

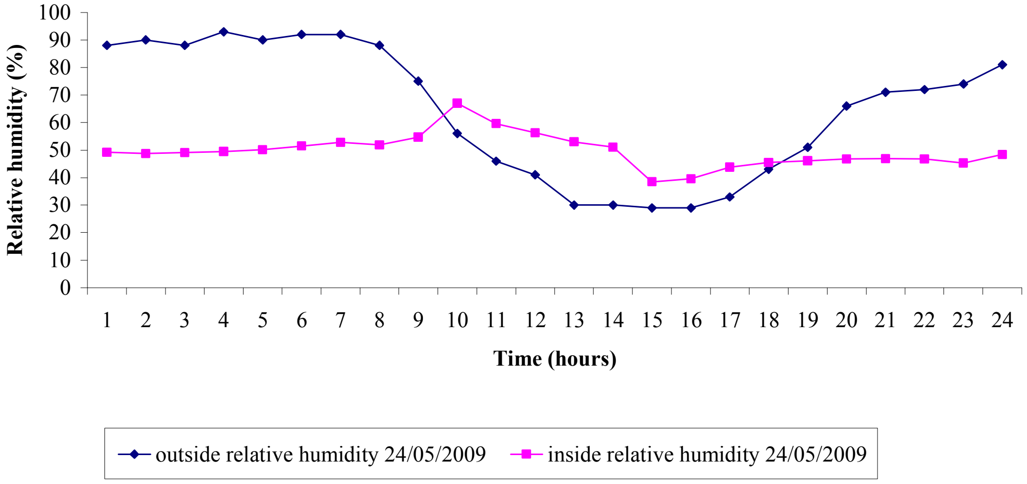


Figure C 12: indoor (measured) relative humidity (shown by pink line) for the base case house plotted against outdoor relative humidity (shown by blue line) for 24 May 2009

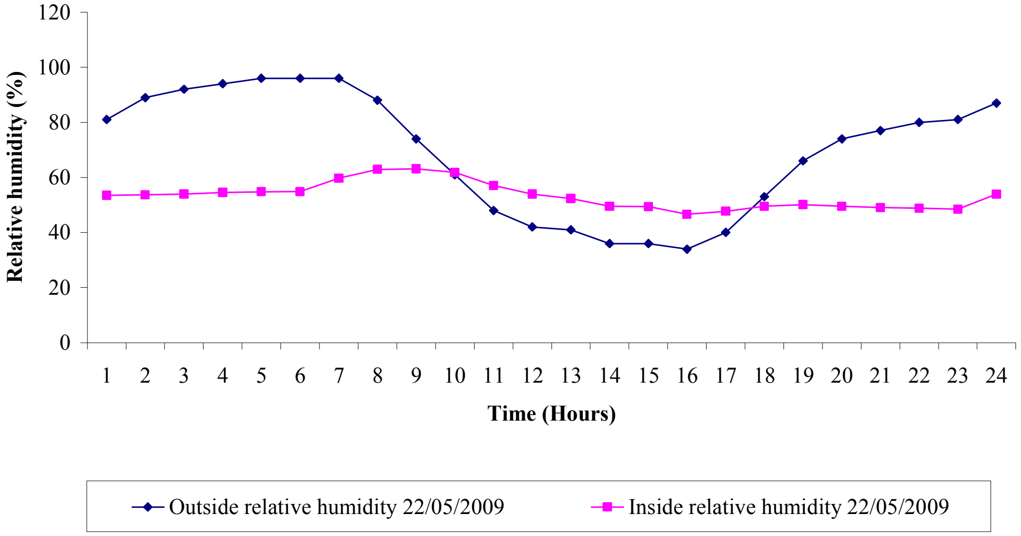


Figure C 13: indoor (measured) relative humidity (shown by pink line) for the base case house plotted against outdoor relative humidity (shown by blue line) for 22 May 2009

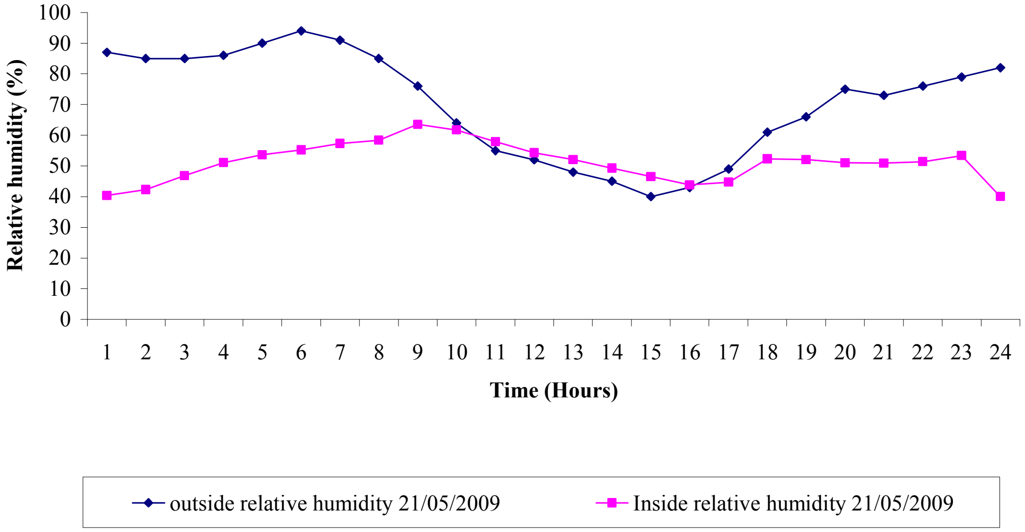
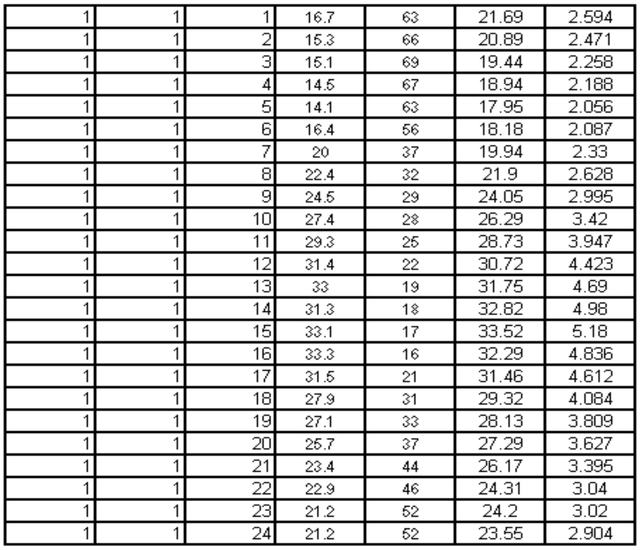


Figure C 14: indoor (measured) relative humidity (shown by pink line) for the base case house plotted against outdoor relative humidity (shown by blue line) for 21 May 2009

APPENDIX D: WEATHER DATA

This appendix presents weather data used for creating the weather file for Bloemfontein. Sample data for the weather file are presented in Table D 1 below. All the data are recorded on the CD attached on the inner back cover under the folder ‘Weather data for weather file’.

Table D 1: Sample data for the weather file



1	1	1	16.7	63	21.69	2.594
1	1	2	15.3	66	20.89	2.471
1	1	3	15.1	69	19.44	2.258
1	1	4	14.5	67	18.94	2.188
1	1	5	14.1	63	17.95	2.056
1	1	6	16.4	56	18.18	2.087
1	1	7	20	37	19.94	2.33
1	1	8	22.4	32	21.9	2.628
1	1	9	24.5	29	24.05	2.995
1	1	10	27.4	28	26.29	3.42
1	1	11	29.3	25	28.73	3.947
1	1	12	31.4	22	30.72	4.423
1	1	13	33	19	31.75	4.69
1	1	14	31.3	18	32.82	4.98
1	1	15	33.1	17	33.52	5.18
1	1	16	33.3	16	32.29	4.836
1	1	17	31.5	21	31.46	4.612
1	1	18	27.9	31	29.32	4.084
1	1	19	27.1	33	28.13	3.809
1	1	20	25.7	37	27.29	3.627
1	1	21	23.4	44	26.17	3.395
1	1	22	22.9	46	24.31	3.04
1	1	23	21.2	52	24.2	3.02
1	1	24	21.2	52	23.55	2.904

The columns above represent the following:

1. Month,
2. date of month,
3. hours,
4. temperature,
5. humidity,
6. solar radiation and
7. wind speed.

APPENDIX E: AS - BUILT ARCHITECTURAL PLAN

APPENDIX F: SECTIONS AND THERMAL PROPERTIES OF BUILDING MATERIALS FOR THE BASE CASE

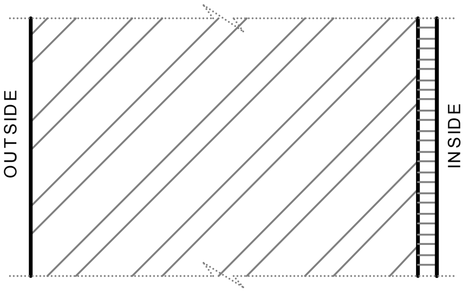


Figure F 1: Section for the outer wall

Table F1: Properties for the outer wall materials as from Ecotect:

Layer name	Width (mm)	Density	Sp. Heat	Conductivity
Brick Masonry	215	2000	836.8	0.711
Cement Plaster	10	1250	1088	0.431

Table F2: Thermal properties for outer wall section as calculated by Ecotect

Property	value
U (W/m².K)	1.99
Admittance ((W/m².K)	4.55
Solar Absorption (0-1)	0.559
Visible transmittance (0-1)	0
Thermal Decrement (0-1)	0.4
Thermal lag (hours)	7.56

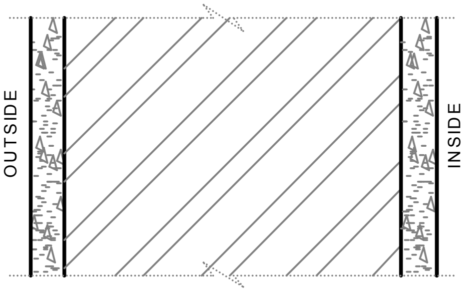


Figure F2: Section for inner wall

Table F 3: Properties for the inner wall materials as from Ecotect:

Layer name	Width	Density	Sp. Heat	Conductivity
Plaster	10	1200	840	0.520
Brick masonry	95	2000	836.8	0.711
Plaster	10	1200	840	0.520

Table F4: Thermal properties for inner wall section as calculated by Ecotect

Property	value
U (W/m².K)	2.86
Admittance ((W/m².K)	4.27
Solar Absorption (0-1)	0.559
Visible transmittance (0-1)	0
Thermal Decrement (0-1)	0.77
Thermal lag (hours)	3.46

Ceiling

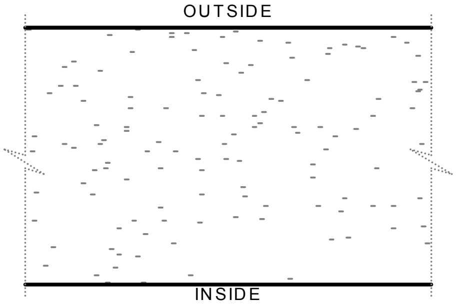


Figure F 3: Ceiling section for base case

Layer name	Width (mm)	Density	Sp. Heat	Conductivity
Board	10	160	1890	0.04

Table F 5: Thermal properties for ceiling section as calculated by Ecotect

Property	value
U (W/m².K)	2.34
Admittance ((W/m².K)	2.33
Solar Absorption (0-1)	0.368
Visible transmittance (0-1)	0
Thermal Decrement (0-1)	0.99
Thermal lag (hours)	0.08

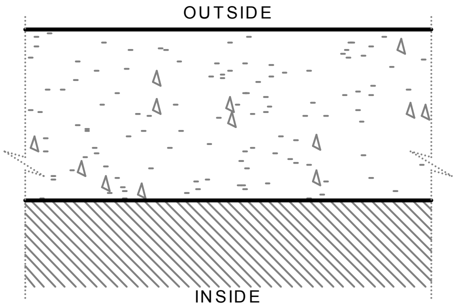


Figure F 4: Roof section of base case

Layer name	Width	Density	Sp. Heat	conductivity
Concrete light weight	20	950	656.9	0.209
Iron (Wrought)	10	7700	460.2	58.576

Table F 6: Thermal properties for roof section as calculated by Ecotect

Property	value
U (W/m².K)	3.65
Admittance ((W/m².K)	3.93
Solar Absorption (0-1)	0.6
Visible transmittance (0-1)	0
Thermal Decrement (0-1)	0.97
Thermal lag (hours)	0.87

Table F 7: Section for steel framed windows for base case

Layer name	Width	Density	Sp. Heat	Conductivity
Steel	5	7800	480	45
Glass standard	6	2300	836.8	1.046
Steel	5	7800	480	45

Table F 8: Thermal properties for window section as calculated by Ecotect

Property	Value
U (W/m².K)	6
Admittance ((W/m².K)	6
Solar heat gain coefficient (0-1)	0.94
Visible transmittance (0-1)	0.753
Refractive index of glass	1.74
Alt solar gain (heavy wt)	0.47
Alt solar gain (light wt)	0.64

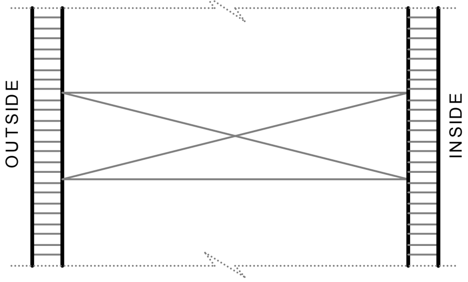


Figure F 5: Section for door of base case

Layer name	Width	Density	Sp. Heat	Conductivity
Plywood	3	530	1400	0.14
Air gap	34	1.3	1004	5.56
Plywood	3	530	1400	0.14

Table F 9: Thermal properties for door section as calculated by Ecotect

Property	value
U (W/m².K)	2.98
Admittance ((W/m².K)	0.65
Solar Absorption (0-1)	0.55
Visible transmittance (0-1)	0
Thermal Decrement (0-1)	0.98
Thermal lag (hours)	0.4

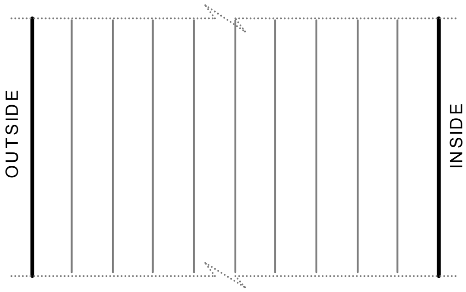


Figure F 6: Glass sliding door

Layer name	Width	Density	Sp. Heat	Conductivity
Glass standard	6	2300	836.8	1.046

Table F10: Thermal properties for glass-door section as calculated by Ecotect

Property	value
U (W/m².K)	5.44
Admittance ((W/m².K)	5.39
Solar Absorption (0-1)	1
Visible transmittance (0-1)	0
Thermal Decrement (0-1)	0.99
Thermal lag (hours)	0.39

APPENDIX G: INDOOR TEMPERATURE PREDICTIONS FOR FIRST CALIBRATION (18-24 MAY)

This appendix shows predicted hourly indoor temperature for the dining / passage zone indicated by a light brown line for the base case. The predictions are for one week from 18 to 24 May.

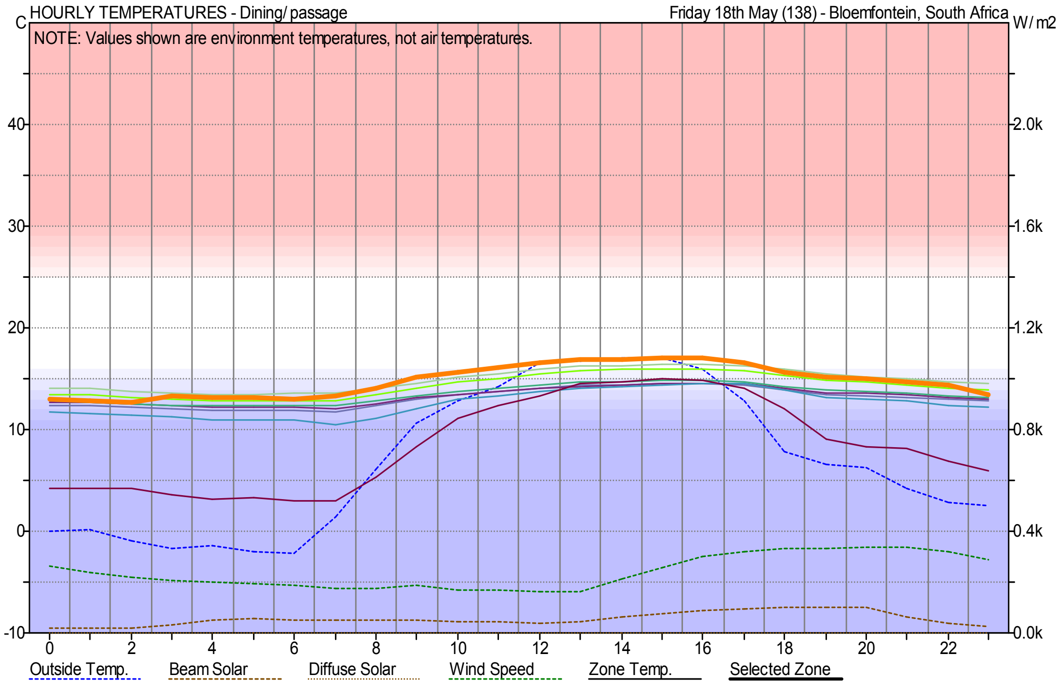


Figure G1: Hourly predicted temperature profile inside Dining/passage zone (light brown line) on 18 May 2009 compared with 2008 weather data for Bloemfontein displayed in Ecotect v.5.60.

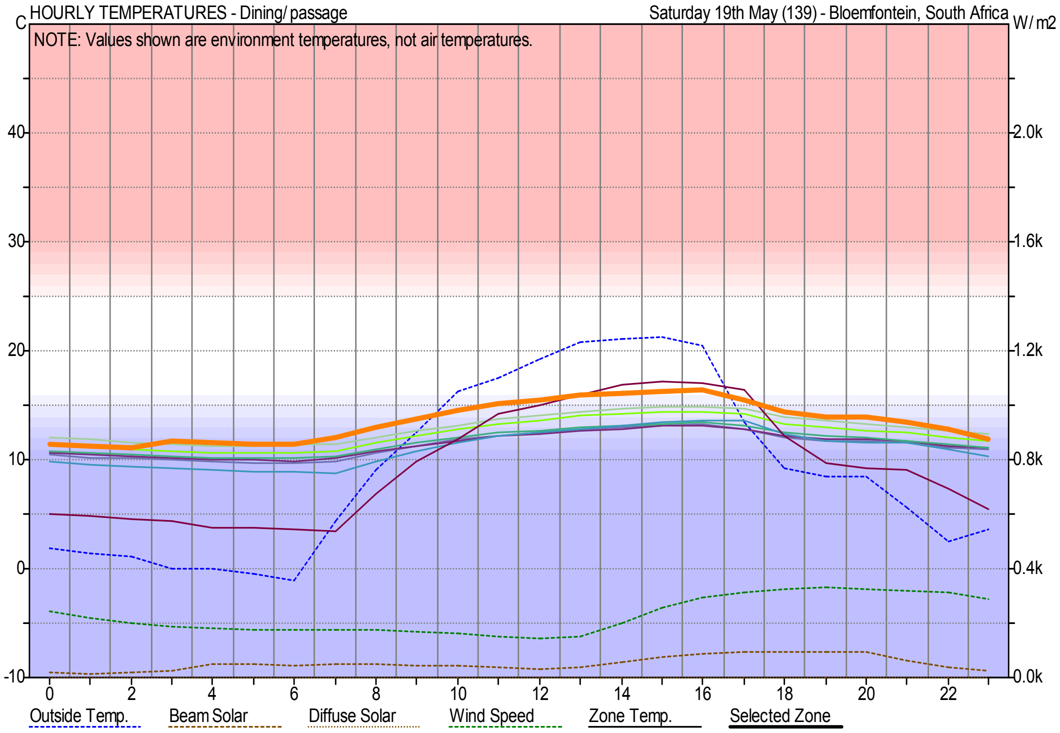


Figure G 2: Hourly predicted temperature profile inside Dining/passage zone (light brown line) on 19 May 2009 compared with 2008 weather data for Bloemfontein displayed in Ecotect v.5.60.

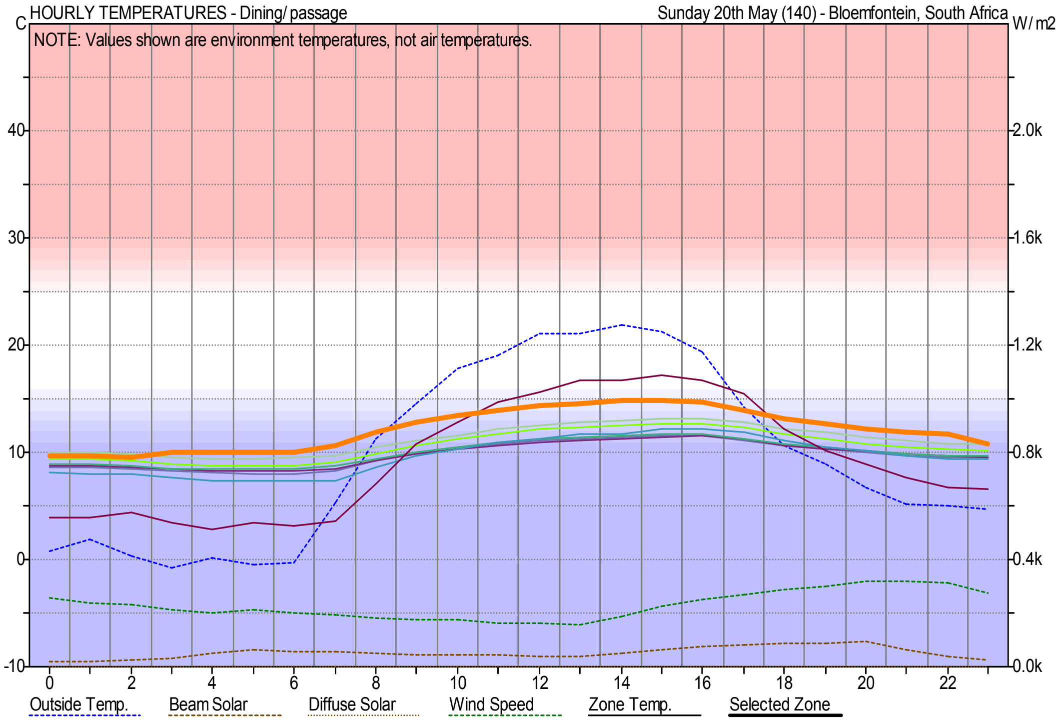


Figure G 3: Hourly predicted temperature profile inside Dining/passage zone (light brown line) on 20 May 2009 compared with 2008 weather data for Bloemfontein displayed in Ecotect v.5.60.

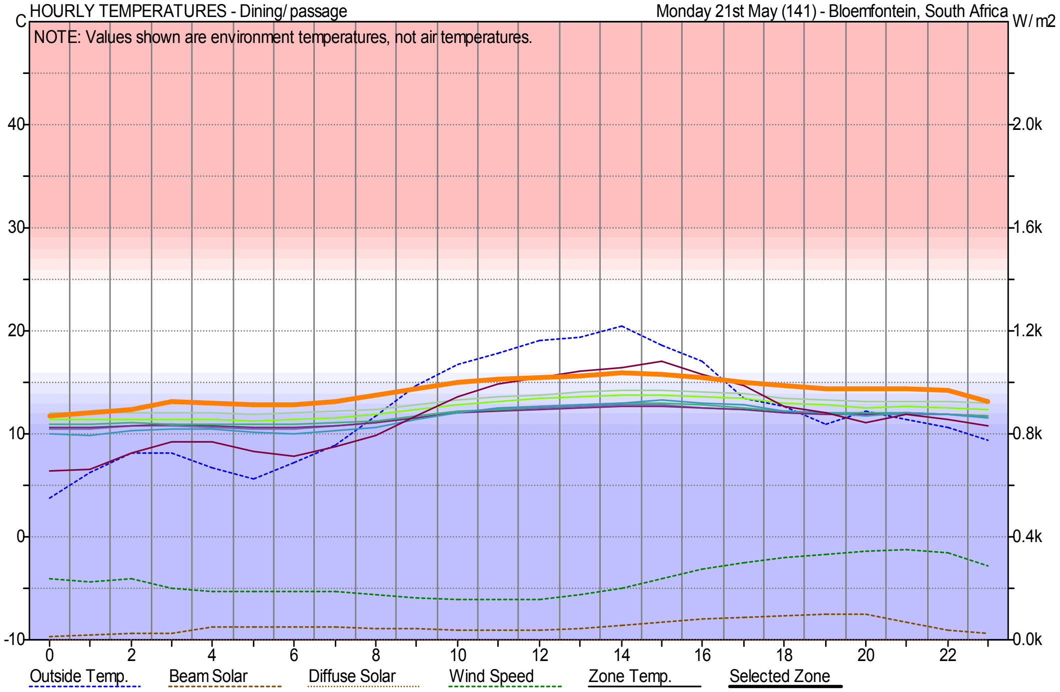


Figure G 4: Hourly predicted temperature profile inside Dining/passage zone (light brown line) on 21 May 2009 compared with 2008 weather data for Bloemfontein displayed in Ecotect v.5.60.

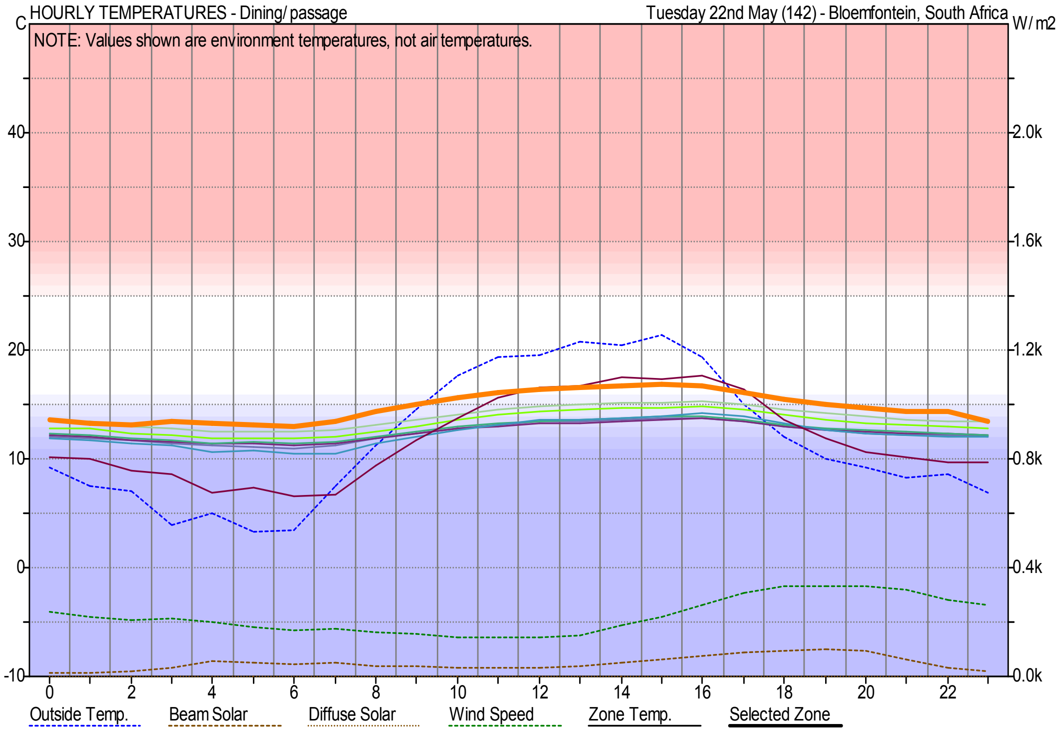


Figure G 5: Hourly predicted temperature profile inside Dining/passage zone (light brown line) on 22 May 2009 compared with 2008 weather data for Bloemfontein displayed in Ecotect v.5.60.

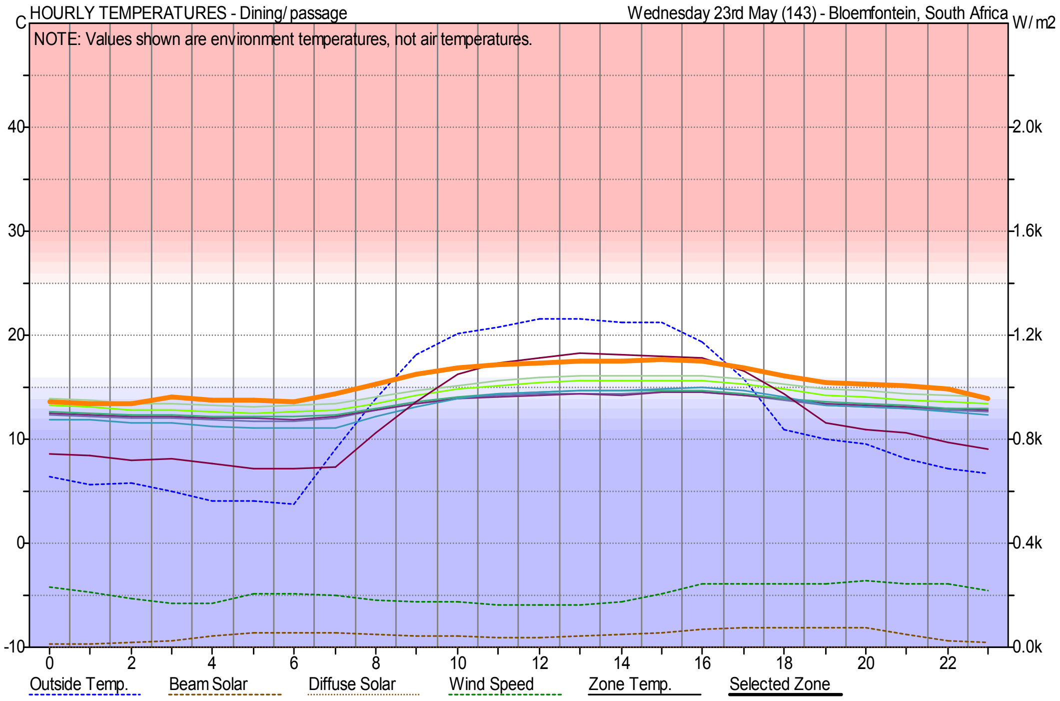


Figure G 6: Hourly predicted temperature profile inside Dining/passage zone (light brown line) on 23 May 2009 compared with 2008 weather data for Bloemfontein displayed in Ecotect v.5.60.

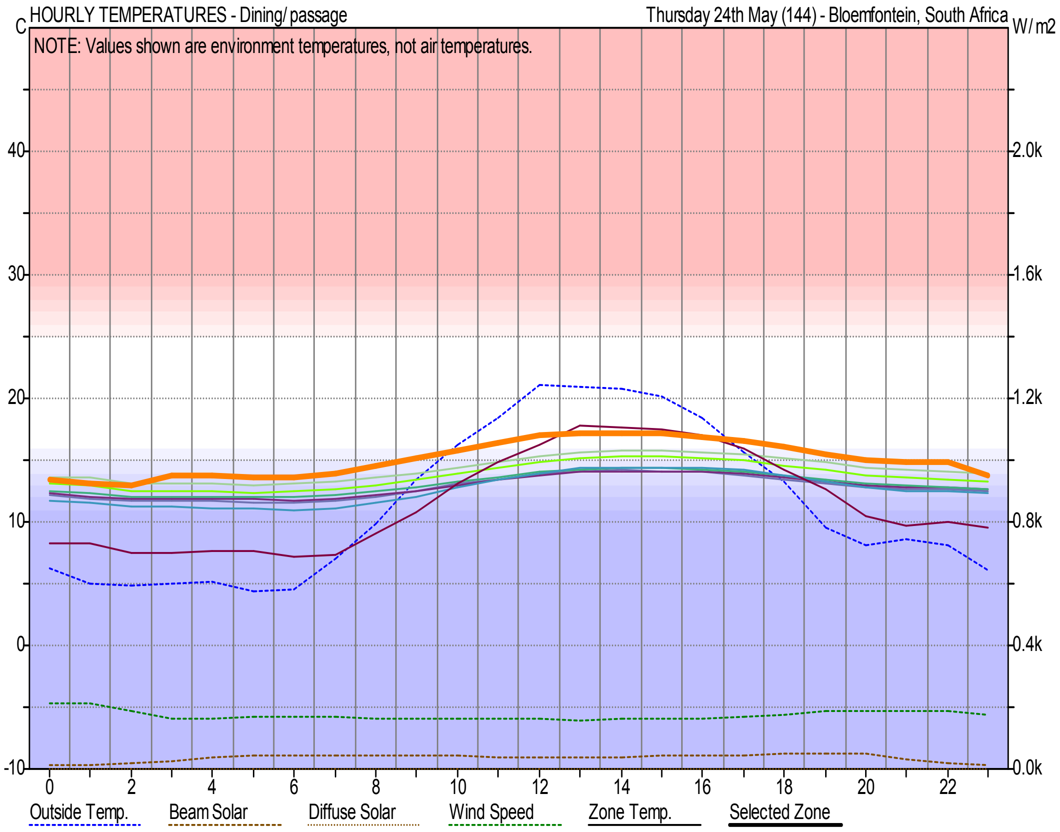


Figure G 7: Hourly predicted temperature profile inside Dining/passage zone (light brown line) on 24 May 2009 compared with 2008 weather data for Bloemfontein displayed in Ecotect v.5.60.

APPENDIX H: PREDICTIONS FOR INDOOR TEMPERATURE FOR FINAL CALIBRATION (FROM 18-24 MAY)

This appendix shows predicted hourly indoor temperature for the dining / passage zone indicated by a light brown line for the base case. The predictions are for one week from 18 to 24 May.

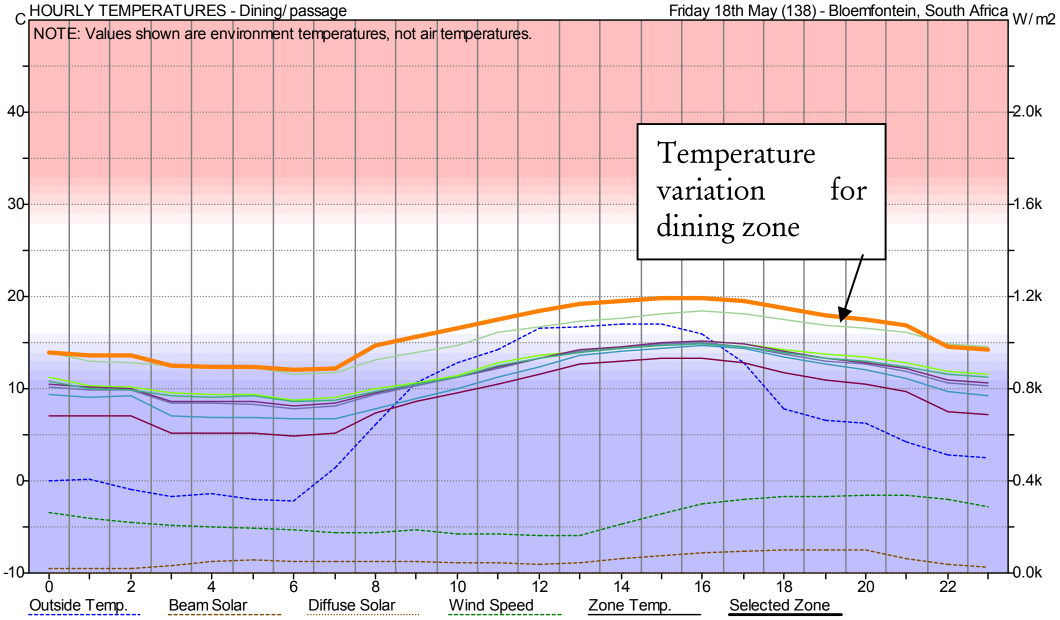


Figure H1: Hourly predicted temperature profile inside Dining/passage zone (light brown line) on 18 May 2009 compared with 2008 weather data for Bloemfontein displayed in Ecotect v.5.60.

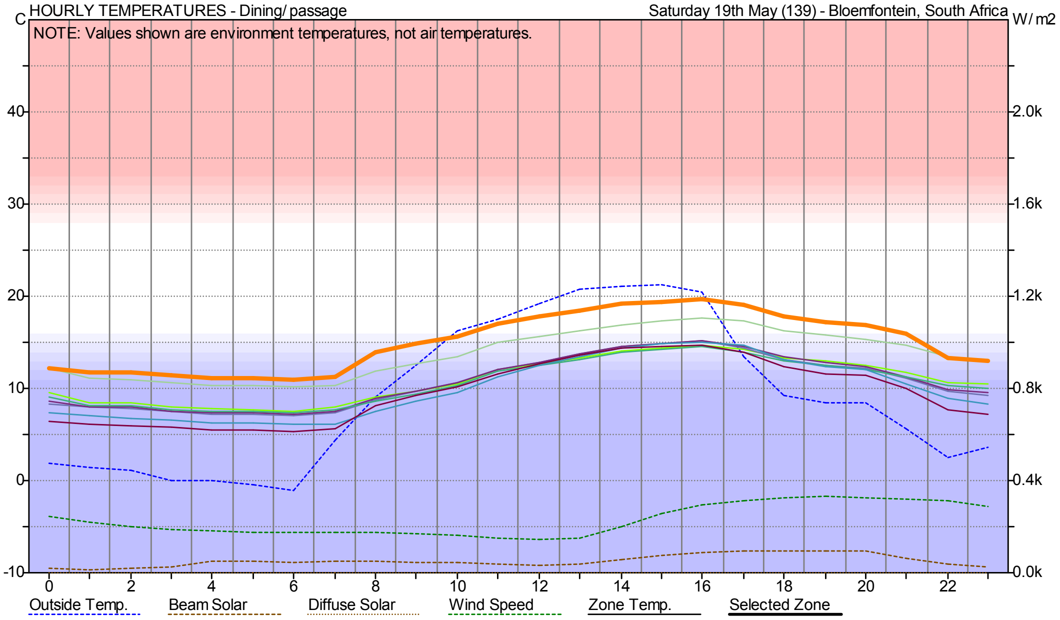


Figure H 2: Hourly predicted temperature profile inside Dining/passage zone (light brown line) on 19 May 2009 compared with 2008 weather data for Bloemfontein displayed in Ecotect v.5.60.

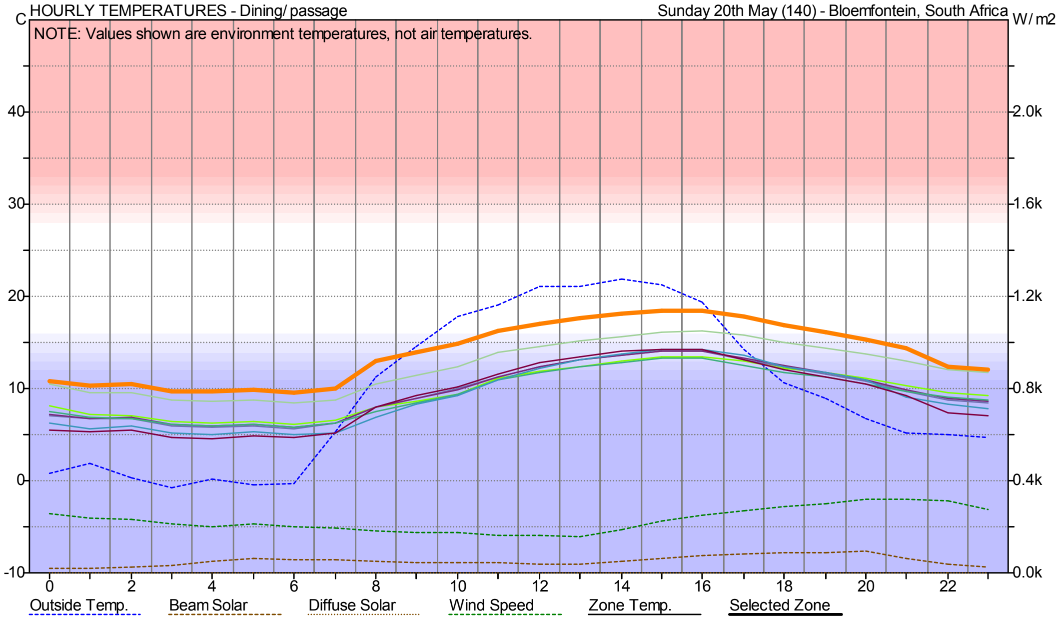


Figure H 3: Hourly predicted temperature profile inside Dining/passage zone (light brown line) on 20 May 2009 compared with 2008 weather data for Bloemfontein displayed in Ecotect v.5.60.

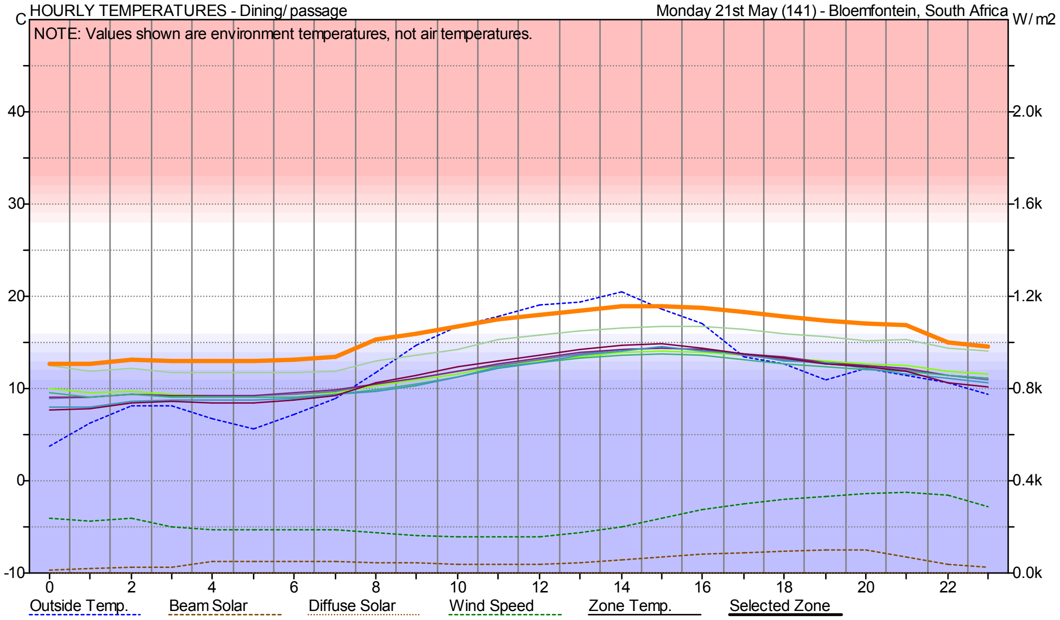


Figure H 4: Hourly predicted temperature profile inside Dining/passage zone (light brown line) on 21 May 2009 compared with 2008 weather data for Bloemfontein displayed in Ecotect v.5.60.

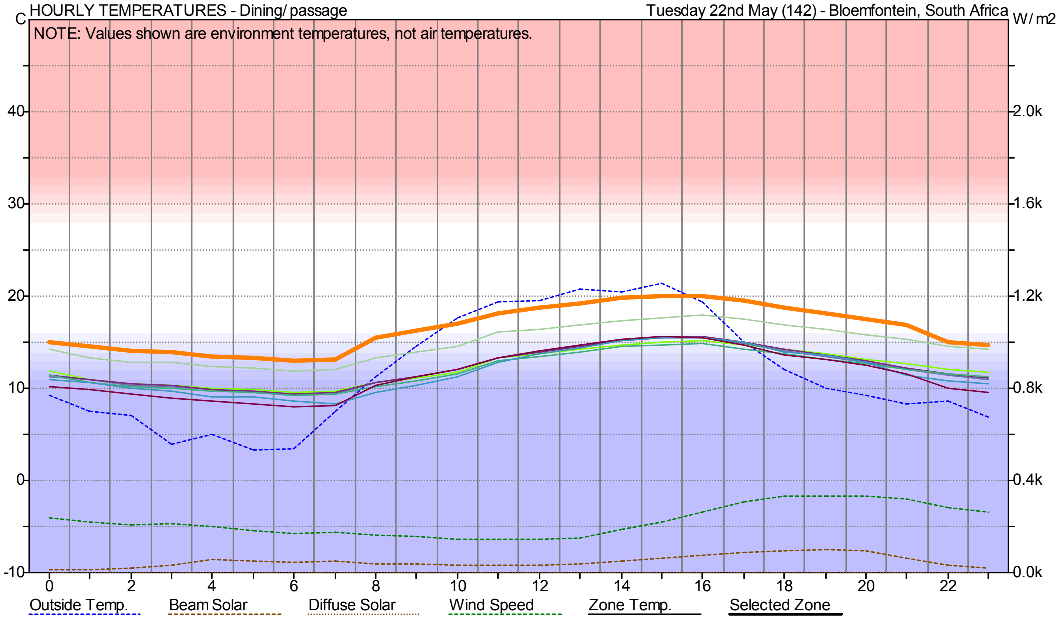


Figure H 5: Hourly predicted temperature profile inside Dining/passage zone (light brown line) on 22 May 2009 compared with 2008 weather data for Bloemfontein displayed in Ecotect v.5.60.

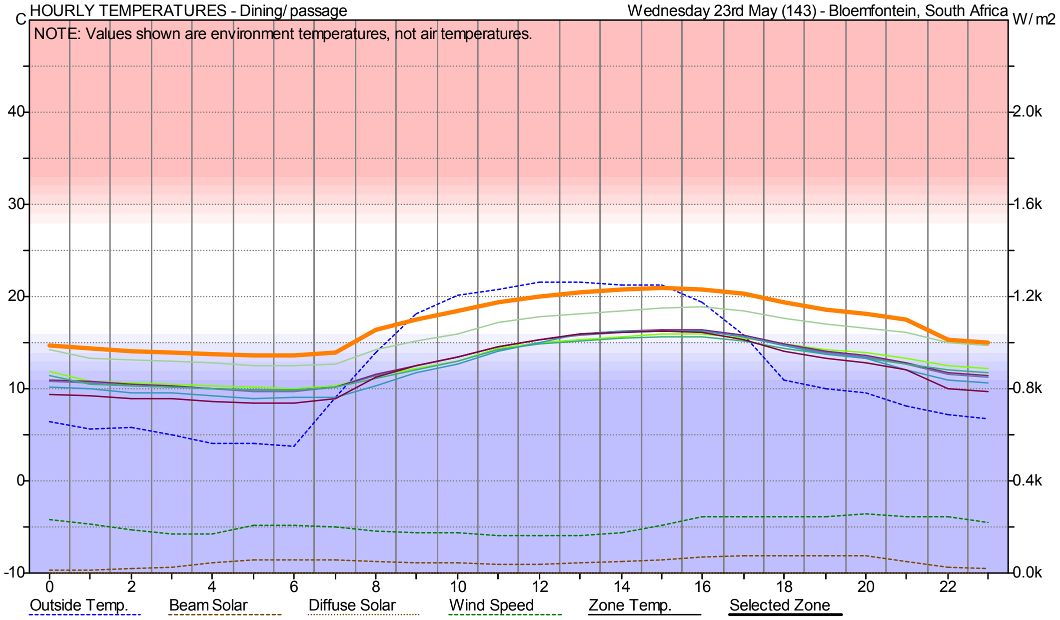


Figure H 6: Hourly predicted temperature profile inside Dining/passage zone (light brown line) on 23 May 2009 compared with 2008 weather data for Bloemfontein displayed in Ecotect v.5.60.

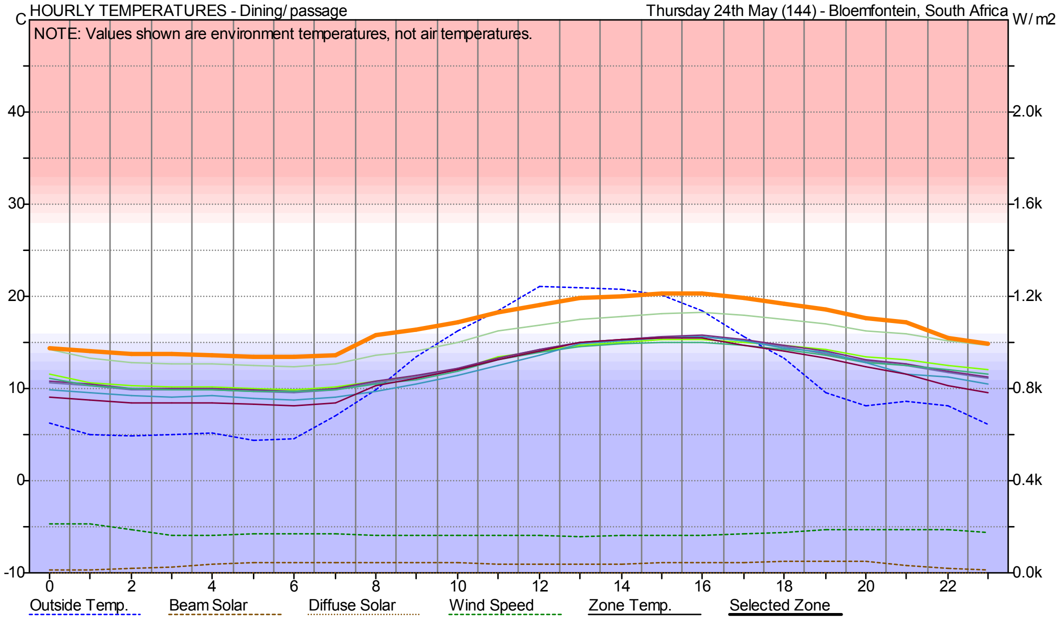


Figure H 7: Hourly predicted temperature profile inside Dining/passage zone (light brown line) on 24 May 2009 compared with 2008 weather data for Bloemfontein displayed in Ecotect v.5.60.

APPENDIX I

This appendix shows cross sections of the passive interventions input on the base case.

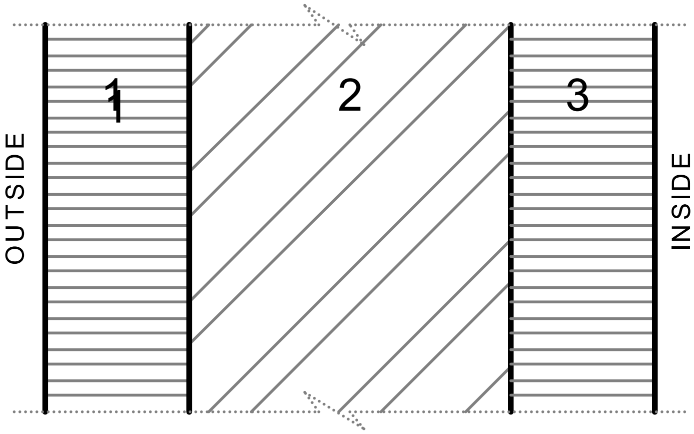


Figure I 1: Outer wall Section with added plaster on the outside

1: outside cement plaster layer
2: brick masonry
3: inside cement plaster layer.

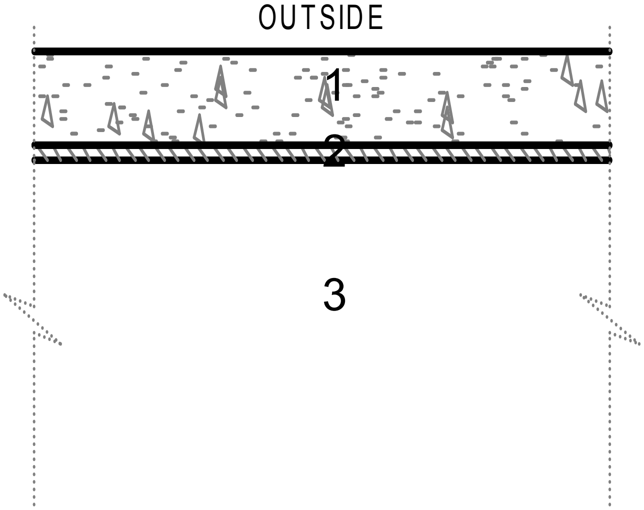


Figure I 2: Roof section with insulation added
1: concrete tiles
2: wrought iron sheets
3: air gap
4: insulation

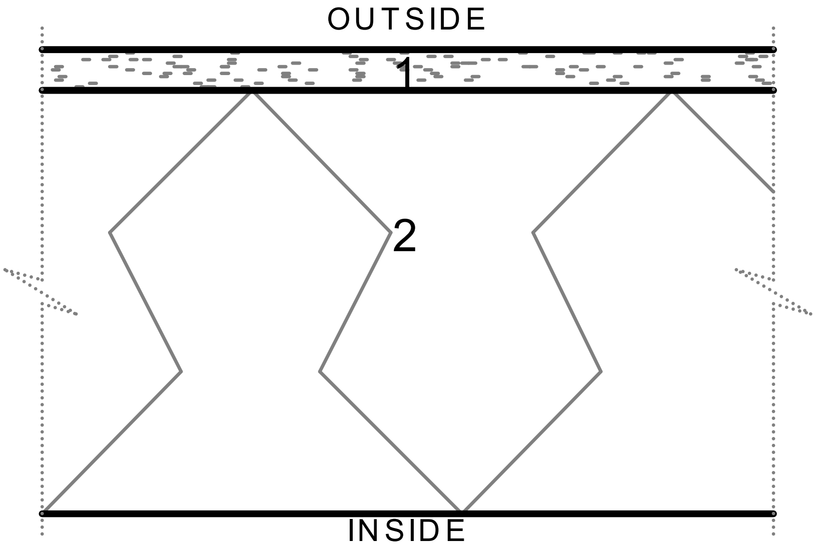


Figure I 3: ceiling section with insulation added

1: Ceiling board
2: Ceiling insulation