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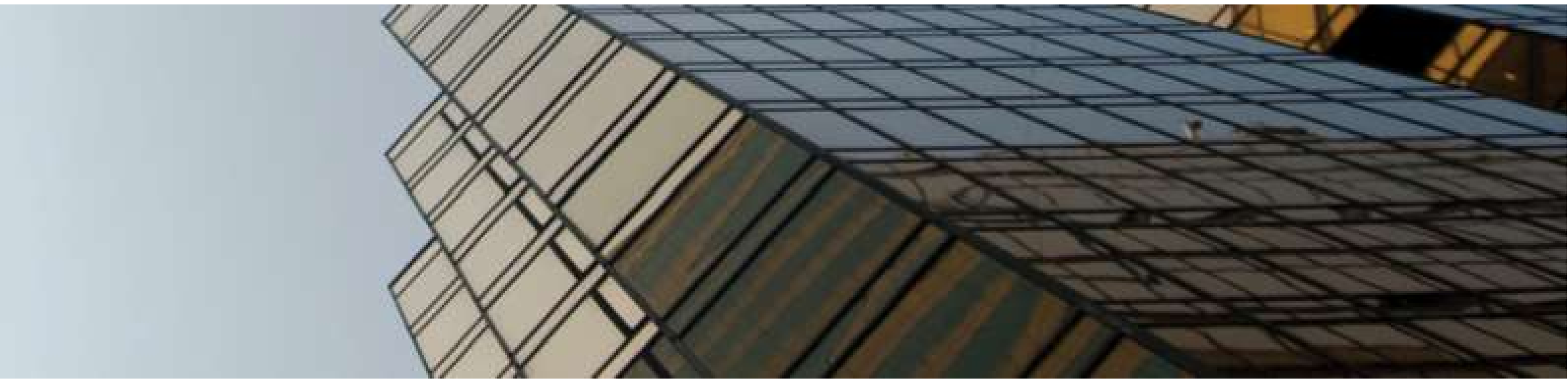

STUDY REPORT SR 277/6 [2012]

BEES INTERIMREPORT

Building Energy End-Use Study - Year 5

BUILDING DESIGN OPTIMISATION

Shaan Cory, Andrew Munn, Anthony Gates and Michael Donn

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BUILDING ENERGY END-USE STUDY (BEES) YEAR 5: BUILDING DESIGN OPTIMISATION

BRANZ Study Report SR 277/6

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Reference

Cory, S., Munn, A., Gates, A., and Donn, M. (2012). Building Energy End-use Study (BEES) Year 5 Interim Report: Building Design Optimisation, BRANZ Study Report 277/6, Judgeford.

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PREFACE

Understanding how energy and water resources are used in non-residential buildings is key to improving the energy and water efficiency of New Zealand's building stock. More efficient buildings will help reduce greenhouse gas emissions and enhance business competitiveness. The Building Energy End-use Study (BEES) is taking the first step towards this by establishing where and how energy and water resources are used in non-residential buildings and what factors drive the use of these resources.

The BEES study started in 2007 and will run for six years, gathering information on energy and water use through carrying out surveys and monitoring non-residential buildings. By analysing the information gathered, we aim to answer eight key research questions about resource use in buildings:

1. What is the aggregate energy and water use of non-residential buildings in New Zealand?
2. What is the average energy and water use per unit area per year?
3. What characterises the buildings that use the most energy and water?
4. What is the average energy use per unit area for different categories of building use?
5. What are the distributions of energy and water use?
6. What are the determinants of water and energy-use patterns e.g. structure, form, function, occupancy, building management etc?
7. Where are the critical intervention points to improve resource use efficiency?
8. What are the likely future changes as the building stock type and distribution change?

Understanding the importance and interaction of users, owners and those who service non-residential buildings is also an important component of the study.

For the BEES study, non-residential buildings have been defined using categories in the New Zealand Building Code, but in general terms the study is mainly looking at commercial office and retail buildings. These vary from small corner store dairies to large multi-storey office buildings. For more information on the building types included in the study please refer to BRANZ report SR224 Building Energy End-use Study (BEES) Years 1 & 2 (2009) available on the BEES website (www.branz.co.nz/BEES).

The study has two main methods of data collection – a high level survey of buildings and businesses, and intensive detailed monitoring of individual premises. The high level survey initially involved collecting data about a large number of buildings. From this large sample, a smaller survey of businesses within buildings was carried out which included a phone survey, and collecting records of energy and water use and data on floor areas. The information will enable a picture to be built up of the total and average energy and water use in non-residential buildings, the intensity of this use and resources used by different categories of building use, answering research questions one to four.

The detailed monitoring of individual premises involves energy and indoor condition monitoring, occupant questionnaires and a number of audits, including: appliances, lighting, building, hot water, water, and equipment.

This is a study of the BEES modelling conducted by the Centre for Building Performance Research. The studies are distributed between three reports. The first report (Gates, Creswell-Wells, Cory, & Donn, 2012) documents the outcomes of a study identifying which aspects of energy simulation models that must be carefully quantified to ensure accurate energy performance modelling.

This (the second) report explores the means by which computer modelling might be used to determine optimum building energy performance. The third report (Creswell-Wells, Donn, & Cory, 2012) applies the results from the first and second reports to examine the likely energy and environmental effects of the proposed urban form in the Christchurch central city draft plan.

SUMMARY

- Savings from natural ventilation and daylight design (replacing electric light) can only be significant if the building form is kept narrow.
- An optimal combination of solar shading, insulation and free cooling can almost eliminate cooling energy consumption for Christchurch commercial buildings.
- Application of the optimisation software, GenOpt in energy simulations was successful and will be used for future research.

This report presents the outcomes of a study that assesses the optimum design parameters for commercial buildings in Christchurch, as part of the BEES study. It establishes key design principles which modelling shows can reduce energy consumption in Christchurch commercial buildings by up to 60% relative to the minimum design levels mandated by the New Zealand Building Code. The study is also used to establish and test a methodology as a preparatory step in the planned analysis during 2012/2013 of calibrated models of the BEES monitoring project buildings.

Figure A displays a commercial building highlighting (in orange) the central 'core' zone which is too far from the windows to be either naturally lit or ventilated. Figure B displays a commercial building with the same floor area, but restricts all zones to be within 7m of the building perimeter, so there is no central core.

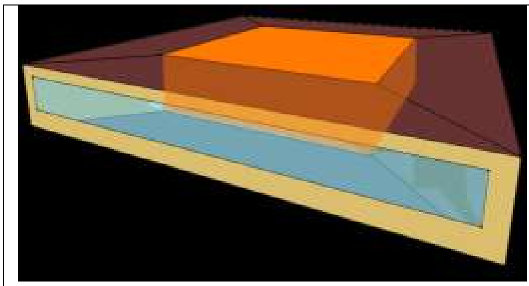

Figure A: Commercial Building showing Central 'Core' Zone

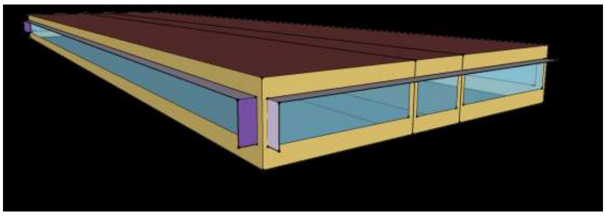

Figure B: Commercial Building with all Zones <7m of the Building Perimeter

Fundamental to significantly lowering energy use in Christchurch commercial buildings is the use of passive design principles; identification of natural ventilation (free cooling) and daylight design (replacing electric light).. However, savings from these two design principles can only be significant if the building form is kept narrow, as these savings are only feasible in rooms near (≤7m) the outside walls of a building as shown in Figure B. Less savings are possible in buildings with a deep plan and thus a core zone because the core zone cannot easily access natural light and air. The analysis also revealed an optimal combination of solar shading, insulation and free cooling can almost eliminate cooling energy consumption for Christchurch commercial buildings.

The methodology used for this modelling trialled an application of the optimisation software, GenOpt. The trial in energy simulations was successful. It was found that a two phase optimisation process was needed to test building design options as well as optimise various building design parameters. Such design options like different solar shading types (overhangs and louvers) need to be modelled in separate models, with the optimization run on each of the design option models. In hindsight some design ideals, such as natural ventilation and electric light dimming, could be added into the models and switched on and off using the optimiser.

The lessons from this study will be used for future optimisation studies on models of the existing building stock in New Zealand.

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GLOSSARY

Calibrated BEES models	The 2012/2013 calibrated models will be used to assess different energy efficiency proposals across the entire commercial building stock.
ACH	Air Changes per Hour – The number of times per hour that the volume of a specific room or building is supplied or removed from that space by mechanical and natural ventilation. (Washington Natural Gas Heating & Air Conditioning Servicing The Greater Puget Sound Area, 2013)
CBPR	Centre for Building Performance Research at Victoria University's School of Architecture: the research team responsible for developing the computer modelling tools for the BEES research.
Conditioning	Refers to the conditioning challenge of a buildings internal spaces.
EnergyPlus	A thermal simulation tool for buildings developed by the US Department of Energy
Envelope	The buildings external fabric which separates the outdoor environment to the internal building spaces.
ESIROI	École Supérieure d'Ingénieurs Réunion Océan Indien – This University department is located on La Reunion Island. It shares leadership of an IEA Net ZEB research project project (International Energy Agency - Solar Heating and Cooling Programme, 2011) with the CBPR. A PhD student from ESIROI on a four month exchange at the CBPR worked on the GenOpt modelling for this project.
GenOpt	An optimisation program used to calculate the optimum combination of building parameters for energy performance developed by Lawrence Berkeley National Laboratory
Glazing solar heat gain coefficient	Indicates how much of the sun's energy striking the window is transmitted through the window as heat. As the SHGC increases, the solar gain potential through a given window increases. (National Institute of Building Sciences, 2012)
Glazing visible transmission	Indicates the percentage of the visible portion of the solar spectrum that is transmitted through a given glass product. (National Institute of Building Sciences, 2012)
HVAC	Heating, Ventilation and Air Conditioning
IEA	International Energy Agency
Net ZEB	Net Zero Energy Building(s) – A building that is very energy efficient and offsets the residual energy consumption with renewable energy generation.
NZBC	New Zealand Building Code
OpenStudio	A SketchUp plug-in with a graphical interface to model building geometry which can then be run in EnergyPlus

Perene Energy Code	Reunion Island Building Code
S-value	Shading Value
SketchUp	A 3D computer modelling tool that is available from Google.
Task 40	IEA Task 40 / Annex 52: International Energy Agency Solar Heating and Cooling Task 40 and Energy Conservation in Buildings and Community Systems
WWR	Window-to-Wall Ratio

1. INTRODUCTION

This report presents two tests of an optimisation methodology for identifying energy use different combinations of building design features. The methodology tests the application of the optimisation software, GenOpt, in energy simulations. Two studies have been completed: an initial learning exercise combining the interests of a PhD student from the ESIROI Department of the Université de la Réunion and the CBPR research team in learning and testing the application of GenOpt (Wetter, 2000) for energy simulation. This first study iwas a learning exercise focused on solar shading in Reunion Island (Section 3.4); and the second study was a research application addressing optimum energy-lowering parameters for Christchurch commercial buildings (Section 4).

The overall goal of the tests was to establish a means by which BEES might run optimisation studies on models of the existing building stock in New Zealand. It is a necessary preparatory step in the planned analysis for the 2012/2013 of calibrated models of the BEES monitoring project buildings. The BEES calibrated models will be a representative sample of commercial buildings in New Zealand and will be available at the conclusion of the BEES project as a tool to assess different energy efficiency proposals across the entire New Zealand commercial building stock. The reliability of the modelling approach – the level of precision in the geometry model and the level of detail in the HVAC model – are the subject of a separate 2012 report (Gates, Creswell-Wells, Cory, & Donn, 2012).

1.1 Solar Shading

For this learning exercise, a number of different parameters describing solar shading devices have been optimised to achieve the lowest total source energy usage for a year, as a result of the heating, cooling and lighting demands on a building. The purpose of the study was to explore the application of an optimisation tool (GenOpt) to a real world issue, providing data for the Perene Energy Code on how best to use solar shading in Reunion Island. It is a continuation of the Perene project which established insulation, shading and other norms for Reunion Island (Garde F. , David, Adelard, & Ottenwelter, 2004). Reunion Island is a small island in the Indian Ocean at latitude 21° south. Its coastal regions are therefore hot, humid areas where shade against the heat of the sun is extremely important and such shade can often compromise the use of daylight for interior lighting. The GenOpt simulations optimised for the S-value of solar shading defined in Perene and also extend this to include energy use for cooling and daylighting. The study additionally acts as a pilot for more complex optimisations, with the intention of being able to optimise numerous “Green Design” principles on a generic set of buildings within a certain location, resulting in the formation of a location-specific sustainable design guide.

1.2 Christchurch Optimum Energy-Lowering Parameters

Once the principles of shading and daylighting had been established in the Reunion Island optimisation, the approach was extended to the more complex, mixed heating and cooling (plus daylight) climate of Christchurch. The aim of this second study was to further test the optimisation process with a broader range of optimisation parameters in a project directed towards development of design principles and guidelines for commercial buildings in Christchurch, New Zealand. The design guidelines are to inform future designers about how to lower the annual energy consumption of commercial buildings in the Christchurch rebuild. The guidelines present the optimum building parameters for achieving the lowest energy consumption in a simple commercial building and offer design principles on what things need to be done to achieve a reasonable reduction in energy consumption.

2. NET ZERO ENERGY BUILDINGS

Before a study of this type can be undertaken, the nature of the parameters that are to be optimised must be determined. For this, the study drew on an exercise undertaken as part of the IEA Net ZEB project, documenting the lessons learned by the design teams for the case study buildings designed, built and monitored within the project. The design teams for seven of the thirty IEA near-zero energy or net-zero energy building (Net ZEB) were interviewed. The lessons learned established what design and technological solutions work, which do not, and why. The lessons helped guide the design-optimisation parameters examined in the Reunion Island and Christchurch buildings.

2.1 Lessons Learned

A range of lessons can be established from the common themes that became apparent in the analysis. The points discussed are only those lessons that were directly applicable to this study. These key lessons were:

- There is a definite hierarchy when designing Net ZEBs – firstly save as much energy passively through the design of the building, then use energy efficient technologies to supplement the energy savings and finally think about offsetting the residual energy consumption through renewable energy.
- There is a shift in the main energy end-uses in Net ZEBs, for which it has been calculated that office equipment can account for up to 50% of the building's total energy consumption. This is due to Net ZEBs being highly passive buildings, with the energy usage of the space conditioning and interior lighting much lower than in standard buildings.
- Using ceiling fans to ventilate and cool the building is a technique found to keep occupants comfortable in temperatures of up to 30^{o}C, due to the increased air movement in the building.
- No active cooling needs to be installed, as natural ventilation and ceiling fans are sufficient to keep the occupants comfortable. This is true regardless of climate, as proven by case study buildings adopting this approach in a heating and cooling climate and an extreme cooling (tropical) climate.

The energy-lowering design and technologies, and optimisation scenario are directly influenced by the lessons presented above. The influences are:

- Due to a definite hierarchy when designing Net ZEBs, the focus of the parameters being optimised is on passive energy-lowering solutions, in particular the façade design.
- The largest single driver of energy use in Net ZEB buildings is the internal equipment. (office equipment and lighting), For this modelling exercise, the focus is on building design options not the installation of lower consumption office equipment although electric lighting controls are used to assess the passive design measures influence on the building's daylight design performance.
- The Net ZEB design teams reported occupants being comfortable in temperatures up to 30^{o}C in buildings with ceiling fans. This was found in a normal European climate, as well as the tropical climate studied. This is a much higher than normal temperature set point at which to switch active cooling on. However, in the study in Christchurch a more conservative 27^{o}C was used as it was in-line with other studies on adaptive comfort (Givoni, 1976). For the Reunion Island optimisation a value of 28^{o}C was used.

2.2 Energy-Lowering Design and Technologies

The lessons learned exercise established the design optimisation strategies for the use of GenOpt (refer Section 2.1). A review and categorisation of the 30 IEA case study Net ZEBs from around the world helped establish the range of strategies to be optimised in combination (International Energy Agency - Solar Heating and Cooling Programme, 2011). Information was collected on each building and a catalogue was created which gives an overview and discusses the various passive design techniques used across all 30 case study buildings. The passive design techniques (or solutions) were split into three groups: ‘cooling strategies’, ‘heating strategies’ and ‘daylight strategies’. The strategies refer to which building energy-related challenge a specific solution is trying to deal with.

2.2.1 Cooling Strategies

Cooling strategies refer to passive solutions that aim to cool the building or to reduce the amount of cooling energy needed in the building.

2.2.1.1 Natural Ventilation

Ventilation uses wind and air properties without the need for active mechanical systems. It is a means to control the thermal environment without consuming electricity. Natural ventilation can be achieved using two major effects: pressure difference and natural buoyancy.

The pressure difference is caused by wind. When wind pushes against a building it causes a pressure difference between the windward and the leeward sides. Natural ventilation is generated when these two pressure levels are connected, commonly through the use of opening windows.

The second effect is natural buoyancy due to differences between warm and cool air, and dry and humid air. This is also called stack ventilation. Warm air inside the building is less dense than cold air outside, therefore it will try to escape the building from high-up openings. The cold and dense air will enter through low-down openings.

2.2.1.2 Solar Shading

Solar shading is a passive solution used to reduce the building’s cooling loads. Its principle is to prevent the sun’s radiation from entering the building by the shading of windows. Shading devices can be either applied to the building externally (See Figure 1 for diagram of overhangs, louvres, and side fins), internally or between double glazing or double façades.

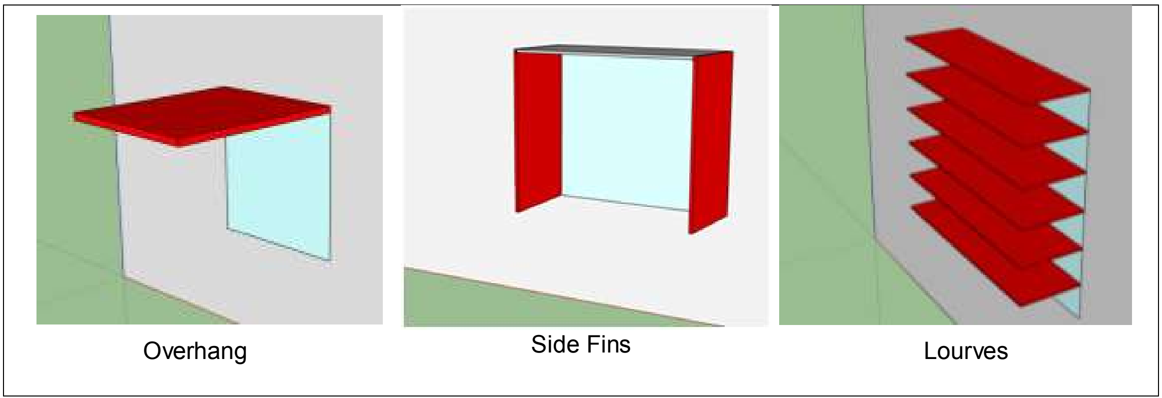

Figure 1: Solar Shading Strategies

2.2.1.3 Night Cooling

Night cooling (or ventilation) is used in order to evacuate the energy stored during the day by the building’s thermal mass. It can therefore reduce the demand for cooling.

“Night ventilation can be applied naturally, by forced ventilation, or in a hybrid combining these two systems. Natural ventilation is obtained by setting up windows on each side of the building. These windows can have multiple positions in order to prevent intrusions” (Fraisse, Boichot, Kouyoumji, & BSouyri, 2010).

2.2.1.4 Ground Cooling

Ground cooling aims to pre-condition (pre-cool) the supply air for mechanical ventilation in order to reduce the energy required for space conditioning. Ground cooling is achieved by an underground air duct. When the supply air goes through the duct, it transfers its heat to the ground.

2.2.2 Heating Strategies

Heating strategies refer to passive solutions that greatly decrease heating, ventilating, air-conditioning (HVAC) system energy consumption. These solutions aim to heat the building or improve the building envelope's ability to store heat.

2.2.2.1 Thermal Mass

In the context of a component of a building's thermal envelope, thermal mass is the ability to store and release heat energy.

"The thermal mass absorbs thermal energy from solar gain and convective transfer from the air when the surroundings are higher in temperature than the mass. It gives thermal energy back through the means of radiation transfer when the surroundings are cooler" (Donn & Thomas, 2010).

2.2.2.2 Solar Heat Gain

This solution is part of the heat storage strategies. It uses the building's orientation, the window orientation and the glazing selection in order to let the maximum sunlight penetrate the building. However, the storage and conservation of the solar gains are only possible through thermal mass. Solar heat gain can be achieved through two principal strategies, direct passive gain and indirect gain.

> 1) Direct passive gain is dependent on a particular thermal mass absorbing excessive heat gains in periods where the sun is directly entering the space.
>
> 2) In indirect gain strategies, a thermal mass separates the collector from the conditioned space. The thermal mass simply manages the flow of heat energy due to the time lag provided by the separator. An example of indirect gain is the use of a Trombe wall.

"A Trombe wall is a thick wall (facing south in the northern hemisphere, facing north in the southern hemisphere) painted black and made of materials that have high thermal mass. A pane of glazing is installed in front of the wall to hold in the heat. The Trombe wall stores energy during the day, and progressively releases it inside of the building during the night" (EcoWho, 2011).

2.2.3 Daylight strategies

Daylight strategies refer to passive solutions that increase illuminance in rooms. These solutions aim to reduce the use of artificial lighting and therefore reduce the electric consumption of the building. Figure 1 displays the four daylighting strategies.

2.2.3.1 Skylight

Skylights are an efficient way to provide light in interior spaces. However, in order to prevent too much light or hot spots of light, they need to be shielded through the use of diffuse glazing, blinds or other materials.

"The inconvenience of skylights is that they have to be installed on the roof and can only bring light in the floor below it" (Bonda & Sosnowchik, 2007).

2.2.3.2 Window

Large windows, when properly oriented (south in northern hemisphere and north in southern hemisphere) bring daylight into the rooms. However, they also bring a lot of heat energy inside, so they might need to be coupled with shading devices in buildings where the conditioning challenge is not heating.

2.2.3.3 Tubular Daylight Systems

Tubular Daylighting Systems are tubes that bring the sunlight into the rooms. At the top end of the tube, a lens collects the natural light which is then transported into the room through the tube (using reflection). In order to provide the room with light, Tubular Daylighting Systems have to be installed on the roof.

2.2.3.4 Light Shelf

Light shelves are a solution for glare issues. They reflect the sunlight onto the ceiling and bounce it deep into the room. This passive design allows the light to penetrate the interior space.

"Light shelves can be suspended from the ceiling or attached to the walls or window frames. They can be interior or exterior (in that case they can become an effective shading solution) or a combination of both" (Bonda & Sosnowchik, 2007) and (Fruteau, 2012).

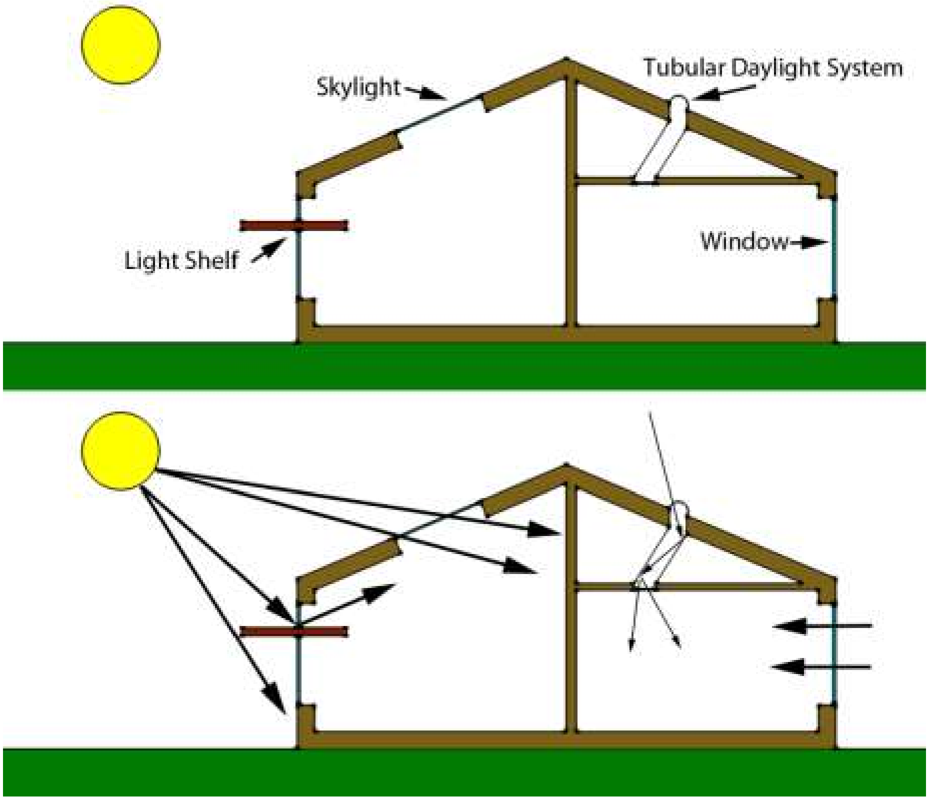

Figure 2: Daylight Design Strategies

2.2.4 Study Design Solutions Implemented

The solar shading techniques tested in the optimisation of solar shading devices in Saint Pierre, Reunion Island were:

- Fenestration overhangs;
- Fenestration side fins; and
- Fenestration louvres (see Figure 1)

The passive design techniques tested in the optimal energy-lowering design of commercial buildings in Christchurch is split into two groups – non-optimised design changes and optimised design changes. Non optimised design changes are design techniques that are implemented and not altered to perform optimally. For example, the building uses natural ventilation, but the natural ventilation rate is not optimised as the windows either open or not. Optimised design changes are design techniques that are installed and then altered to perform optimally. For example, an overhang solar shade is installed and the depth and length of the overhang is altered to find what the best or most optimal length and depth for the overhang is to achieve a maximum reduction in energy consumption. The non-optimised parameters are:

- Natural ventilation; and
- Electric light controls (only used to show potential daylight design performance).

The optimised parameters are:

- Fenestration overhangs and side fins;
- Window-to-wall Ratio (WWR);
- Window height;
- Envelope and glazing insulation; and
- Glazing solar heat gain coefficient and visible transmittance.

3. METHODOLOGY

The methodology below describes the process used to create the models, simulate their energy use and optimise the energy use in both the solar shading study in Reunion Island and the optimum energy-lowering parameters study in Christchurch.

To undertake the two studies, the thermal simulation tool EnergyPlus (US Department of Energy, 2012) was used to calculate the energy performance and consumption of the building's lighting, equipment, heating and cooling for all 8,760 hours of the year.

An optimisation program called GenOpt (Lawrence Berkeley National Laboratory, 2010) was then used to calculate the optimum combination of building parameters for lowering the annual energy consumption for an office test cell in Reunion Island and for a typical commercial building in Christchurch. The user defines the minimum and maximum values of certain building parameters and GenOpt completes as many EnergyPlus simulations (typically hundreds) as it needs to, to establish the optimum set of building parameters for lowering the annual energy consumption.

3.1 Optimisation Functions – Energy Consumption

The aim is to reduce the annual energy consumption of buildings, which is defined in GenOpt by the equations:

$$E_{Total} = E_{Heat} + E_{Cool} + E_{Lighting} + E_{Equipment} \quad (1)$$

Where:

E	= energy
E_{Heat}	= building heating consumption
E_{Cool}	= building cooling consumption
$E_{Lighting}$	= building electric lighting consumption
$E_{Equipment}$	= building electric equipment consumption

3.2 Initial Optimisation Learning Exercise: Solar Shading Office Test Cell

Optimising the window functions of shading versus daylight is a subset of the range of energy performance influencing design parameters that might be optimised in a building. In a tropical climate like Reunion Island this simple practice optimisation has direct application. A single building model is used to assess solar shading in Reunion Island. The model is an office test cell which has a window on the equator-facing façade. Solar shading devices are the parameters being used to alter the E_{Total}figure. The three shading types that are tested are overhangs, side fins and louvres. The models are also simulated facing different orientations and with three different window sizes of 20%, 35% and 50% WWR. This creates 18 baseline models against which to compare the results of the shading devices.

The office test cell was created using the Google SketchUp plug-in OpenStudio, which allows models to be created from a graphic interface, for the program EnergyPlus. Once the models have been created, GenOpt runs the optimisations through EnergyPlus, providing a text file output which can be read in a program such as MS Excel.

3.2.1 Building Model Creation

Using OpenStudio, the basic dimensions of the test cell were created. OpenStudio automatically assigned construction types and material properties to the drawn elements. The window(s) and a light meter were then added.

Once the model had been created, it was opened in EnergyPlus in order that various default settings could be changed. The default values for things such as infiltration rates, internal heat gains, occupancy and heating schedules, heating and cooling set points, ground temperatures etc were adjusted to suit the simulation location. A metre of gravel was also added under the building to ensure that it was not sitting directly on the ground temperature in the weather file and giving inaccurate results. The particular outputs required from EnergyPlus (annual lighting, heating and cooling energy) were also established at this time.

A single simulation was then run from EnergyPlus for each of the four orientations to gain a baseline figure against which the optimised results could be compared. Following this, a shading device was added to the models and resaved under a different file name. Subsequent models were made with different orientations, shading devices and in the case of the louvres, angles and 'number of' set points, completing the models required for optimisation.

3.2.2 Office Test Cell

The model used to simulate the office is a single zoned room, 4m long, 3m wide and 2.7m high. A single window is located in the centre of the 4m wall and can be 20%, 35% or 50% of the total wall area depending on the simulation. The orientation of the model is referenced by the direction that the window is facing.

3.2.2.1 Materials

The construction of the various elements is as follows:

- Floor/foundations – 1m gravel base, 50mm insulation board, 200mm concrete, acoustic tile, 100mm lightweight concrete
- Roof – 100mm lightweight concrete, air gap, acoustic tile
- Walls –200mm concrete, 50mm insulation, air gap, 19mm gypsum board lining
- Window – 3mm glazing, air gap, 3mm glazing

3.2.2.2 Ventilation/HVAC

The thermostat was set to cool when the internal temperatures were above 28^{o}C and heat when below 18^{o}C. With no specified size limit on the HVAC system, a required energy use to achieve these temperatures can be gauged.

The office has an infiltration rate of 0.5 air changes per hour (ACH) and a natural ventilation rate of 30 ACH, provided external air temperatures will be optimal to maintain the internal environment between 20-28^{o}C.

3.2.2.3 Lighting

The model is setup to maintain a constant 300 Lux reading in the centre of the room 600mm above the floor. If natural daylight entering the space cannot provide the required 300 Lux, the electric lighting runs. The electric lights can run at three varying levels between 0 and 300lux to maintain the required level of light. The energy usage of these lights is set at 8.5W/m^2.

3.2.2.4 Internal Heat Gains

The model is set up to simulate having electrical office equipment running at a rate of 8.5W/m^2. There is one person to every 10m^2 of space within the office. The lighting, as mentioned above, contributes a further 8.5W/m^2 of heat gains when on at full capacity.

3.2.2.5 Schedules

The heating and cooling is on from 7am to 7pm weekdays. Electrical equipment is on at varying capacities 24 hours per day, to account for items on standby during non-working hours, with 90% running capacity between 8am and 6pm. The occupancy of the building is at 95% between 7am and 5pm with a drop to 50% between 12pm and 1pm to account for lunchtime.

3.2.3 Saint Pierre Weather File

The location used for the simulations was Ligne Paradis, in the city of Saint Pierre, Reunion Island, which is located in the Indian Ocean. The average temperature across the year is 25°C, with the average high and low temperatures being 28°C and 23°C, respectively.

3.2.4 Office Test Cell Solar Shading Optimisation Parameters

3.2.4.1 Overhangs

When optimising the use of overhangs as the shading device, four independent parameters were trialled. The first parameter is the depth of the overhang (Figure 3) which is the horizontal distance that the shade protrudes from the wall. The depth was constrained to be between 0.1m and 2m with an initial starting figure of 0.1m. The next two parameters are the extensions both left and right (Figure 4); this is the horizontal distance that the edge of the shade extends past the edge of the window. The left and right sides optimise independently of each other but have the same constraints of 0m-1m and initial starting values of 0m. The final optimised parameter is the height above the window (Figure 5), the vertical distance up the wall from the top of the window to the shade. This is constrained to between 0m and 1m with an initial starting point of 0m.

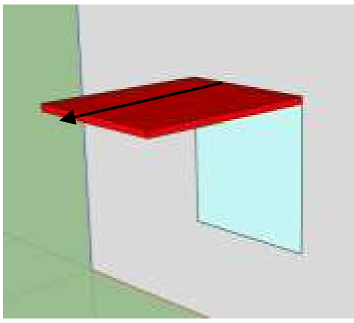

Figure 3: Overhang Depth

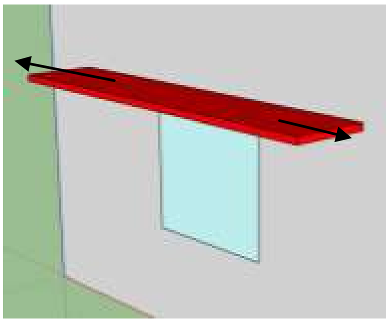

Figure 4: Overhang Extensions

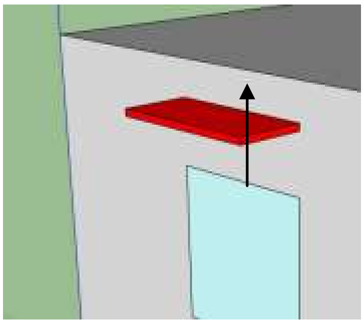

Figure 5: Overhang Height

3.2.4.2 Side Fins

The side fins are the vertical shading devices on the sides of the windows. Whenever side fins are used in the simulations an overhang is also included.

The optimisations were run twice for the side fins, once with all the parameters linked together and once with independent parameters. There are five parameters in total which can be categorised as depths or extensions. For depths (horizontal distance that the shade protrudes from the wall) there is a left, right and overhang parameter. These three are all linked together with the constraints of 0.1m-1m and a starting value of 0.1m, when running the linked optimisation. For the independent optimisation, the constraints remain the same but each parameter can move independently of the others. The extensions parameter is the vertical distance which the side fins extend below the window. The constraints for this are 0-0.5m with an initial starting point of 0m. In the linked runs there is just one parameter, in the independent runs there is a left and right parameter.

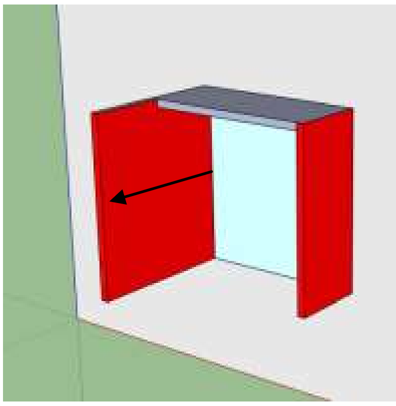

Figure 6: Side Fins Left Depth

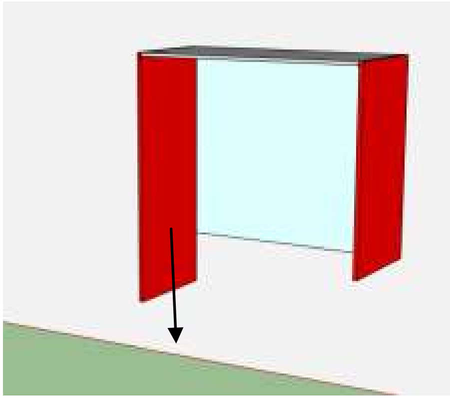

Figure 7: Side Fins Left Extension

3.2.4.3 Louvres

The louvres were being optimised for only one independent parameter, the depth, which is the horizontal distance that the shade protrudes from the wall; however different optimisations were being run for three set angles and three different amounts of louvres over the window. The constraints on the depth are 0.05m-1m with an initial starting point of 0.05m. The three angles being used are 30°, 60° and 90° and the number of louvres are three, six or nine.

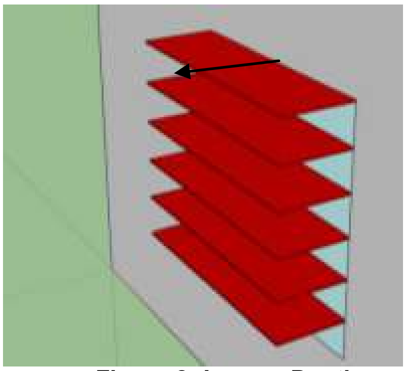

Figure 8: Louvre Depth

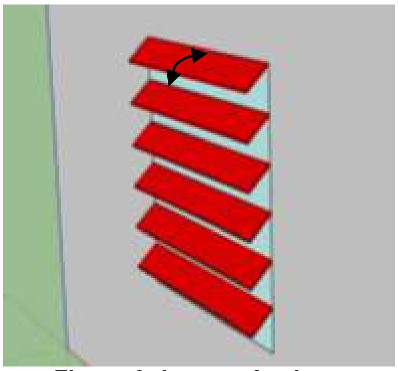

Figure 9: Louvre Angle

3.3 Christchurch Energy-Lowering Reference Buildings

A Christchurch baseline scenario EnergyPlus model was made to represent what would currently be built to meet the New Zealand Building Code (NZBC). The base scenarios model was used to optimise the building parameters to lower the annual energy consumption; however, the building also had some design changes applied to determine the degree to which they would lower the energy use. These design scenarios form starting points for the GenOpt optimising.

Note: the optimum design parameters determined by this combination of applied design change and GenOpt are optimum for the building scenarios tested in this study. Generalising from this optimising process is not a matter of rote copying of the 'conclusions', rather it is a matter of learning from the observable trends. These trends are 'design principles' that express the likely influence of each parameter on building performance. Specific buildings with very different patterns of use, or installed equipment may behave differently.

3.3.1 Christchurch Base Building Model

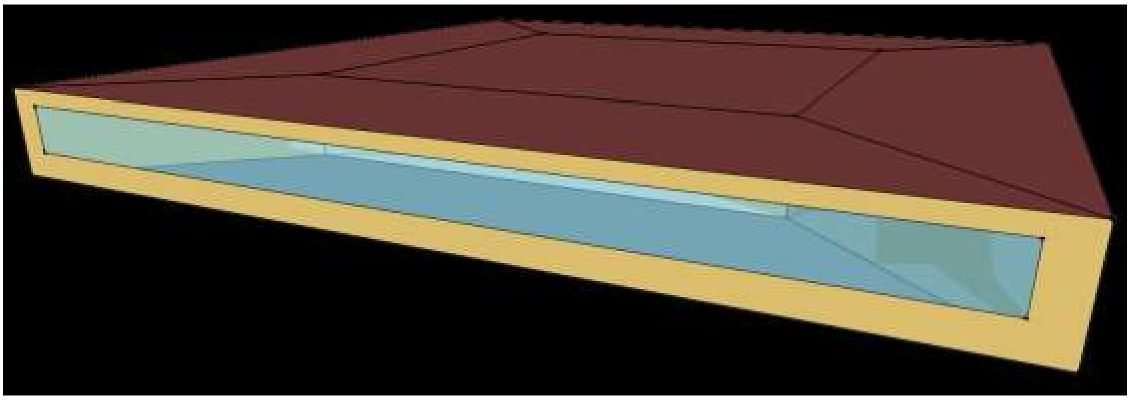

Figure 10:Christchurch Base Scenario Model

Figure 10 displays the EnergyPlus base scenario building model for Christchurch. The model is a 1000 m^2 single-storey building which is split into five zones: four perimeter zones and one core zone. The zones are visible in Figure 10 as the lines on the 'roof' of the model. Modelling these perimeter and core zones separately better simulates the interaction between the external environment and the internal building environment. The NZBC building parameters are:

Table 1: Christchurch Base Model Parameter Values

Building Parameter	Parameter Value
Wall Insulation	1.2 m^2-K/W (Standards New Zealand, 2007a)
Roof Insulation	1.3 m^2-K/W (Standards New Zealand, 2007a)
Floor Insulation	1.9 m^2-K/W (Standards New Zealand, 2007a)
Glazing	No requirement in the standard, so, assumed to be single glazing (Standards New Zealand, 2007a) Insulation: 0.15 m^2-K/W (Standards New Zealand, 1992) Solar Heat Gain Coefficient: 0.81 (National Institute of Building Sciences, 2012) Visible Transmission: 0.89 (National Institute of Building Sciences, 2012)
Window-to-Wall Ratio (WWR)	50% (Standards New Zealand, 2007a)
Lighting Power density	12W/m^2 (Standards New Zealand, 2007b)
Electric Equipment Power Density	8.5 W/m^2 (Standards New Zealand, 2007a)
People Density	0.1 people/m^2 (Standards New Zealand, 2007a)
Fresh Air rate	10L/s.person (Standards New Zealand, 1990)

The building has a concrete slab installed for use as thermal mass.

BEES surveyed a number of commercial buildings around New Zealand. The typical operational schedule found for a 1000 m^2 commercial office building is from 8am to 5pm (Saville-Smith & Fraser, 2012). The occupancy, electric light, electric equipment, heating and cooling are all assumed to be on from 8am to 5pm every day.

The heating and cooling set points were established from the 30 IEA Task 40 case study buildings from Europe, Asia and North America. It was found that buildings in similar climates to Christchurch, not just those in tropical climates, can save a significant amount of cooling energy by using a much higher cooling set point than what is considered normal in New Zealand. For example, with the use of ceiling fans, occupants in temperate climates like Paris, reported being comfortable in temperatures up to 30°C (Cory, Lenoir, Donn, & Garde, 2012). This is considerably higher than the accepted temperatures of 25-26°C when cooling would conventionally be turned on in temperate climates like those in New Zealand. In this study, a higher than normal, but still relatively conservative 27°C is used as the cooling set point. The heating set point is 18°C which is the minimum comfort temperature for healthy occupants (American Society of Heating, Refrigerating and Air-conditioning Engineers, 1992).

3.3.2 Christchurch design change and optimization Building Model

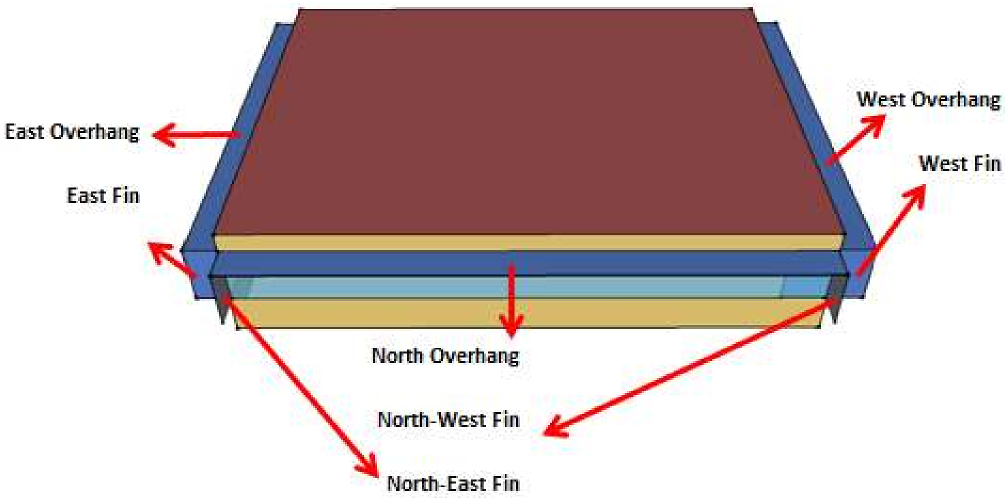

Figure 11: Christchurch Design Change and Optimisation Scenario Model and Solar Shading Location

Figure 11 shows the EnergyPlus design change and optimisation scenario building model for Christchurch. The model is the same 1000 m^2 single-storey building split into five zones (see Figure 11 above) but with overhangs, side fins and/or louvres.

The first scenario tested is the base model with no external solar shading, but with natural ventilation and electric light controls installed in the perimeter zones. Natural ventilation opens the external windows at 26°C to cool the building naturally. This is set below the mechanical cooling set point to ensure that the program only calculates the energy use for cooling when the natural ventilation is inadequate. The electric light controls turn off the perimeter electric lights when the minimum illuminance set point is reached. The minimum illuminance set point used in this study is 350 Lux and is 30 Lux higher than the minimum value set for general office tasks in the NZBC (Standards New Zealand, 2009).

The second scenario tested incorporates the first scenario's design changes of natural ventilation and electric light controls, but also optimises various other building parameters, as shown in the table below. With GenOpt, the program requires minimum and maximum values to be set for each parameter.

Table 2: Christchurch Optimisation Building Parameters

Building Parameter	Minimum and Maximum Parameter Values
North, East, and West Overhang	0m-3m
North-East, North-West, East and West Fins	0m-3m
Wall, Roof, Floor Insulation	0.1 m²-K/W-12 m²-K/W
Glazing Insulation	0.15 m²-K/W-10 m²-K/W
Solar Heat Gain Coefficient and Visible Transmission (*Linked Parameter*)	0.1-0.9
WWR	10-90%
Window Height	The ability to move the window sill to 0.1m above the ground and the window head to 0.1m below the roof

3.3.3 Christchurch Weather File

At the Christchurch location used for the simulations the average temperature across the year is 10.8°C, with the average high and low temperatures being 16.5°C and 6.5°C, respectively.

3.4 Office Test Cell Solar Shading Optimisation Results for Reunion

Two strong trends emerged from the optimisations of the office in St Pierre in Reunion Island: the models orientated to the east and west have significantly larger energy needs and consequently larger potential savings compared to the north or south directions, and the benefits of the shading devices are increased on larger windows. The graph below shows these trends.

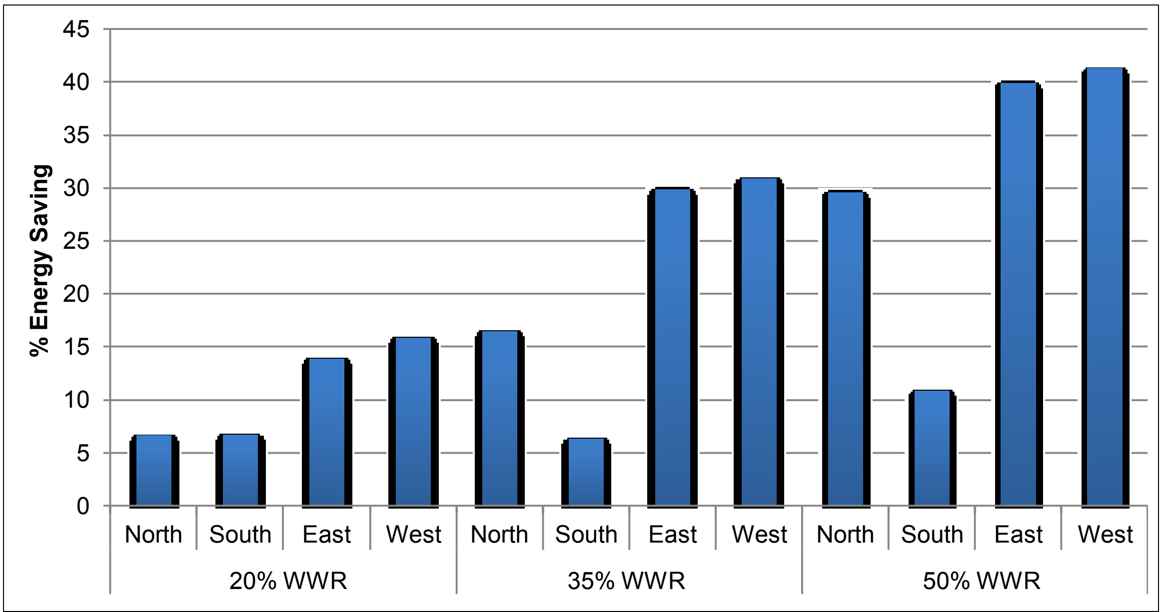

Figure 12:Average Energy Saving of All Shading Devices per Window Size and Orientation

As the benefits of the shading devices mostly follow this trend regardless of window size, the 35% windows will be used to compare the results of specific shading devices for each of the four orientations. The trend is that there is less potential energy savings for windows on the south facade, while there are good energy savings on the West, East, and North facades. Also, the potential benefits in terms of percentage savings are less for the 20% windows and greater for the 50% windows. However, no direct relationships could be derived between window size and savings percentage.

3.5 Optimum North Façade Solar Shading in Reunion

For the north orientation, nine 0.1m louvres at an angle of 30°, saves the most energy across the course of a year. An overhang with a depth of 1.6m will give almost the same result, whilst the side fins, both linked and independent variations, are within 30kWhs of the louvres result. The devices range from giving a 13.8% to 17.3% saving.

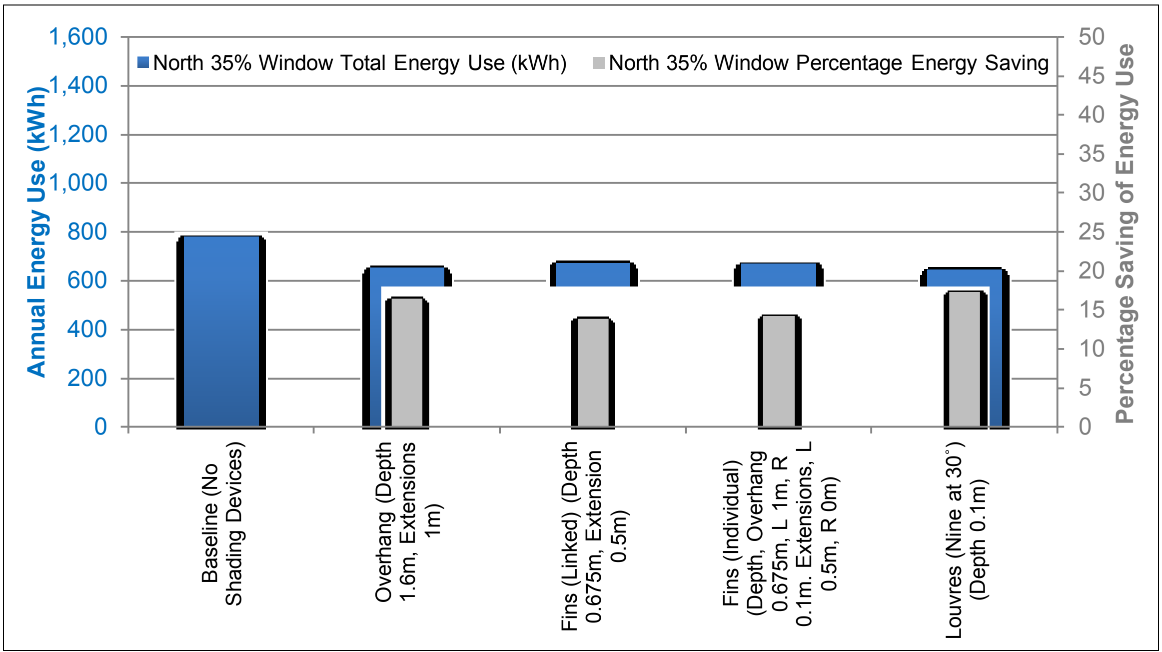

Figure 13: Energy Use and Percentage Savings resulting from Shading Devices for the North Orientation with a 35% Window

3.6 Optimum South Façade Solar Shadings

The south orientation had the lowest total energy use figures. However, compared to the baseline model the shading devices also had the least impact in reducing the energy consumption. Louvres were again the most effective providing 7.4% savings when set at a depth of 0.1m and 30° angle for nine louvres. Individually optimised side fins, entailing a 1m fin on the left/east and 0.1m fin on the right/west combined with a 0.675m overhang, was the second-best solution, requiring an extra 9 kWh than that of the louvres and totalling 653 kWh compared to the 693 kWh of the baseline.

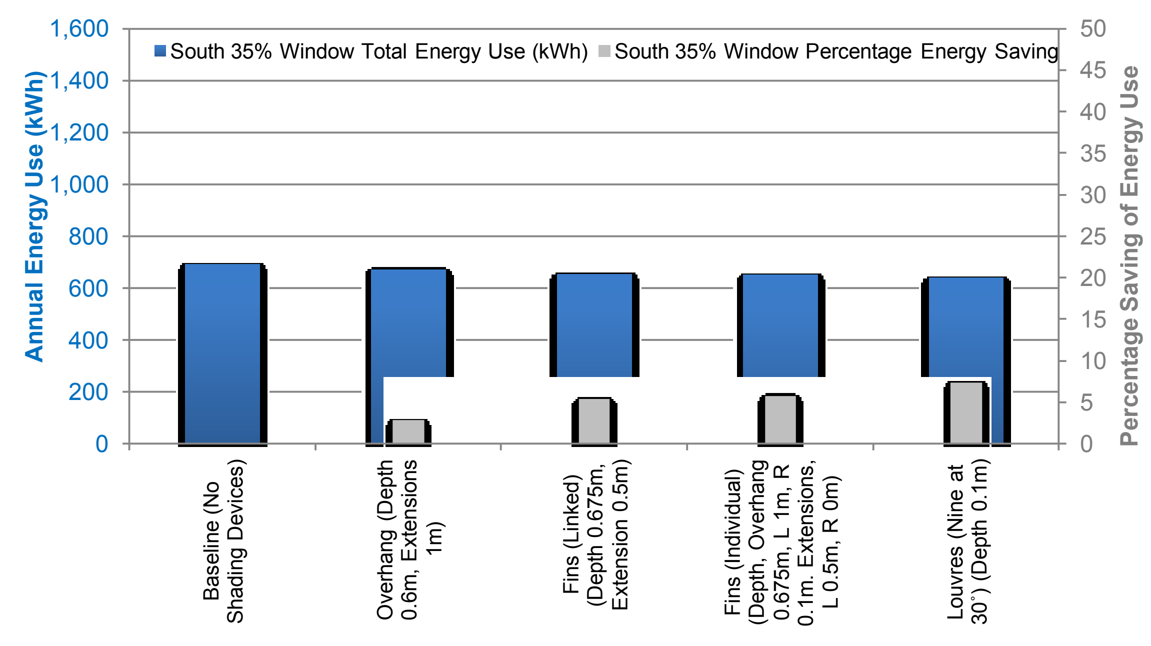

Figure 14: Energy Use and Percentage Savings resulting from Shading Devices for the South Orientation with a 35% Window

3.7 Optimum East Façade Solar Shading in Reunion

The overhang was the second-best performer for the east direction at a depth of 1.6m and the louvres were again the best solution, this time at a depth of 0.125m, providing a 31% saving in annual energy use.

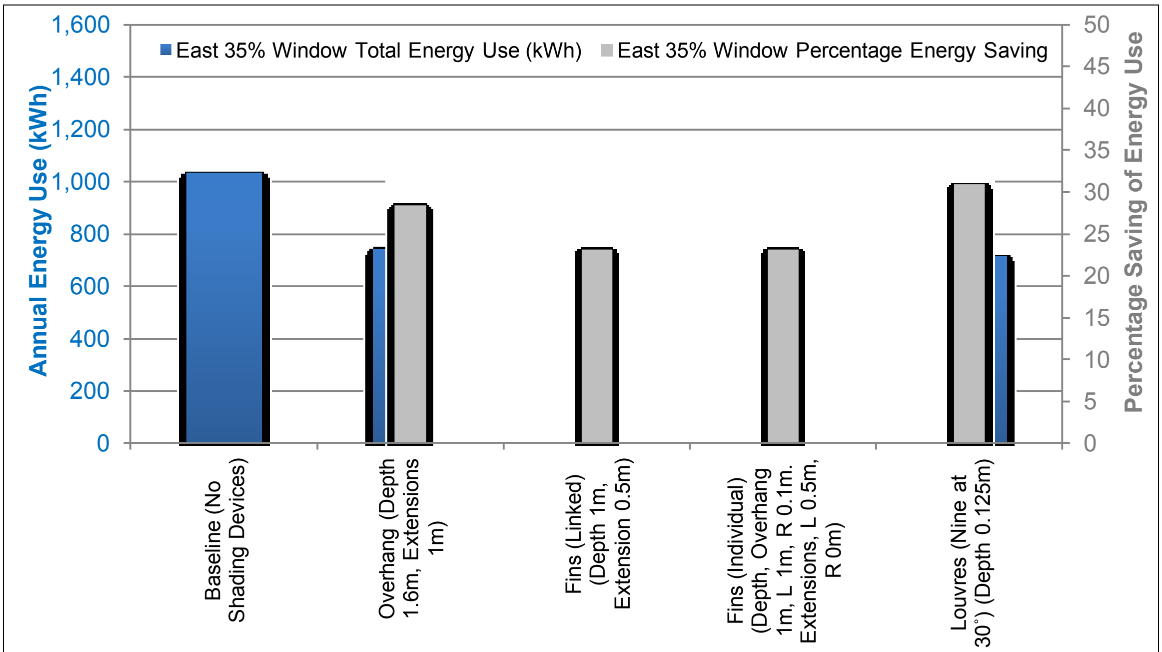

Figure 15: Energy Use and Percentage Savings resulting from Shading Devices for the East Orientation with a 35% Window

The various louvre combinations all outperformed the side fins for the east window and many also outperformed the overhang. As such, the graph below presents the depth, number and angle of the louvres to achieve the corresponding energy savings. Depending on design requirements, several approaches can be used to achieve the same results. For example, as six louvres at a depth of 0.2m and angle of 60° requires 718 kWhs of energy and nine louvres at a depth of 0.125m and an angle of 30° requires 713 kWhs, either option could be used to achieve significant savings.

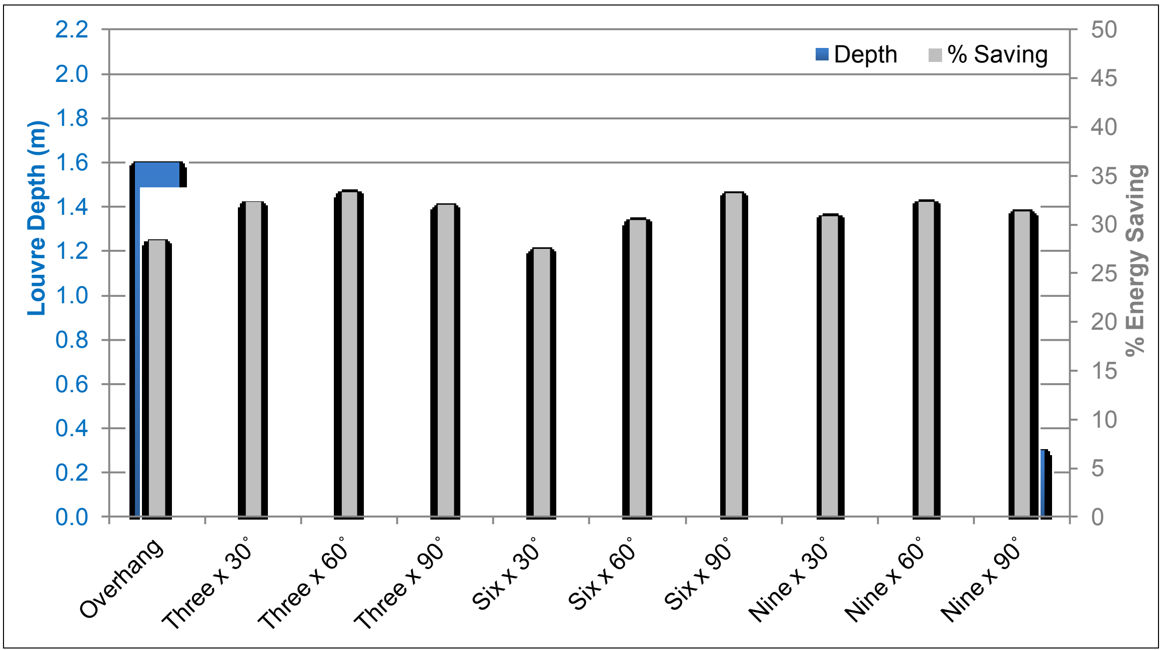

Figure 16:Depth and Percentage Energy Savings of all Louvre Types on East-facing 35% Window

3.8 Optimum West Façade Solar Shading in Reunion

As with the other orientations, louvres are the best option for saving energy in terms of heating, cooling and lighting needs. An overhang is the second-best option; however a number of different louvre combinations are significantly better than the overhang. Side fins are considerably less effective.

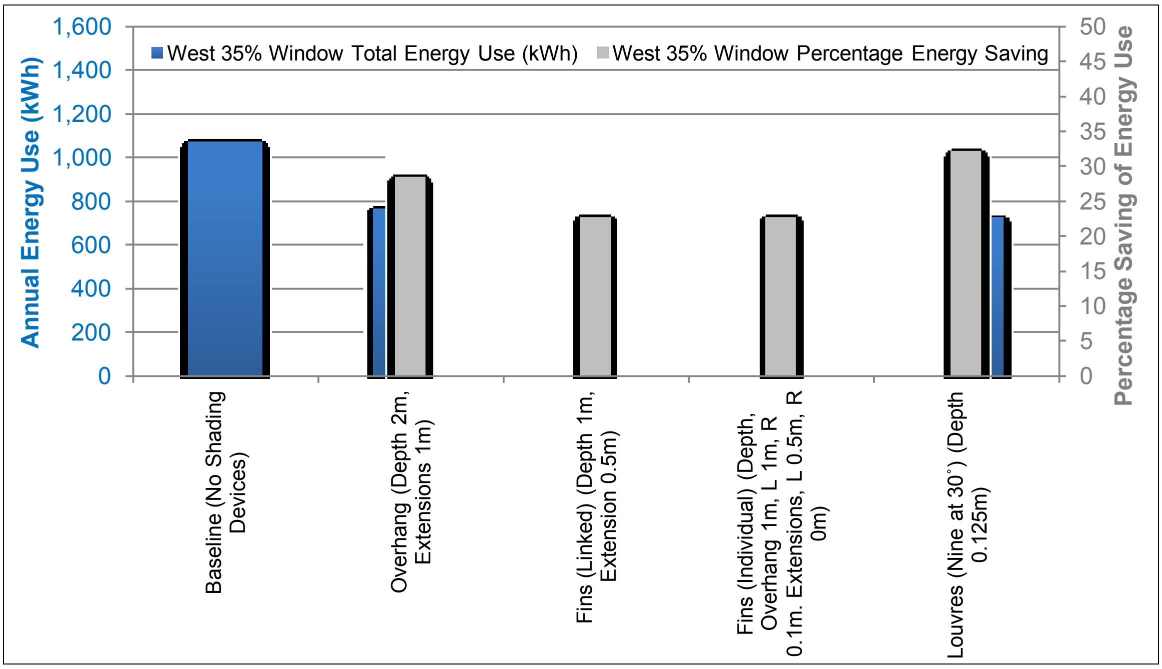

Figure 17: Energy Use and Savings resulting from Shading Devices on West-facing Office Test Cell

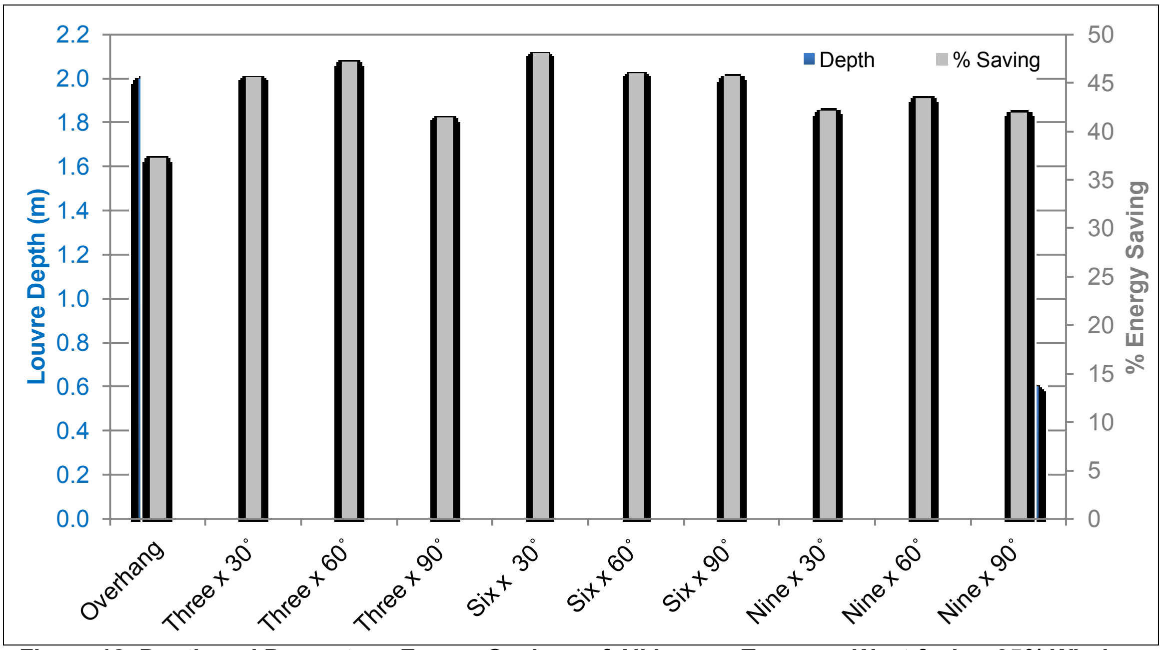

Figure 18: Depth and Percentage Energy Savings of All Louvre Types on West-facing 35% Window

3.9 GenOpt initial Exercise – Lessons Learned

It can be concluded that louvres provide the best energy saving potential for buildings being built in Reunion Island. Louvres save on heating, cooling and lighting energy when compared to overhangs and fins. Overhangs provide the second best energy saving potential.

The main lesson learned from the optimization of the solar shading in Reunion Island is that some systems cannot be optimized in the same EnergyPlus model. This is due to some systems not being able to be modelled in the same EnergyPlus model. For example, overhangs, fins and louvres are all types of solar shading and they are all modelled differently in EnergyPlus. Therefore, three different EnergyPlus models need to be created to optimize each system. This lesson is used to test optimal parameters for various energy lowering solutions in commercial buildings in Christchurch.

4. OPTIMUM ENERGY-LOWERING DESIGN AND TECHNOLOGY RESULTS FOR CHRISTCHURCH

4.1 Optimised Building Parameters

The following results present the optimised building parameters for lowering the annual energy consumption in a 1000 m^2 single storey commercial building in Christchurch. A standardised commercial building was modelled to the New Zealand building Code (NZBC) in EnergyPlus. Various energy lowering solutions (specified in section 3.31) were optimised using GenOpt to ascertain the most favourable parameters for saving energy in the Christchurch climate. The results are summarised in the following sections.

4.1.1 Solar shading

Figure 19 displays the optimum solar shading parameters for both the overhang and fin depths on each façade. The optimum shading parameters are:

- North Overhang: 1.2m
- North-West Fin: 0.625m
- North-East Fin: 1.375m
- West Overhang: 2.45m
- West Fin: 0.125m
- East Overhang: 2.5m
- East Fin: 0.125m

Most shading is needed on the east façade, with the overhang being 2.5m, the east fin being 0.125m and the north-east fin being 1.375m deep. Additionally, the west and north overhangs are large and are 2.45m and 1.2m deep, respectively. The west fin depth is 0.125m and the north-west fin depth is 0.625m. It is indicated that the early morning and late afternoon sun needs to be protected against to lower excess solar heat gains. Also, a general north overhang is needed to prevent unwanted solar gains throughout the day.

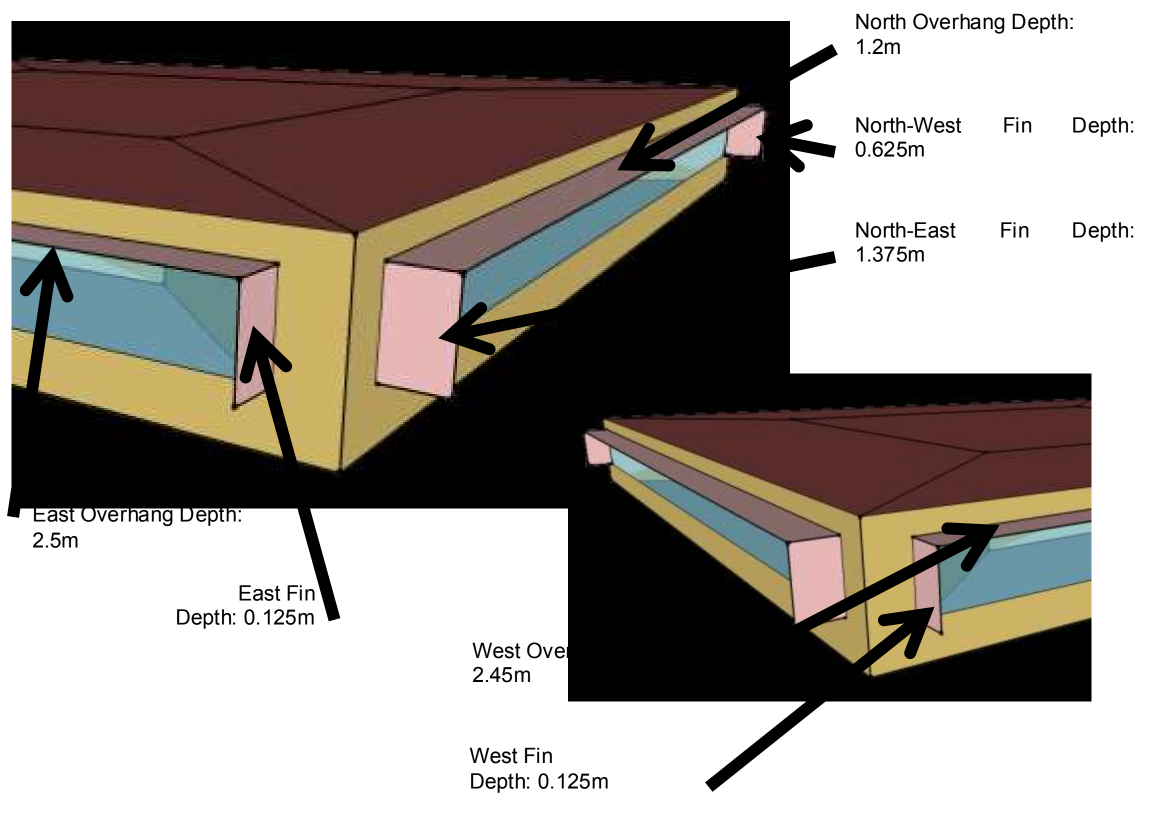

Figure 19:Optimum Solar Shading Parameters

4.1.2 Optimum Window Design

Figure 20 displays the optimum window parameters. The WWR stays at 50%, which is the maximum allowed by the NZBC prescriptive method of compliance. However, the window did move up each façade vertically above centre by 200mm to allow for better daylight penetration into the rear of the perimeter spaces. These results indicate that the NZBC requirement is correct and windows in commercial buildings should not take up more than 50% of the building's façade. Also, the window design should focus on placement for daylight entry rather than increasing their size.

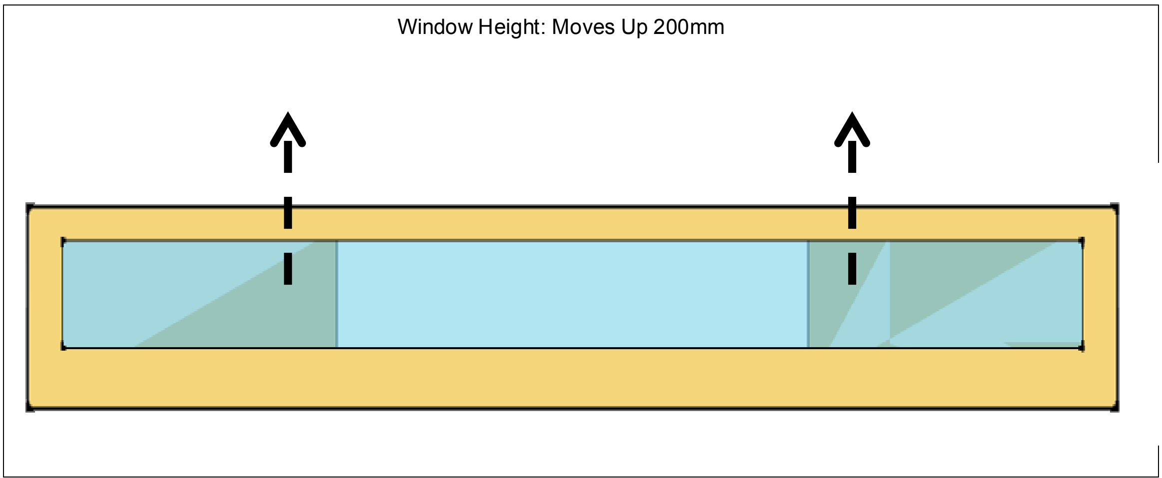

Figure 20: Optimum Window parameters

4.1.3 Construction: Insulation and Glazing

Figure 21 displays the 'optimum' construction parameters for the insulation of each envelope element, the glazing solar heat gain coefficient and glazing visible transmission. Optimum construction parameters are:

- Roof Insulation: 12 m²-K/W
- Wall Insulation: 12 m²-K/W
- Floor Insulation: 1.5 m²-K/W
- Glazing Insulation: 0.77 m²-K/W
- Glazing solar heat gain coefficient and visible transmission: 0.80 m²-K/W

The roof, wall and glazing insulation increased well above the NZBC values with all three insulation results possibly not reaching 'optimal' (minimum energy use) levels as they reached the maximum optimisation value of insulation allowed in the modelling process: i.e. wall and roof: 12 m²-K/W; glazing: 0.77 m²-K/W. This is in the nature of the optimisation process: increasing insulation will always reduce energy use just in diminishing amounts. With devices like sun shades there is an 'optimum' where reduced summer solar gain leading to reduced summer cooling energy balances increased winter heating energy use due to loss of solar gain. The optimisation stopped once it reached these two values. More energy reductions could have been achieved with higher insulation values. The floor insulation is shown to be less important with it only increasing slightly when compared to the NZBC value of 1.3 m²-K/W to 1.5 m²-K/W. The glazing's solar heat gain coefficient and visible transmission were optimised to 0.80 m²-K/W and is what typically found in double glazing (National Institute of Building Sciences, 2012). The key principle learned is that the roof, wall and glazing are important elements to insulate, especially when considering that glazing has no requirements under the NZBC.

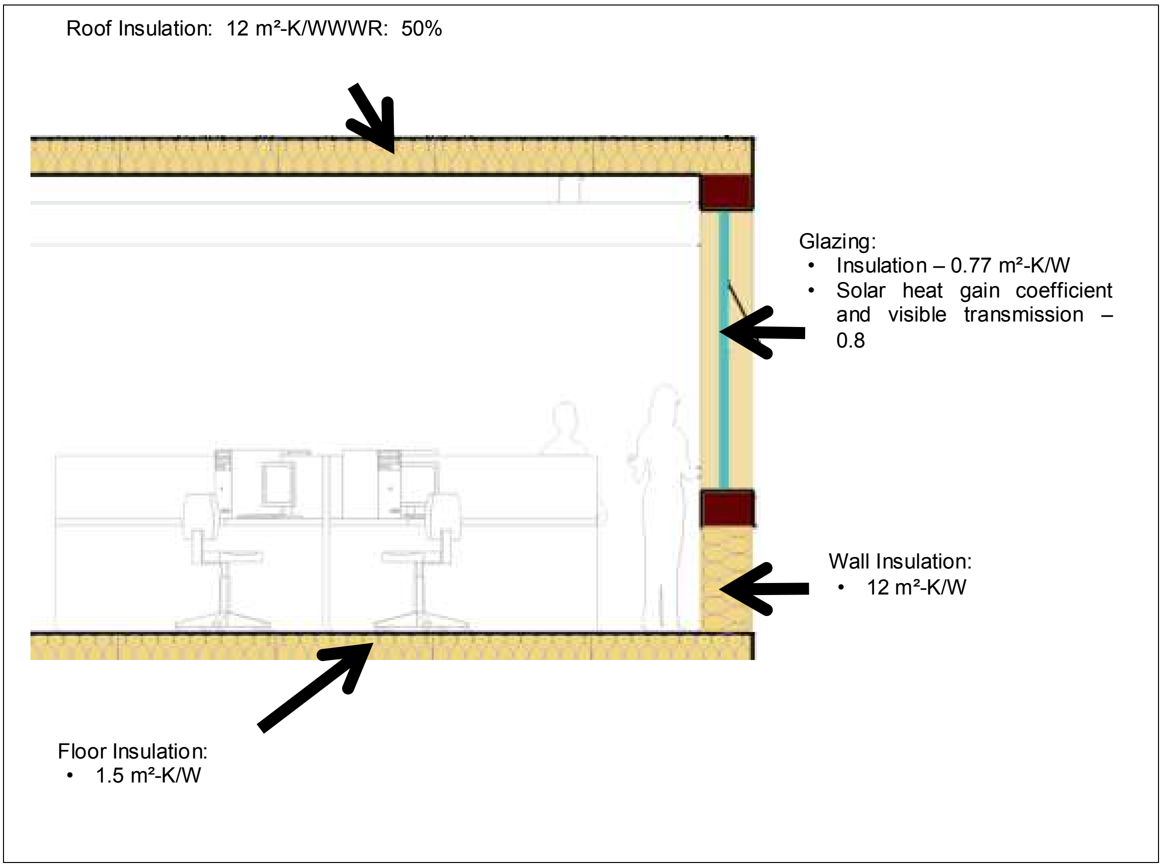

Figure 21:'Optimum' Construction Parameters

Figure 22 below illustrates the diminishing returns that occur from having an increased value of insulation. The vertical axis shows the compiling energy savings and the horizontal axis has the insulation value. As can be seen in the area highlighted, the amount of energy savings achieved decreases when using a higher level of insulation on each element. GenOpt only selects the optimum level of insulation for achieving the lowest possible annual energy consumption, it does not 'think' about lack of savings from increasing the insulation or practicalities of construction.

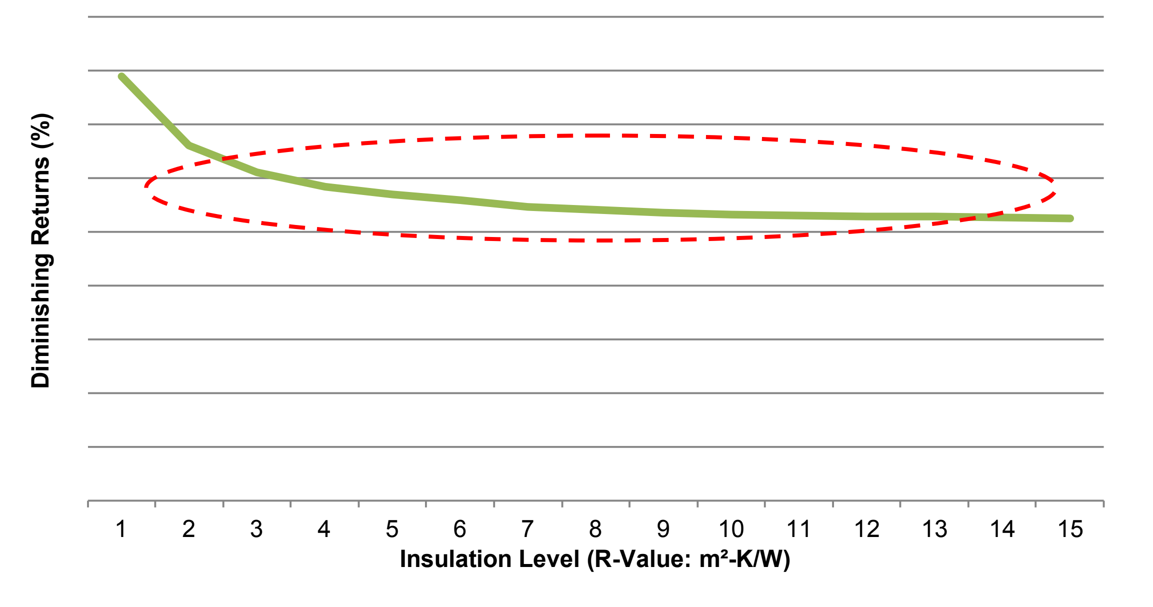

Figure 22: Diminishing Energy Saving returns from Increased Levels of Insulation in Christchurch

4.2 Energy-Lowering Results

Figure 23 displays the energy end-use breakdown of the energy consumption for each of the three building scenarios. The coloured bars are the results for the perimeter zones and the orange lines the results for the core zone. The blue bars represent the energy end-use consumption for the base scenario, the red bars represent the scenario with natural ventilation and electric light controls installed, and the green bars represent the fully-optimised solution set scenario (with optimum solar shading, insulation, WWR etc). Figure 24 displays the energy end-use savings for the two energy lowering building scenarios. Energy savings achieved by each scenario are represented by the two coloured bars, with the red for the natural ventilation and electric light controls scenario, and the green for the fully-optimised solution set scenario.

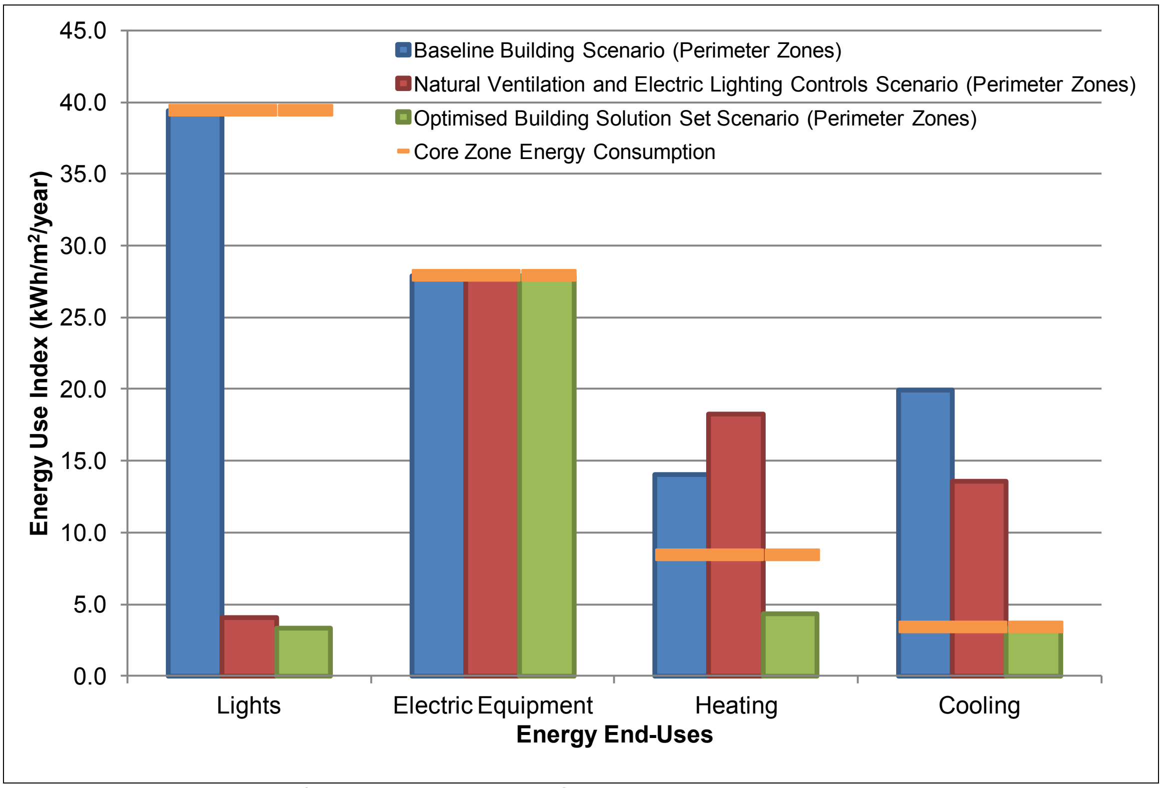

Figure 23: Christchurch Building Scenario Energy End-use Breakdown

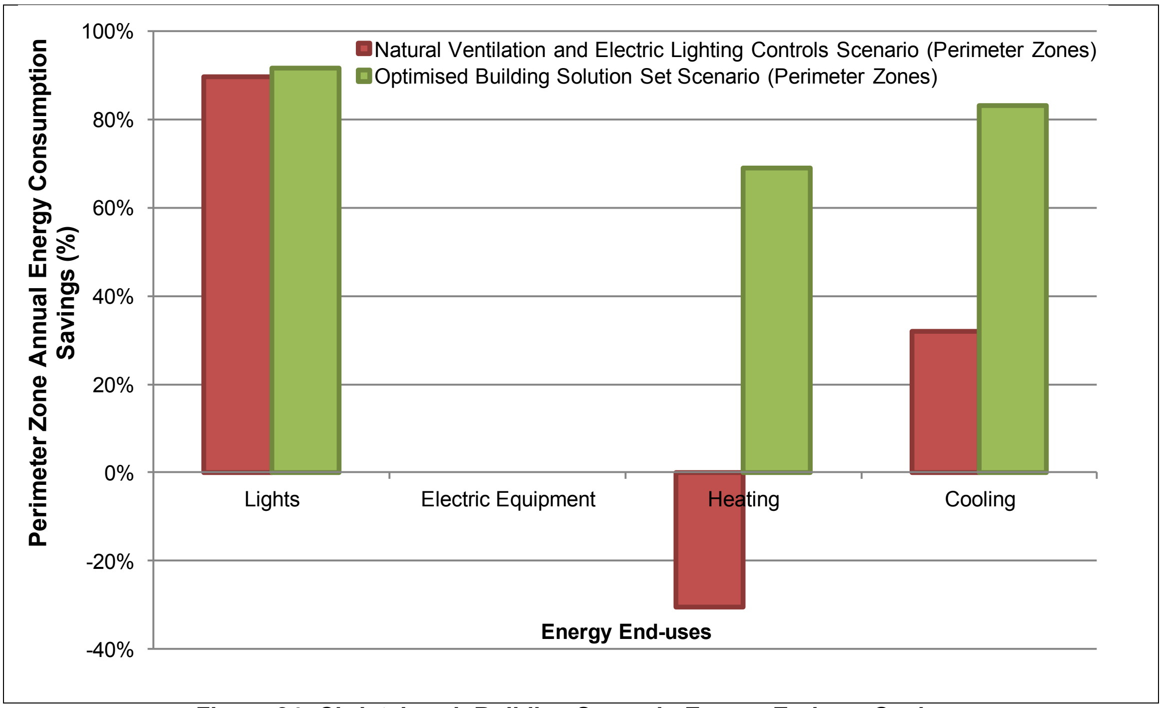

Figure 24: Christchurch Building Scenario Energy End-use Savings

As can be seen in Figure 24, the large energy savings are achieved in the cooling, heating and lighting building energy end-uses. Large reductions in the cooling and lighting energy consumption are achieved with just the natural ventilation and electric light controls. However, more energy can be saved when the building's envelope is optimised. These savings are mostly attained in the cooling and heating energy end-uses.

The cooling consumption is reduced by 32% with natural ventilation and electric light controls, and by 83% with the fully-optimised solution set. Only using natural ventilation and electric light controls increases the annual heating consumption by 30%, but when combined with high levels of insulation, the heating energy use is reduced by 67% when compared to the baseline building. The lighting energy consumption is reduced by 90% with natural ventilation and electric light controls, and is reduced a further 2% with optimised window height and glazing visible transmission. This is even with the solar shading impeding on the daylight availability into the space. The results indicate that with the fully-optimised solution set, building design, the cooling and lighting energy consumption can be almost be eliminated in the Christchurch climate.

In the base scenario, the four perimeter zones consume more energy than the core zone (Figure 23). However, this radically changes when the energy-lowering design changes are implemented. In the base scenario the perimeter zones consume 21.9 kWh/m^2/year more energy than the core zone, in the natural ventilation and electric light controls scenario the perimeter zones use 15.5 kWh/m^2/year less than the core zone, and in the fully-optimised solution set scenario the perimeter zones use 40.4 kWh/m^2/year less than the core zone.

In the building scenario implementing natural ventilation and electric light controls, the perimeter energy savings are gained purely from the lighting end-use as the heating and cooling consumption in the core are still lower than in the perimeter. However, in the fully-optimised design scenario, the perimeter savings are gains from all three energy end-uses: lighting; heating; and cooling. Therefore, a shallower-plan building is only more economical if the whole building is designed well.

Figure 25 and Figure 26 display the split of energy end-use consumption between the baseline and fully-optimised solution set building scenarios.

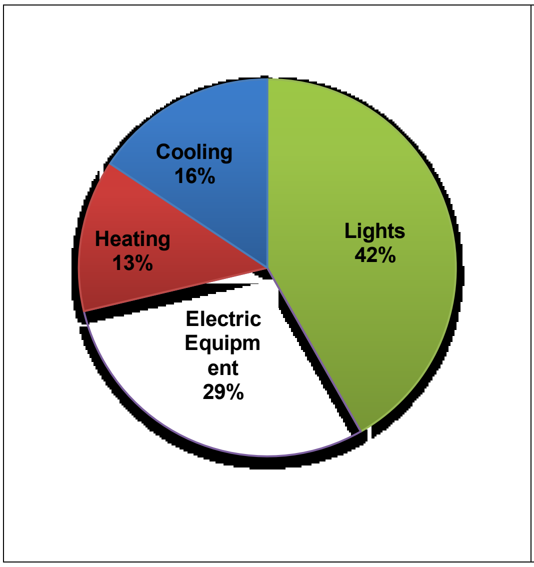

Figure 25: Christchurch Baseline Building Scenario Energy End-use Split

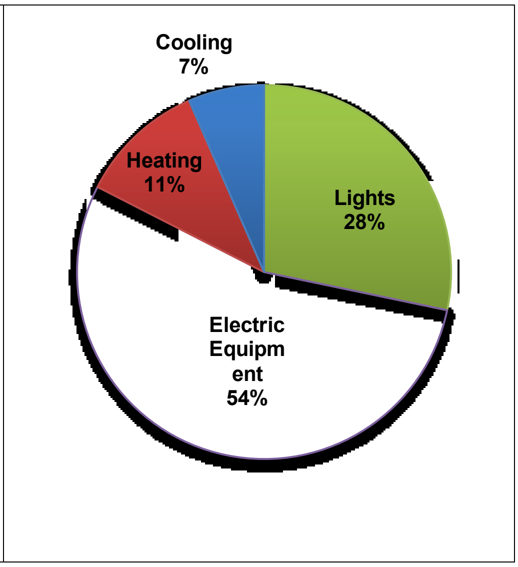

Figure 26: Christchurch Optimised Building Solution Set Scenario Energy End-use Split

As can be seen in Figure 25, the base building has roughly a one-third split between the lighting, office (electric) equipment and space conditioning (with equal cooling and heating). This split follows what other studies have found in standard commercial buildings (Itron Inc, 2006).

However, as can be seen in Figure 26 the end-use split changes dramatically in the scenario with a fully-optimised solution set building design. The building becomes heavily electric equipment and lighting dominated, and the space conditioning (heating and cooling) only makes up a small percentage (18%). The electric equipment end-use becomes the dominant energy consumer with an increase from 29% to 54% of the total annual energy consumption. The lighting becomes the second-largest energy consumer, dropping from 42% to 28%. The cooling reduces from 16% to 7% of the annual energy consumption and the heating decreases from 13% to 11% of the annual energy consumption. These results also follow the trend found in existing Net ZEBs from around the world (Cory, Lenoir, Donn, & Garde, 2012).

Figure 27 displays the building's total annual energy consumption in black columns and percentage of annual energy savings in green dots for the three building design scenarios introduced above, as well as a fourth building scenario. The fourth building scenario is the fully-optimised solution set design in a shallow floor plan; this means all 1000 m^2 of floor area is contained in a building which acts entirely like a perimeter zone (Diagram of building - Figure 28).

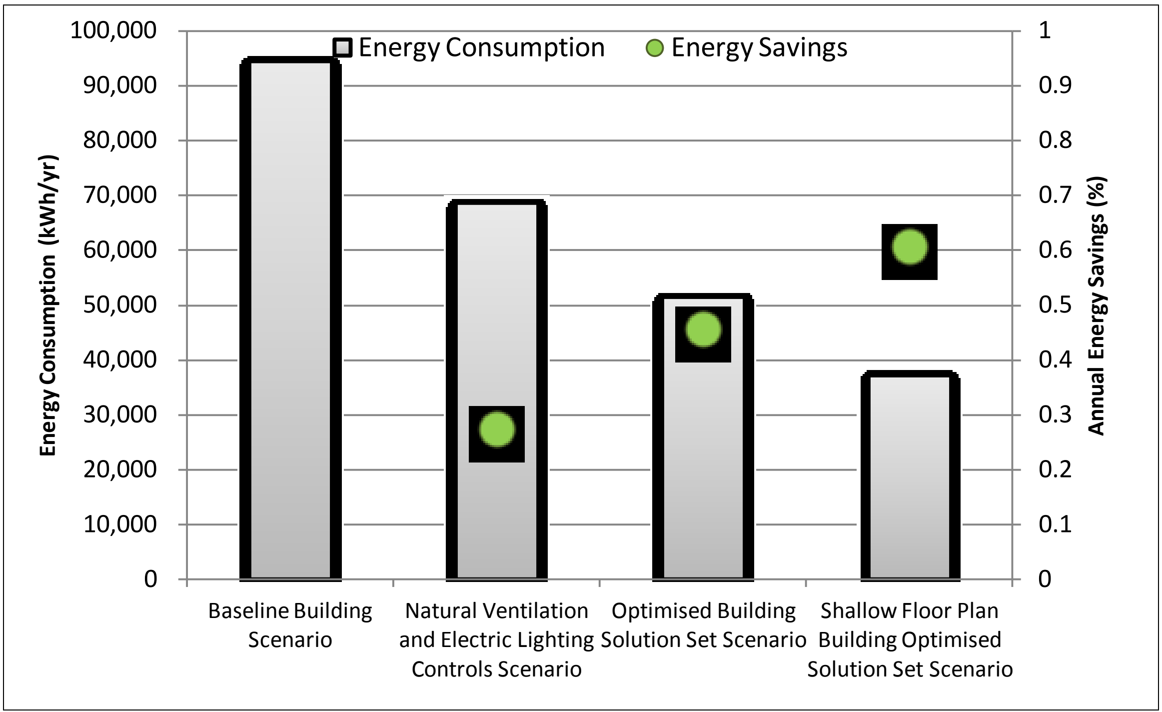

Figure 27: :Christchurch Building Scenario Annual Energy Consumption Results

As can be seen, each stage reduces the energy consumption dramatically. In the building scenario implementing natural ventilation and electric light controls, the annual energy consumption is reduced by 27%. With the fully-optimised solution set implemented, the energy is reduced a further 18% to reach total energy savings of 46% when compared to the base scenario. By just using a shallow floor plan, the annual energy consumption can be reduced by another 15% to reach total energy savings of 61% when compared to the base scenario. Therefore, optimising just the building layout and envelope can reduce the energy consumption in Christchurch commercial buildings by approximately 60%.

Figure 28 displays a shallow floor plan which houses all 1000 m^2 of floor area in perimeter-like zones. The building is much more narrow and long, and is orientated length-ways east to west. The building has two 7m perimeter zones and a 3m corridor zone to make it a total of 17m in width. This is half almost of the deep plan's width which is 31.6m in depth and width. The length of the building is 58.8m. The shallow building implements the optimised solution set design scenario: insulation; solar shading; WWR; window height; natural ventilation; and electric light controls.

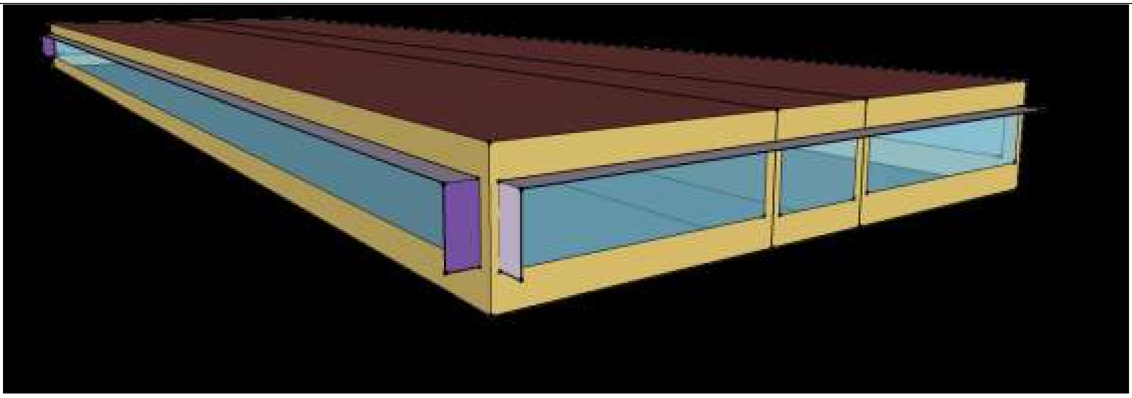

Figure 28: Shallow Floor Plan Optimised Building Scenario

5. CONCLUSIONS

This report identified a methodology for application of the optimisation software, GenOpt, in energy simulations that will enable future optimisation studies on models of the existing building stock in New Zealand. The first learning exercise used solar shading in Reunion Island as a simple pilot test with limited parameters of the optimisation software; and a more comprehensive and complex case study addressing optimum energy-lowering parameters for Christchurch commercial buildings was then trialled successfully. It was found that a two phase optimisation process (phase 1: non-optimised design options and phase 2: optimised design options) is needed to test building design options as well as optimise various building design parameters. However, in hindsight some building design options, such as the use of natural ventilation and electric light dimming, could be more automated and completely optimised within the model. This is achieved using the control option and GenOpt being able to switch each design option on and off. But, in the case of testing other design options, such as different solar shading types (overhangs and louvres), separate models need to be constructed and an optimization run on each design option. Also, the window-to-wall ratio on each facade is all connected together in this report's tests. For example, each facades window-to-wall ratio is optimised to the same size. In reality each façade could be optimised separately. These optimization lessons learned will be implemented in the next phase of the planned analysis during 2012/2013 of calibrated models of the BEES monitoring project buildings.

5.1 Recommendations for Solar Shading in Saint-Pierre

In all cases a large number of small louvres should be considered as the first option. This is a particularly good replacement for large overhangs. If considering using a lesser number of louvres then an overhang is likely to be more beneficial as the depth of the louvres becomes relatively large. Side fins only have a significant impact when used in conjunction with an overhang and are most beneficial on the eastern and western sides.

If considering making interventions on the south side, serious thought must be given to the cost of the particular device compared with its potential savings as the benefits are very small compared to the other orientations.

5.2 Christchurch Design Principles and Guidelines

This report presented results from a study looking at design principles and design guidelines for commercial buildings in Christchurch, New Zealand. The results were found to be in line with the lessons learned from existing buildings around the world. These lessons are that cooling can almost be eliminated in the perimeter zones of buildings and that very low-energy and Net ZEBs have their annual energy consumption dominated by internal equipment.

Having a fully-optimised solution set implemented in new Christchurch commercial buildings can reduce the annual energy consumption by as much as 46% when compared to a standard built-to-code commercial building. Furthermore, by just using a shallow floor plan, the annual energy consumption can be reduced by a further 15% to reach total energy savings of 61% when compared to a standard built-to-code commercial building. Therefore, optimising just the building layout and envelope can reduce the energy consumption in Christchurch commercial buildings by approximately 60%.

Five design principles are established in the work presented in this study. The first is that natural ventilation/free cooling and daylight design is crucial to lowering energy in Christchurch commercial buildings. This principle also indicated that the savings could be large if the building form is kept narrow as the perimeter savings would be more prominent without an internal building core zone. The second guideline is that with the combination of optimal solar shading, insulation and free cooling, the cooling energy consumption is almost eliminated.

The third lesson is that commercial buildings need to be insulated well, especially the roof AND glazing. The fourth guideline is that the WWR does not need to be bigger than the maximum NZBC value of 50%, but should definitely not be smaller. The last principle is that the windows need to be situated high on the façade to allow for good daylight penetration.

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