ENERGY EFFICIENT URBAN FORM

A Simulation of Building Energy Performance in Wynyard Quarter

Auckland

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A dissertation submitted to
Auckland University of Technology
in fulfilment of the requirements for the degree
of
Master of Art & Design (Spatial Design)
2017
School of Art and Design

Abstract

Climate change has become a challenge with adverse impacts on the Earth. Coastal cities, such as Auckland, are now more vulnerable to natural disasters arising from climate change, mainly sea-level rise. Waterfronts are unique locations of coastal cities, around which primary settlements have been formed or have become invaluable for many reasons such as extending land reclamation. Wynyard Quarter on Auckland's waterfront is reclaimed land that in recent years has been undergoing major redevelopment. Although Wynyard Quarter is vulnerable to the adverse impact of climate change, it is believed that the current altitude of the land will be greater than the projected sea-level rise for the next century. Therefore, redevelopment of the area is deemed inevitable. However, redevelopment aims to reduce its long-term impact by reducing its carbon footprint and, consequently, greenhouse gas emissions. A more sustainable built environment can be achieved by improving the energy efficiency of buildings. In order to achieve this, sustainability strategies, frameworks, and standards have been produced for Wynyard Quarter. The two main outcomes from these initiatives are firstly, conserving more energy in buildings, and, secondly, generating more clean energy on-site.

Wynyard Quarter's urban design framework identifies the development potential for the area and guides future development to achieve the best urban design outcomes. The Urban Design Framework was first published in 2007 and a revision of it was published in 2014. The 2014 version of the framework investigates flexibility in terms of improving development capacities for some sites in Wynyard Quarter. The aim of this research is to investigate how the Urban Design Framework provides opportunities for a more energy efficient development in Wynyard Quarter. The research adopts a mixed-methods approach. As will be developed in the course of the thesis, the mixed-methods approach enables the gathering and analysis of both qualitative and quantitative data. The research chooses one case study in Wynyard Central. Two different development scenarios are modelled to understand the potential energy demands of each scenario as well as modelling the potential for on-site solar energy generation in order to understand the potentials for offsetting each scenario's energy consumption.

By aggregating the results of the two-staged analysis, the research aims to determine which version of the urban design framework supports the more energy efficient development in the case study. The research also reviews the relevant policies that support the achievement of a more energy efficient built environment, so it can identify opportunities for improvement in terms of planning and policy.

Dedication

To my Nana, Shahrbanoo.

Acknowledgment

I would like to thank my supervisors Amanda Yates and Dr Mark Jackson for their guidance and help throughout my thesis. My gratitude also goes to the Auckland Design Office (ADO), especially Monique Jones who supported me during the research. I would also like to thank the management at Auckland Council, particularly the ADO's General Manager Ludo Campbell-Reid, for their generosity in making their resources available to me. Finally, I am grateful for the love and support of Amir Kayal, who was by my side and kept me motivated during this project.

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Attestation of Authorship

I hereby declare that this submission is my own work and that, to the best of my knowledge and belief, it contains no material previously published or written by another person (except where explicitly defined in the acknowledgements), nor material which to a substantial extent has been submitted for the award of any other degree or diploma of a university or other institution of higher learning.

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CHAPTER ONE

Towards Low Carbon Urban Design

Statement of problem

This chapter introduces – opens the window into – the research. As an introduction to the research, it manifests the research purpose, its underpinning rationale, the methodological approach to the topic, and the geographical context. It also narrows down the scope of the research and outlines the research question and objective as well as the expected findings. This research examines the impact of revising urban design parameters in creating a low-carbon urban development in Auckland, New Zealand. The research is quantitative in nature, choosing a case-study approach as its primary research method. In addition, the research presents findings from sources such as governmental and non-governmental reports and guidelines concerning climate change, mitigation methods, urban design, and other relevant topics.

According to the definitions provided by the International Panel on Climate Change (IPCC), this research is categorised as a bottom-up approach towards mitigation of climate change. Generally, there are two main approaches towards sustainability and mitigation of climate change – top-down and bottom-up approaches. The former aims to develop policies, strategies, and standards while the latter is often less aggregated, with a strong focus on engineering aspects of energy demand and production. This research focuses on technical aspects of climate change mitigation in a particular geographical locale: Wynyard Quarter on Auckland's waterfront. In doing so, the research utilises modelling techniques, both for urban form as well as energy performance.

Modelling energy performance of urban form means literally that the energy performance of particular building forms is measured. This includes projections of their energy demand and the potentials for energy generation. The goal of this research is to identify the most responsive urban form in supporting greenhouse gas reduction goals set by the Auckland Plan. The Auckland Plan is the strategic document in which a long-term vision and a set of outcomes are set for Auckland's future in the next 30 years. Accordingly, the objective of this research is to examine how the proposed urban design framework for Wynyard Quarter – which governs building form development – will support this goal. The Auckland Plan has set aspirational goals, the ultimate one to achieve a 50% reduction of greenhouse gas emissions (based on the 1990 emission levels) by 2050.

Wynyard Quarter was chosen as the case study due to a few unique characteristics that this precinct presents in terms of development potentials, strategic location on Auckland's waterfront and CBD, climate change hazards, and sustainability initiatives in the past few years.

Research purpose

The purpose of the research is to explore a design approach to energy performance of built form on a waterfront, a site which is most vulnerable to impacts of climate change, particularly sea level rise and storm surge.

Research scope

The scope of the research includes the current proposals for Wynyard Quarter in Auckland, which used to be a highly industrial site, providing business support to the operational Auckland Port. The location of the site is invaluable in terms of the natural setting and land value, and its close proximity to the Auckland CBD, which is the 'heart of the city'. Wynyard Quarter has become a great opportunity for higher density mixed-use developments. The Wynyard Precinct: Urban Design Framework (Waterfront Auckland, 2014) sets out the design roadmap for the precinct. It is supported by other policies such as Wynyard Central Sustainability Standards that specify the sustainability standards required for the new development in the precinct. This research focuses on two urban design frameworks – 2007 and 2014 – for the same block development in order to identify how well the proposed developments and recent revisions of them are aligned with the sustainability objectives for the area. The research focuses on an urban block with a significant change in its proposed building forms in the two urban design framework documents.

Research objective and questions

The main objective of this research is to identify the urban design parameters that will have the greatest impact on the optimum energy efficiency of the built form in Wynyard Quarter developments. The research is primarily concerned with identifying those parameters, and secondly their implementation as part of greater development policies that may diverge focus from sustainability due to other competing objectives of developments. Therefore, the primary research question is:

- What urban design parameters will achieve the optimum energy efficiency of the built form in Wynyard Quarter?

The supplementary questions to the above are:

- How are such parameters implemented in combination with other competing parameters that may diverge the focus from energy efficiency in Wynyard Quarter?
- What policies for the Wynyard Quarter developments may diverge focus from sustainable development of the urban form?

Research methodology

The research methodology for this project is comprised of the following:
Data collection of the Wynyard Quarter development plans, sustainability standards, information required by the modelling software such as weather files, building materials and their energy performance statistics, etc.

- Collecting data about Wynyard Quarter development including government reports, standards, plans, sustainability objectives of the Auckland Plan, Urban Design Framework documents
- Development of 3D models in relevant software including City Engine, eQUEST, Revit, and Sketch-Up
- Model the buildings’ energy demand in eQUEST
- Prepare the model of the building forms in City Engine and Sketch-Up
- Model the solar radiation of the buildings and relevant analysis in Revit
- Interpret and evaluate the results from the two stages of analysis above
- Document the challenges and limitations in each step
- Discuss the results of energy use and energy generation patterns of the two scenarios and identify the impact of the urban design policies, namely the urban design frameworks, in achieving a more energy efficient urban form on the waterfront

Limitation and delimitation

This research identified a number of limitations during the course of the research. These limitations include technical software issues, modelling complications, as well as difficulties in data gathering and adaptation of the data to the case study’s context. One of the challenges in the research was the requirement to learn the software used for modelling and analysis within a short period. In fact, learning the software needed to be paralleled with other research activities, such as scoping out the research, the literature review, and designing the research methodology. Therefore, multiple refinements were required during the course of the research to update or adapt the research methodology as required. Also, learning-by-working slowed progress at some stages, as further modelling investigations were required – for instance, on an occasion, the information required for the modelling software had to be cross-examined to ensure the appropriate data were used in modelling.

Research significance

The significance of this research includes the methodology developed for analysis in which software modelling is used for separate performance analysis. This allows a detailed documentation of the process, including the challenges and shortcomings of the software. Moreover, the research examines the impact of urban design policies alongside sustainability standards set out for a waterfront development in the context of the regeneration of a critically important development on Auckland's waterfront. The findings of the research can be useful in identifying the strength of current redevelopment regimes in building a more energy efficient urban form as well as identifying further potentials for urban design parameters to complement current practice.

CHAPTER TWO

Auckland / Climate / Building

Part One – Research Contexts

Climate change

Climate change may be simply defined as changes in weather pattern distributions that can last for a relatively long time, ranging from decades to millions of years. Climate change happens due to many kinds of natural processes that impact the Earth's energy intake and the radiation of this energy (Committee on Ecological Impacts of Climate Change, 2008). Global advances in technology since the 1850s have made it possible to document temperature more accurately and more consistently. These data show a rapid increase in temperature globally during the 20th century. This rapid change is often associated with the increased levels of greenhouse gas emissions that are a result of human activity. If this trend continues unchanged, since 1990 it will have resulted in a global temperature increase of 2 to 4 degrees Celsius by 2100 (Committee on Ecological Impacts of Climate Change, 2008).

Although climate change can happen naturally, the rapid increase of temperatures within the atmosphere and in the oceans is worrying. These rapid temperature increases have resulted in the faster melting of glacial ice that has, consequently, resulted in an increased sea level rise (Committee on Ecological Impacts of Climate Change, 2008; Smith, 2015; The Habitable Planet, n.d.).

The role of human activities in climate change

Global warming is attributed as being the main reason for climate change. The accumulation of greenhouse gases at an excessive rate in the atmosphere is the main reason for the current rapid increase in global warming (IPCC, 2007; NASA, 2016). Greenhouse gases – carbon dioxide (CO_2) is the most important – trap long-wave radiation in the upper atmosphere. This entrapment increases the atmospheric temperature. Anthropogenic climate change refers to the production of greenhouse gases emitted by human activities. Human activities are considered as the most important contributing factors to climate change globally. These activities have dramatically increased the levels of atmospheric CO_2 concentration (Salinger, Renwick, & Mullan, 2001). In fact, it is estimated that since 1750 about two thirds of anthropogenic climate change CO_2 emissions have come from fossil fuel burning (coal and petroleum) and about one third from land use change (mainly deforestation and agricultural). About 45% of this CO_2 has remained in the atmosphere, while about 30% has been taken up by the oceans and the remainder has been taken up by trees and plants. Many aspects of climate change and the impacts associated with it will continue for centuries, even if anthropogenic emissions of greenhouse gases are stopped (IPCC, 2014).

Cities and climate change

As the population growth in cities continues to rise (United Nations, 2015), the impact of cities on climate change rises. By 2014, 63% of countries were more than half urban and one-third were more than 75% urban. By 2050 more than 80% of countries in the world are projected to be at least half urban and just under 50% will be at least 75% urban (United Nations, 2015). Changes in urbanisation can affect economic growth, energy use, and CO_2 emissions (Sadorsky, 2014). One estimate showed that urban areas contributed 67% and 71% to the global primary energy demand and energy-related CO_2 emissions respectively for 2006 (Makido, Dhakal, & Yamagata, 2012). In addition, energy efficiency will play a critical role in limiting world energy demand growth to one-third by 2040, while the global economy grows by 150% (International Enery Agency, 2015). Thus, urbanisation and urban development are critical factors for CO_2 emissions and mitigation (Makido et al., 2012; Sadorsky, 2014). Urban development will transform a significant part of natural environments into built environments, which will impact wider ecosystems and consequently climate. Moreover, the greater demand for activities in cities will result in a greater emission of greenhouse gas. This is how cities impact climate (Abunnasr, 2013; Smith, 2015), which consequently increases their vulnerability against the challenges imposed by climate change (Abunnasr, 2013; Smith, 2015).

Sea level rise

The immediate consequence of greenhouse gas accumulation globally has been the increase in the average surface temperature, which is estimated at 1.4 to 5.8°C over the period of 1990 to 2100 (Abeysirigunawardena, 2010). During this period, some parts of the world will experience greater temperature increases than others. As the global temperature rises, it is expected that sea levels will also rise due to the thermal expansion of ocean water coupled with ice melting from mountain glaciers. The role of the former is seen as having a greater impact (up to 50%) on global sea level rise than the latter (Abeysirigunawardena, 2010; Office of the Prime Minister's Science Advisory Committee, 2013). Therefore, global sea level rise, even with successful future greenhouse gas emission mitigation programmes globally, will continue to happen. This is because of the response lag in the global ocean system (Abeysirigunawardena, 2010). The overall rate of sea level rise is predicted to be at a minimum rate of double – or up to four times – the observed rate over the 20th century. The estimates are based on the projections of CO_2 concentrations – 2-4 times the rates of the pre-industrial period (Abeysirigunawardena, 2010). Sea level rise estimates for the 20th century are based on worldwide tide gauge records. The estimates, however, may reveal different results from one study to another. The estimates of sea level rise were higher during the 1990s, especially after new technologies, such as satellite altimetry, became available and were used along with global tide gauge records. However, studies such as that of Church and White (2006) and Holgate (2007), show a consistency in their estimates of 1.70 ± 0.3 and 1.74 ± 0.16 per year, respectively, for most of the 20th century. This is a far smaller sea level rise estimate compared with some studies done during the 1990s, where rates of about 3.1 ± 0.7 per year were made (Abeysirigunawardena, 2010).

Despite various studies that have projected global sea level rise, it is still unclear how such projections are to demonstrate local impact. It is understood that the distributions of the sea-level rise are not globally uniform, yet they are still frequently used in local sea level rise impact assessments (Church, White, Coleman, Lambeck, & Mitrovica, 2004). Consideration of localised information is important as it can better reflect sea level rise by taking into account localised land movements that demonstrate local relative sea level rise (Abeysirigunawardena, 2010). One of the challenges for using localised information for coastal impact studies is the uncertainty about its scales. Uncertainty caused by the complex dynamics of regional and local climate systems, such as peak-winds or storm-surges, can either boost the impact of global warming or calm it periodically (Abeysirigunawardena, 2010; Peltier, 2000).

The contribution of the building section to GHG emissions

Currently, buildings are estimated to be responsible for over 40% of the overall energy used globally, counting for an aggregated of 30% of global greenhouse gas emissions. These figures have grown over the past decades and are expected to continue rising in the future. The average growth rate has been recorded at rates of 2.5% and 1.7% per year for commercial and residential buildings respectively over a period of 30 years since the 1970s. These figures only concern CO_2 emissions and do not consider other greenhouse gas emissions resulting from the building and construction sectors (Office of the Prime Minister's Science Advisory Committee, 2013). Despite the huge contribution of the building sector to greenhouse gas emissions, it is one of the areas where huge adaptation can be made to reduce emissions. This opportunity is partly due to available and foreseeable technological advances in materials and construction methods. Based on the fourth edition of the IPCC report, the greatest advantage of the availability of new technologies is that they can be deployed to existing and new buildings. Also, the majority of countries can access these technologies irrespective of their economical profile – that is, whether or not they are developed, developing or in transition between the two. Therefore, there is huge potential for a faster transition to low-carbon buildings, with a potential of energy consumption depreciation of 30% to 80% (UNEP, 2009).

Adaptation to climate change

It has been established that urban regions are contributing to the process of climate change, while at the same time, climate change impacts urban regions (Keirstead, Jennings, & Sivakumar, 2012; Stone, 2005; Watkins, Palmer, & Kolokotroni, 2007). Urban regions influence climate change, firstly, through adding greenhouse emissions to the already existing global stock of suspended particles in the atmosphere (Chingcuanco & Miller, 2012; Keirstead, Jennings, & Sivakumar, 2012; Kennedy et al., 2009; Solecki et al., 2015; Tirumalachetty, Kockelman, & Nichols, 2013). The second contributing factor to climate change by urban regions is the morphological nature of urban areas, which is significantly different from pre-development conditions. These contributing factors influence the well-being of communities and the ecological systems within which these communities function by forcing changes to their local and regional climates. As a result, urban regions, communities, and ecological systems within them become 'vulnerable' to climate change impacts. 'Vulnerability' can be defined here as deficiency in coping measures with the impacts of climate change. An increase or decrease in rainfall, drought, daily temperatures, as well as rising sea levels are among these impacts (Abunnasr, 2013). Therefore, according to the IPCC report 2014, the response to climate change threat should focus on two main objectives. The first should address the high levels of greenhouse gas emissions. This goal requires a united global action that seems to be very difficult to achieve. The other response should be adaptation programmes to mitigate the adverse effects of climate change, especially in the most vulnerable locations (Solecki et al., 2015; Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, 2013).

Low carbon urban design

One way by which the impact of climate change can be managed is to transform cities towards what is known as 'Low-Carbon Resilience'. This will result in adopting urban design principles, which will help to transform existing cities towards becoming resilient in dealing with the impacts of climate change (Lehmann, 2016). This is part of the global movement of cities towards transitioning into low carbon urbanism (Moloney & Horne, 2013). These low-carbon development principles have already been adopted in some development plans under different names. Among the adopted names are energy efficient city, 'Transit Oriented Development' and 'sustainable building and lifestyles' (Wei, 2011).

Climate change in New Zealand & Auckland

Climate in New Zealand is affected by several mechanisms of the global climate system. The predominant one is the mid-latitude westerly circulation. It has the most impact on New Zealand climate change each year. The other influencing components are the El Nino-Southern Oscillation (ENSO) cycle and the Inter-decadal Pacific Oscillation (IPO) every few years (Renwick, Mladenov, Purdie, Mckerchar, & Jamieson, 2010). Auckland, as a coastal city, has been exposed to greater risk of climate change. The majority of such risks have been heat waves, droughts, or tropical storms over the years. Although some of the risks are a result of natural process, there is a consensus among scientists that the severity and likelihood of such events have been largely worsened because of greater greenhouse gas emissions. The majority of such emissions are attributed to human activities, primarily to the use of fossil fuels (Auckland Council, 2012a; Smith, 2015).

New Zealand Greenhouse Gas Emissions

Although New Zealand's gross greenhouse gas emissions have increased significantly during the past two decades, this only amounts to less than 1% globally. The majority of emissions are made in the northern hemisphere, within the major industrialised nations, such as the USA and developing countries such as China. Each has significant emission levels. While this trend suggests that any action from New Zealand will have less than significant impact globally, it does not suggest that more sustainable approaches to energy production and consumption should not take place (Office of the Prime Minister's Science Advisory Committee, 2013). Since the 1990s, the level of CO_2 emissions, as a key greenhouse gas, has increased by almost a third. This change is significant as the levels of CO_2 and methane emissions were almost the same during the 1990s. Changes in the road transport patterns, more cars, longer distance commuting, and traffic congestion have resulted in this remarkable change in the emission patterns. Emissions from road transport were measured as high as almost a fifth of total greenhouse gas emissions in New Zealand in 2011. Globally, the per capita road transport emissions in New Zealand exceed over 1.5 times the per capita amount in the Euro zone (Office of the Prime Minister's Science Advisory Committee, 2013).

The electricity sector's emission levels are almost a third of the road transport sector, being responsible for 7% of total greenhouse gas emissions in New Zealand. Although the road transport and electricity sectors amount to less than 30% of emissions nationally, following the agriculture sector with a greenhouse gas emission level of 47% they are accountable for a significant part of emissions in Auckland. Therefore, New Zealand has currently two different trends: one in its regions and one in Auckland, each requiring attention in order to mitigate the levels of greenhouse gas emissions (Office of the Prime Minister's Science Advisory Committee, 2013).

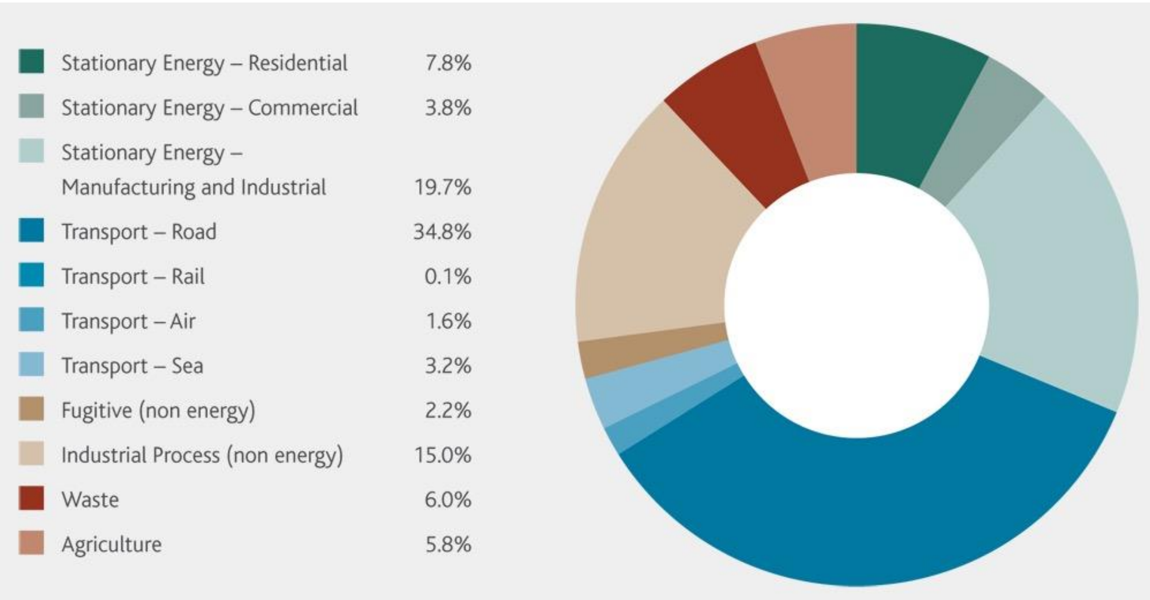


Figure 1: Auckland's emission profile (Auckland Council, 2012)

As a signatory to the Kyoto Protocol, New Zealand has committed to long-term aspirational greenhouse gas emission reduction over the next three decades. The goals, as reflected in the Auckland Plan, are to reduce the net emissions by a maximum of 50% of the 1990 levels by 2050. There are interim benchmarks that require a reduction of 10-20% of greenhouse emissions by 2020 and 40% by 2040 (Auckland Council, 2012a).

Compliance with required changes in order to achieve these ambitious targets will be challenging. Overall trends still demonstrate increase in the level of emissions despite Auckland having a different profile from the rest of the country. Agriculture has the most greenhouse gas emissions in regional New Zealand while Auckland demonstrates a very different pattern. Energy consumption is the leading factor in greenhouse gas emissions in Auckland due to transportation and electricity generation sectors. This difference can be mitigated by the fact that Auckland is experiencing dramatic population and economic growth (Auckland Council, 2012a). In fact, the dilemma that Auckland faces is how to maintain current levels of growth and prosperity while mitigating their environmental impact, especially in regards to greenhouse gas emissions (Auckland Council, 2012a).

The challenge mentioned above is twofold. First, the population and the development associated to it will continue to grow in the next three decades. Secondly, the majority of energy consumption, within either electricity or transportation sectors, will likely continue to be fossil-based fuels. Therefore, unless a major shift happens in the course of energy consumption in Auckland, the level of emissions will grow at a higher rate than the rest of New Zealand. This will result in much higher greenhouse gas emissions in the next decade. In order to successfully transition Auckland into a low carbon future, other progressive mechanisms are required (Auckland Council, 2012a). Without having progressive mechanisms that transition Auckland into a lower carbon city, the vulnerability of Auckland to the adverse impacts of climate change will be high (Auckland Council, 2012b). Some of the impacts that will threaten Auckland will be increased rainfall, increased drought conditions, and a sea level rise of 180-590mm, with a possible extreme of 1500mm by the end of the century (Auckland Council, 2012b; Renwick et al., 2010).

Sea level rise in New Zealand

Despite some regional variations in sea levels in New Zealand, the overall sea level rise has been generally consistent with the global trend, rising at a rate of 170mm per year since 1900 (Office of the Prime Minister's Science Advisory Committee, 2013).

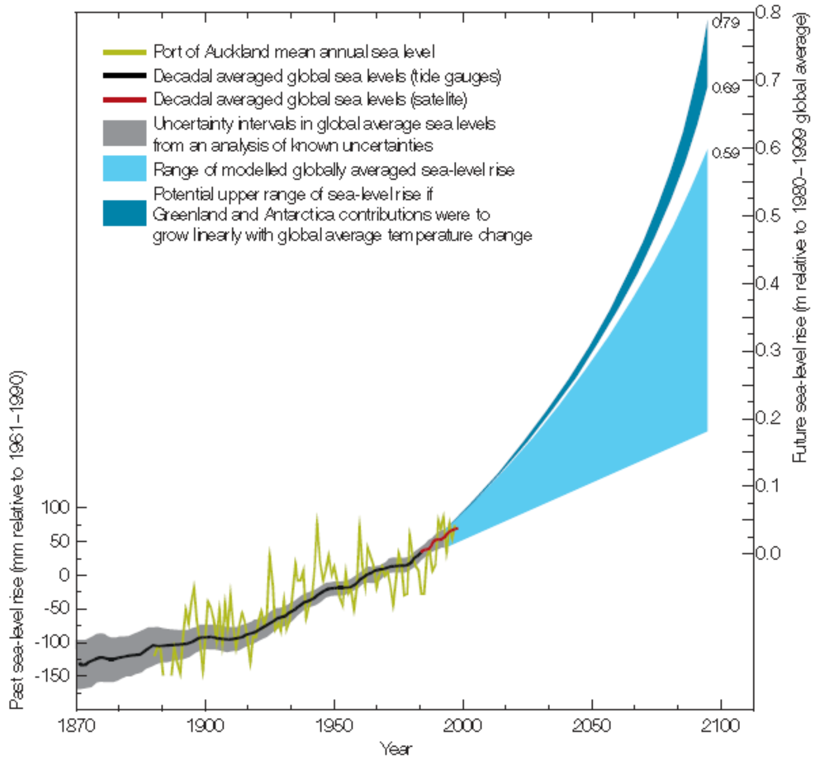


Figure 2: Sea level rise trend in New Zealand (Ministry for the Environment, 2008)

The New Zealand Ministry for the Environment recommends for consideration a 500mm sea level rise relative to 1990s levels for planning and decision making purposes in a timeframe extending to the 2090s. It also recommends for consideration the impact of a greater change of 800mm on local infrastructure and storm surge in impact assessments. The guidelines also recommend for consideration a continued 10mm sea level rise for any time-frame beyond 2100. These guidelines are primarily produced to be used as a tool for local risk assessment rather than predictions of the actual future sea level rise (Office of the Prime Minister's Science Advisory Committee, 2013).

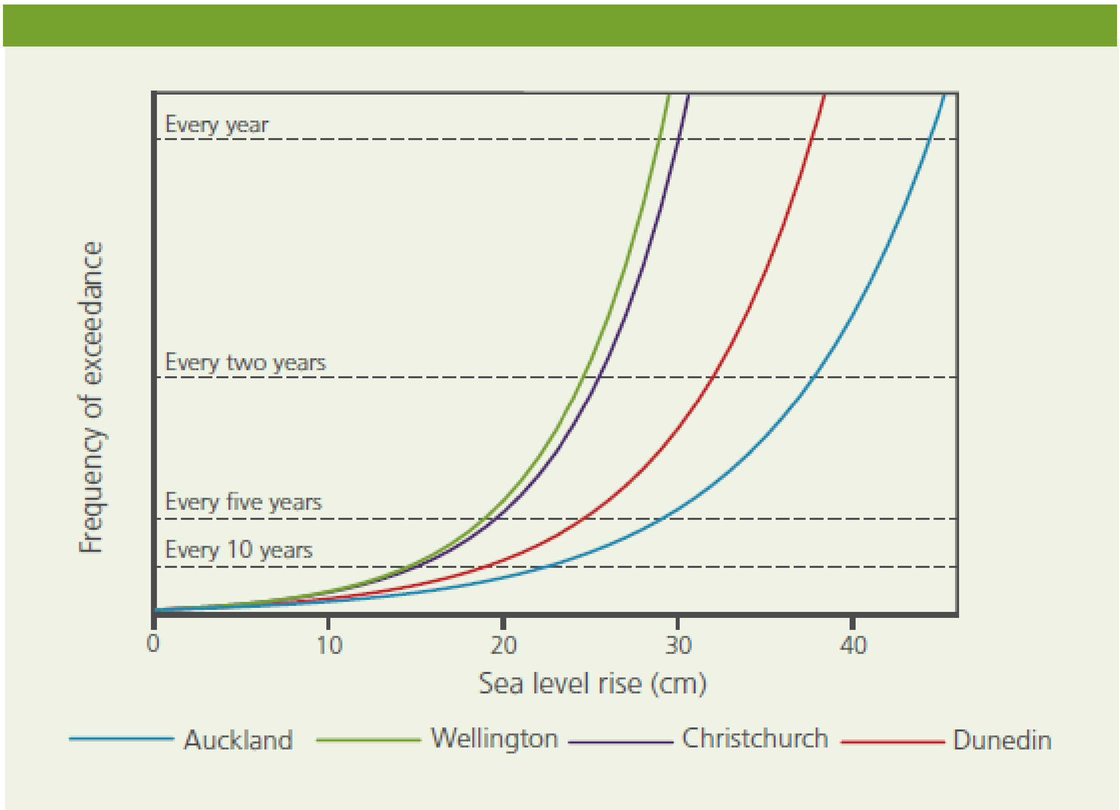


Figure 3: '100 year event' frequency forecast at different ports in New Zealand (Parliamentary Commissioner for the Environment, 2015)

Figure 3 suggests that the frequency of '100 year events' will increase across New Zealand. The frequency of such events will increase more rapidly once they reached a certain frequency threshold over time (Parliamentary Commissioner for the Environment, 2015). New Zealand has a relatively high concentration of population and infrastructure within coastal areas. Continuous development over the past few years has further increased vulnerability against the impact of coastal natural hazards (Office of the Prime Minister's Science Advisory Committee, 2013). The overall increase of mean sea level rise, coupled with increases in wind intensities, is expected to result in more frequent natural hazards such as flooding and harsh storms. Moreover, sub-tropical cyclones are also expected to track south more frequently due to circulation changes in climate systems globally (Office of the Prime Minister's Science Advisory Committee, 2013). The level of vulnerability is better understood when considering that the current structures that are engineered to reduce or prevent coastal hazards have typically not considered the future impact of climate change and its different patterns and the severity of hazards (Office of the Prime Minister's Science Advisory Committee, 2013).

Auckland

Compared with other coastal towns and cities in New Zealand, a relatively small proportion of Auckland is low-lying. However, the Auckland region is threatened by coastal hazards, such as tsunami, storm erosion, and storm-tide inundation (Stephens et al., 2013). The table below shows the number of low-lying homes, businesses, and roads in three different ranges of below 50cm, between 50 and 100cm, and between 100 and 150cm.

	0–50 cm	50–100 cm	100–150 cm	Total (0–150 cm)
Homes	108	457	795	1,360
Businesses	4	13	43	60
Roads (km)	9	18	29	56

Figure 4: Low-lying homes, businesses, and roads in Auckland (Parliamentary Commissioner for the Environment, 2015)

Figure 5: Low-lying coastal land in Auckland (Parliamentary Commissioner for the Environment, 2015)

The Proposed Auckland Unitary Plan has projected different scenarios which show the vulnerability of different parts of Auckland to potential sea level rise. For example, the maps below show which areas within the Auckland Isthmus will be submerged in cases of 10m, 25m, and 80m sea level rise. Although the last two maps consider very extreme scenarios, they highlight the vulnerability of the Auckland CBD, with the highest rate of employment and investment in the Auckland region if not nationally.

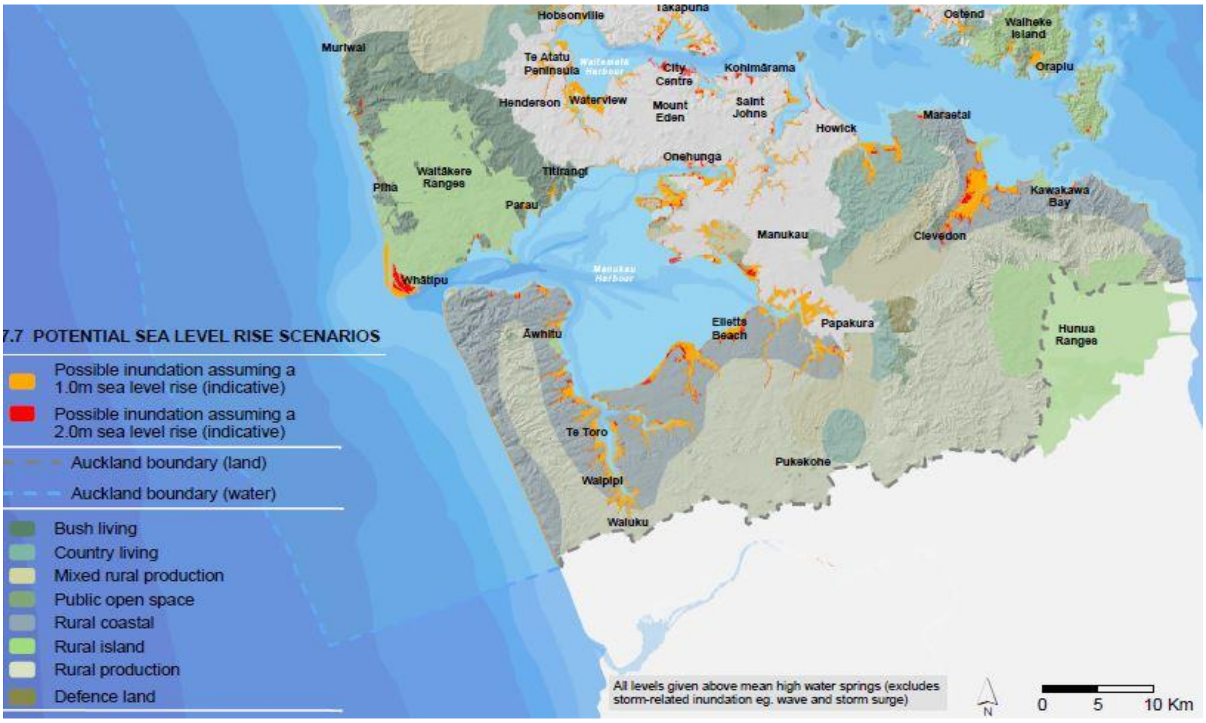


Figure 6: Potential sea level rise scenarios (The Auckland Plan 2012)

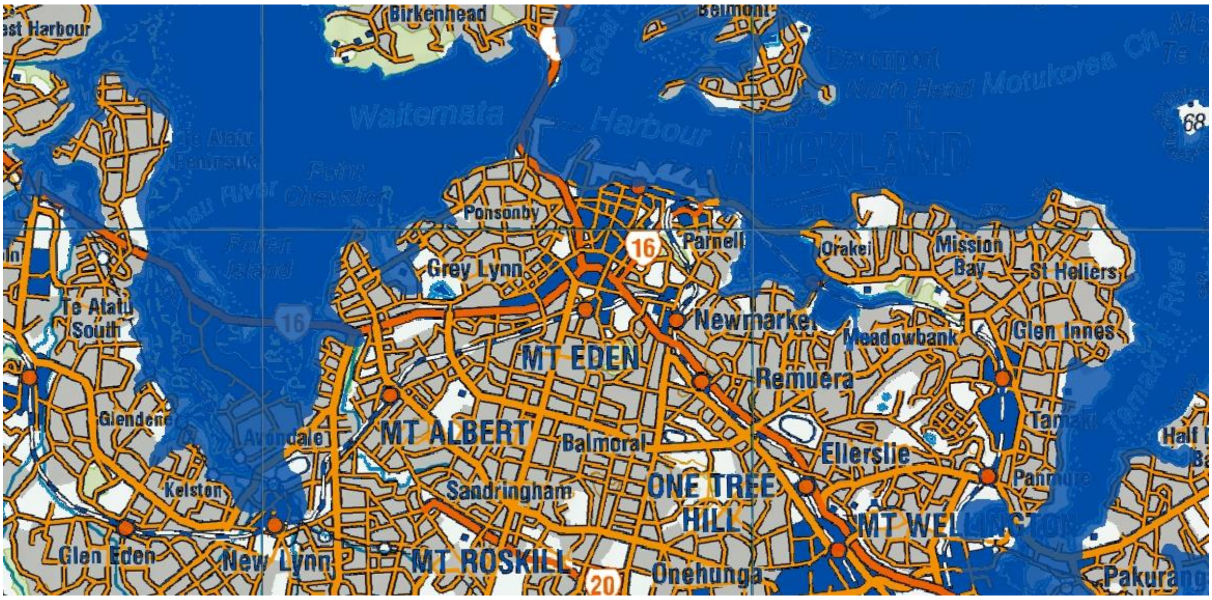


Figure 7: The projection of 10m sea level rise (Musther, n.d.)

Figure 8: The projection of 25m sea level rise (Musther, n.d.)

Figure 9: The projection of 80m sea level rise (Musther, n.d.)

Sea level rise already impacts Auckland. In the last few years the number of flooding incidents across Auckland has increased (Office of the Prime Minister’s Science Advisory Committee, 2013). The photographs below show some of these incidents, where current infrastructure has been impacted.

Figure 10: Impacts of high tide in recent years in Auckland –a boardwalk is flooded in Howick in February 2015, Auckland (Parliamentary Commissioner for the Environment, 2015)

Figure 11: Serious impacts of Storms in recent years in Auckland –Tamaki Drive is seriously impacted by incidents of high tide or storms in Auckland (NBR, 2014)

Figure 12: Tamaki Drive flooded, September 2015 (Auckland Council, 2015)

Low carbon Auckland

The Auckland Plan has set an aspirational goal of reducing the GHG emissions progressively by 40% by 2040 (Auckland Council, 2014). To achieve such a target, an estimated 5.3 tonnes of GHG emission needs to be reduced. This requires major shifts in the current forms of energy sources (fossil fuel), and energy performance. Auckland Council has adopted a 30-year low-carbon strategy as well as a 10-year action plan to transform Auckland into a low carbon city (Auckland Council, 2014).

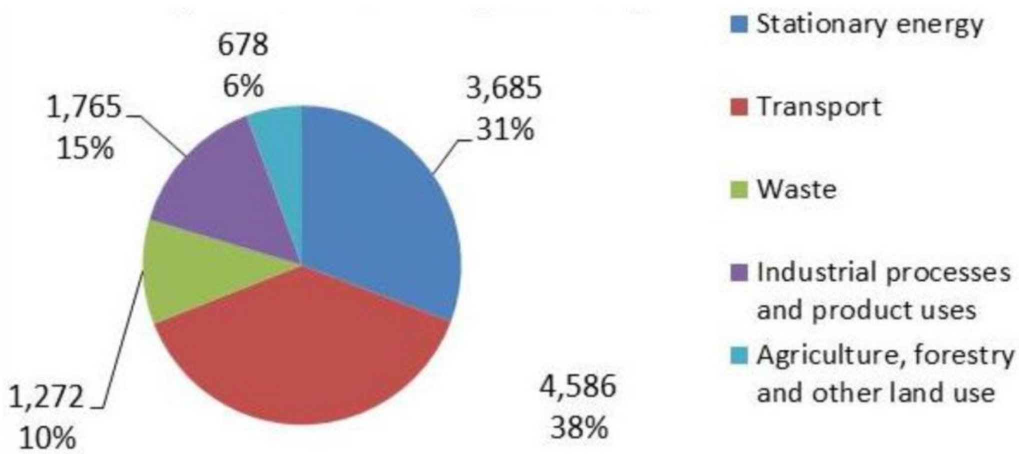


Figure 13: Auckland's GHG emission profile in 2013 (Auckland Council, 2014)

Energy and carbon efficiency of urban form

As research has shown, urban form can play a significant role in developing regulations for the energy performance of buildings. Taking into consideration the parameters of urban form in the early stages of design development enables planning for minimizing the energy demands of buildings. Examples of urban parameters include building shape, density, and green ratio (Shang & Hou, 2013). The concept of low carbon urban design suggests that the patterns of energy use and carbon performance can be altered through forcing changes in urban design. This is done by changing urban forms and building typologies to meet lower carbon emission standards. Low carbon urban design measures energy performance and carbon efficiency and analyses how they can be optimised in different urban precincts, such as street blocks, neighbourhoods, and urban districts. In accounting for energy performance, for planners and urban designers 'building energy' use is of particular importance. This is because building energy use has a predominant share in the total energy use of cities (Chingcuanco & Miller, 2012; Steemers, 2003)**.**

Previous research has identified the impact of building form on energy performance (Ko, 2012; Ratti, Baker, & Steemers, 2005; Steemers, 2003). It has also highlighted that energy performance, including both energy consumption and energy production, is affected by urban design parameters. Such parameters include density, building typology, layout, and the like. These parameters usually affect building form, which plays a critical role in determining the energy performance of a building. Therefore, many researchers (Ali, 2012; Depecker, Menezo, Virgone, & Lepers, 2001; Hemsath & Bandhosseini, 2015; Li, Quan, & Yang, 2015; Ourghi, Al-Anzi, & Krarti, 2007; Parasonis, Keizikas, & Kalibatiene, 2012) have focused on determining the most energy efficient form of a building. Another approach adopted by researchers such as Martin and March (1972) and Ratti et al. (2005) has shifted the focus from individual building form to building typologies. This is because building forms tend not to be unique and usually can be categorised into several typologies. Martin and March have introduced a particular approach that reduces building form to three main typologies: pavilion, street and court, and hybrids. This methodology has been widely used by other researchers. Despite using a similar methodology, results were not necessarily consistent across this research.

In research by Cheng, Steemers, Montavon, and Compagnon (2006), the relationship between solar accessibility and building form as well as density was investigated. In order to do so, the main criteria for the modelling was based on solar accessibility, considering sky view at ground level, building facade exposure to daylight, and building envelope potential for solar energy harvesting. Despite the fact that methods for energy performance have been documented, there is still a lack in the development of methods for scaling building energy performance. There have been, however, a few methods proposed to measure building energy use. These methods have encouraged the use of bottom-up approaches, scaling up from a building system to the block, and from the block to the neighbourhood. All of these methods categorise buildings into different groups. Buildings with similar characteristics have similar features. Some of these features are floor area, window to wall ratio, building age, household type, dwelling type, building functional type, and climate zone. (Jones, Lannon, & Williams, 2001a; Shimoda, Fujii, Morikawa, & Mizuno, 2004; Yamaguchi, Shimoda, & Mizuno, 2007).

In order to measure total energy consumption, energy consumption of a representative building in a category is calculated. By aggregating the buildings in one category, the total energy consumption of that category is measured. By aggregating the results of all categories, overall total energy consumption is measured. These methods use different approaches in order to relate building characteristics to energy consumption. For example, some methods use detailed input information such as microclimate weather information, thermal properties of building envelopes, and occupant behaviour. Others are based on artificial calculation procedures that have been validated by numerous cases (Jones, Lannon, & Williams, 2001b; Shimoda et al., 2004). In the following section, the research design for this project is discussed in detail and the methods used are explained.

Part Two – Research Methodology

This section of the research discusses the research methodology adopted to study the impact of urban form on energy efficiency in a waterfront location in Auckland's CBD. This location is considered prone to climate change and its consequences such as sea level rise. This section includes the research design, study area, the methods used for data gathering, and software used for data analysis.

Research approach

This research is both qualitative and quantitative in approach – a mixed-methods engagement. The mixture of qualitative and quantitative methods in a single study can provide opportunities to engage with the research question better and improve the confidence of the results (Bulsara, 2015; Creswell, 2003). A mixed-method research integrates different types of data, and requires a phased data collection and analysis, which improves the verification process of the results (Tashakkori, A. & Teddlie, 2003).

This research mainly adopts a qualitative approach in its data collection that includes accessing secondary data. Case study is chosen as the approach in the research design. The research investigates the case study using quantitative methods. These methods include the modelling of two scenarios to achieve quantitative data that will allow the scenarios to be compared against each other. In other words, the research requires data that can be used to understand which of the urban design frameworks can provide a more energy efficient development.

The main sources for secondary data in this research are official local and international data including governmental and non-governmental reports, plans, and statistics related to climate change, sustainable development, sea level-rise, and building energy efficiency. This data, according to Lee (2009), can be considered as qualitative information.

Though the research is qualitative, working with a case-study building development, the research engages with quantitative analysis of data pertaining to building performance, materials performance, and environment performance. Hence, the research works between analyses of hard and quantifiable data as well as interpretative data relating to analyses of the impact of design measures to minimise energy consumption in buildings. Though aspects of the research are thus positivist in method, the predominant aim of the research concerns interpretation and possible generalisations from the case study that are not themselves positivist.

Research method

Qualitative research can adopt case studies as its method, which for this research is manifested in a relatively small geographical area, Wynyard Quarter on Auckland's waterfront. Case-study research is widely recognised as a qualitative method while it is sometimes argued otherwise (Zucker, 2009). This could be because this method was initially less considered as a scientific method. This view has changed significantly over the years and a surge in the use of case-study research has been emerging in some fields, such as law, business, planning, and design disciplines (Baxter & Jack, 2008; Francis, 2001; Johansson, 2003). A case study is an in-depth study of a particular situation rather than a sweeping statistical survey. It is a method used to narrow down a very broad field of research into one easily researchable topic (Shuttleworth, 2008). This can require research to have single or multiple case studies. The aim of this research is not to compare two or more different settings. It is, rather, to focus on one location and carry out the proposed investigation in detail. This defines the research as a single case-study approach. According to Franklin and Blyton (2011) and Baxter and Jack (2008), in most disciplines where the case-study method is selected, the ultimate aim of the research is to answer 'how' or 'why' questions. In spite of this, the main question of this research is, "What urban design parameters will achieve the most energy-efficient urban form for Wynyard Quarter?" This question is immediately followed by another question that asks how such urban design parameters can be implemented.

According to Johansson (2003), a case study should have a case that has a number of qualities. These qualities include complexity, investigation in natural settings, and contemporariness (Zainal, 2007). The selection of a case in case-study research can be largely based on the accessibility of information about it as well as the richness of information (Davis, 2016). Therefore, a case should, according to Stake (1995), (Patton, 1990, 2002) be information-rich, critical, or unique, as opposed to being selected within a representational sample strategy used in correlational research (Johansson, 2003). Wynyard Quarter has all these qualities, as it is a contemporary area for significant development that has sustainability plans, it is located on the Auckland waterfront and CBD, and it is vulnerable to the adverse impact of climate change and sea level rise. One particular aspect of case-study research is 'interest' in the case because of any or all of the attributes mentioned above. This aspect of research is often seen as more important than the methods used for the case study itself (Johansson, 2003). This is important to consider because the nature of the interest, and case itself, can justify one tool over the other in the course of research. The main objective of this research is to investigate the impacts of urban form on building energy efficiency in Wynyard Quarter. This has enabled the researcher to look for and identify what tools, modelling, and analysis software are appropriate for this research.

From a landscape perspective, Francis (1999) categorised case studies to be useful in describing or evaluating a project or process while being capable of explaining or predicting phenomena that would enhance the relationship between theory and practice. He argues that similar to some disciplines, such as business, medicine, or law, case-study research is well established and used widely for different purposes, including education (Francis, 1999). Furthermore case-study research has been a key component to research in urban planning, urban design, and architecture in a variety of social or policy-oriented arenas. Case-study research has some limitations, resulting in criticism of this method. One of the major critics of the case study approach has been researchers in the field of science, who have a positivist approach in research. This criticism became more apparent after the Second World War when a positivist approach in research became popular. This criticism was later opposed by researchers in the field of the humanities, questioning why social sciences should heavily rely on methods in the natural sciences (Blatter, 2008; Johansson, 2003).

Apart from the above historical evolution, case-study research has a limitation in its potential for generalisation. Some solutions have been suggested to minimise this drawback, such as triangulation (Francis, 1999; Zucker, 2009). However, one response to such criticism is that case-study research aims to investigate one case in-depth, which means it is not seeking for generalisation by default. In this research, the case is a spatial configuration within a physical environment. However, the same principles of case study apply to it. Wynyard Quarter was chosen as the case study of this research because it has qualities such as:

- The location
- The redevelopment of the area
- The sustainability framework of the area
- The political support to achieve its strategic sustainability goals

Case study: Wynyard Central

Wynyard Quarter is located on Auckland’s waterfront and extends between Viaduct Harbour and Westhaven Marina. This area was reclaimed by the Ports of Auckland, Auckland Harbour Board, in the 1930s (Auckland Regional Council, 2007). This development increased berthage capacity and accommodated port-related activities, mainly petro-chemical and fuel storage. Wynyard Quarter is also known as Tank Farm, Wynyard Point, or Western Reclamation.

Figure 14: Auckland's waterfront from the air, 1920s (Timespanner, 2013)

Wynyard Quarter shares the cultural heritage of the Auckland waterfront. Maori were the first to encounter the Auckland waterfront and recognise its value. Tamaki Makarau, which is Auckland's name in Te Reo (Maori language) – meaning 'the bridge sought by a hundred suitors' – speaks to its cultural value and importance. The Auckland waterfront accommodated many villages and Waitemata Harbour has been a great resource to Maori, explaining the importance of the waterfront to iwi (Maori tribes). This importance is reflected in places like Karanga (welcome) Plaza, which is an important public place, as an access point to Wynyard Quarter. Wynyard Quarter redevelopment embraces the cultural concept of Kaitiakitanga, which preserves the heritage and character of the place during the revitalisation of Wynyard Quarter.

Figure 15: Auckland's waterfront 1940 (Panuku Development Auckland, 2015a)

Figure 16: Auckland's waterfront 1990-2000 (Panuku Development Auckland, 2015b)

Figure 17: Auckland's waterfront 2000-2010 (Panuku Development Auckland, 2015b)

Overall development of the port's operations over the years, especially the supply of fuel, has reduced the operational needs of the land in Wynyard Quarter, creating opportunities for its revitalisation. The redevelopment of Wynyard Quarter started in 2005 with a long-term vision of 25 years to make it an accessible space to the public. The first stage of the development that included new public parks, plaza, and pedestrian bridge was opened to the public in 2011 (Panuku Development Auckland, n.d.). Wynyard Quarter consists of several sub-precincts. Wynyard Central is one of them, which is chosen as the case study for the research project. The development of Wynyard Central aims to demonstrate quality urban living and exemplary sustainable development. It is expected to deliver high quality, high density, mixed use development and public space that incorporate cultural values and community infrastructure to enable a vibrant new neighbourhood.

Methods and software

This section discusses the use, capacity, and benefits of software packages available to the researcher for data collection and analysis. This research required modelling for three main reasons:

- Spatial modelling of the study area
- Solar radiation modelling and analysis
- Energy demand modelling of the study area

This modelling had to follow the order mentioned above. In each of these three steps, particular software is required. The selection of the most appropriate software required the researcher to consider the following criteria:

- The most suitable software that, according to the literature, delivers the most accurate outcome
- The availability of software to the researcher. This means that software should be open access, requiring no purchase license, being available to students free of charge.
- The familiarity of the researcher with the software environments and their user-friendly nature

Table 1: 3D Modelling Software

Software	Suitability	Availability	Familiarity
CityEngine	Parametric 3D modelling – suitable for modelling at the urban scale	Yes – through Auckland Council	No. The researcher was familiar with the GIS environment, but not CityEngine. It was expected that the researcher would learn the software as research progressed.
Sketch-up	Yes, for non-parametric 3D modelling	Yes – through Auckland Council and AUT	Yes

The parametric modelling in CityEngine allowed for quantitative data, such as Floor Area Ratio (FAR), Gross Floor Area (GFR), parcel area, and building height. This information was useful in the next stages of research, where energy demands of a building needed to be modelled.

Auckland Council had a digital model of the waterfront dating from 2011, used as a baseline in this research. This model was based on an older version of the Wynyard Quarter Urban Design Framework. In 2014, a newer version of the Urban Design Framework was undertaken as a feasibility study, in which the form and building heights of some blocks in Wynyard Quarter were altered. This required the researcher to update the available model in order to achieve the most accurate data concerning urban form. This data was used in the following stages of the modelling process.

CityEngine

CityEngine is a 3D modelling software package, from Esri, that was first developed during the PhD studies of Pascal Mueller, at ETH Zurich (Singh, Jain, & Mandla, 2014). CityEngine has considerable flexibility and computational power, with the programme able to work with extremely large datasets and vast amounts of geometry (in the order of 10 to 20 million polygons). Fully integrated with Arc GIS, CityEngine contributes a rule-based tool (parametric) allowing for fast development of 3D models, which can test zoning in 3D, model parameters such as heat, shadows and views, and develop rule-based reports (Walliss & Rahmann, 2016). In this software, different rules and scenarios are defined for everything from the shape of the block to cycleway widths. Besides being a quick way of generating an entire community, the models generated can contain analytical information such as zoning and square footage (Pierre, 2015). Some of its main features include rule-based and parametric modelling of 3D buildings and streets, dynamic city layouts, map-controlled city modelling, generic reporting, facade wizard, interactive editing, and city model updating (Singh et al., 2014).

Auckland Council supported and granted the researcher access to its software resource, CityEngine, as well as available maps and 3D models. This was essential for the research. However, it required the researcher to update the modelling according to the updated plans and frameworks. As parametric modelling software, it uses 'rules' to construct the model. This process is highly efficient as it can render larger scale development, even at the scale of a city. To be able to use such functions properly, it is important that the user is familiar with the software, and its programming language. Utilisation of the software was not easy for the researcher, as several technical issues emerged, each taking a significant time to be completely or partially resolved. One of the situations is explained below.

For modelling, the researcher used Auckland Council's CityEngine mapping software for the waterfront area. CityEngine has the ability to provide reports for building blocks, and is able to update the footprint of the model or add new blocks. Using this software required the researcher to become completely familiar with the programming language and the structure used for Wynyard Quarter. In order to resolve this issue, several informants were consulted in order to find a resolution. The key difficulty in engaging with the Council model was that a new object ID could not be defined for the new forms that were required to be added to the model. In the end, the issue was resolved by actually drawing a new footprint for the block that followed the rules applied to building footprints. As a result the CityEngine software became a powerful tool with which to investigate energy effects resultant from design choices.

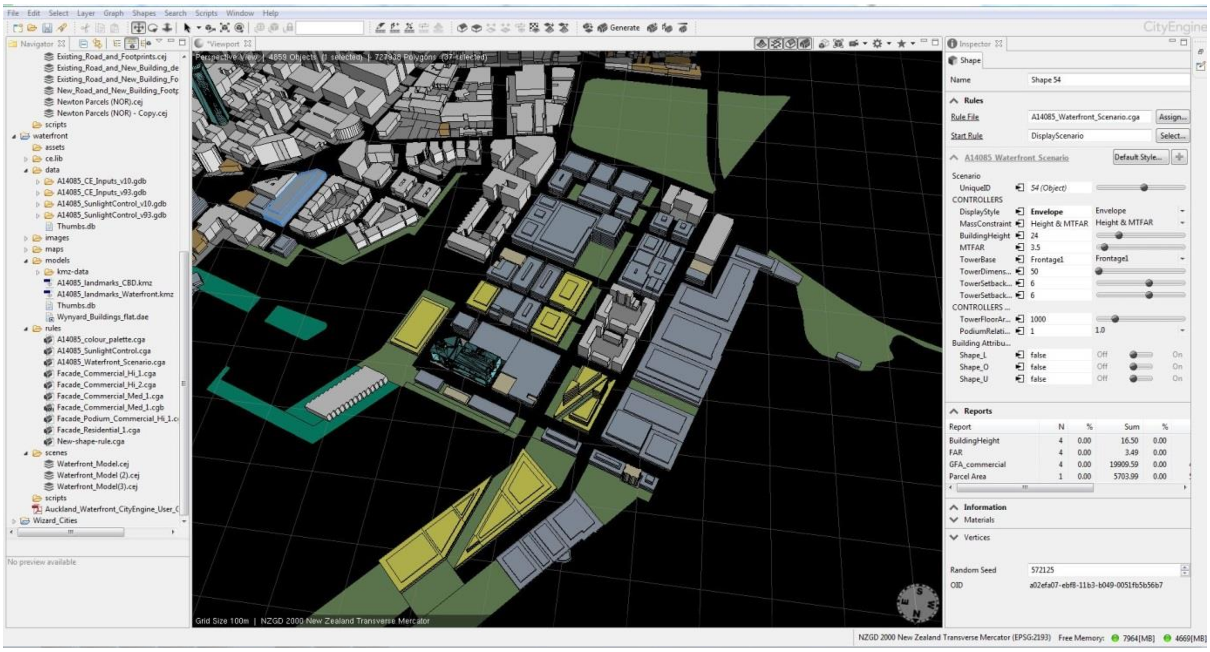


Figure 18: Modelling in CityEngine

Energy simulation tools

Energy simulation tools are increasingly used for analysis of energy performance of buildings and the thermal comfort of their occupants. Today, there are many building performance simulation programmes with different user interfaces and different simulation engines that are capable of these analyses (Rallapalli, 2010). With the increasing interest in energy efficient building design, whole-building energy simulation programmes are increasingly employed in the design process to help architects and engineers determine which design alternatives save energy and are cost effective (Rallapalli, 2010).

eQUEST

eQUEST is a building energy simulation tool from James J. Hirsch and Associates that is based on the older and more widely known energy analysis programme, DOE-2, from the Lawrence Berkeley National Laboratory (Wood, 2011). The Quick Energy Simulation Tool, or eQUEST, allows users with limited simulation experience to develop 3D simulation models of a particular building design. These simulations incorporate building location, orientation, wall/roof construction, window properties, as well as HVAC systems, day-lighting, and various control strategies, along with the ability to evaluate design options for any single or combination of energy conservation measures (“The Quick Energy Simulation Tool (eQUEST)”, n.d.). One of eQUEST’s particularly useful extensions to DOE-2’s capabilities is the implementation of dynamic, intelligent defaults. Every input specification has an industry standard default value that is dynamically determined, based on the user’s previous entries. Where a user simply has no knowledge of them, eQUEST’s intelligent default system boosts usability by making the simulation setup faster and independent of level of expertise (Ziai, 2006). For this research, the schematic wizard design was used, which has 41 step wizards. In each step various information inputs are required. This information includes general information about location, building area, number of floors, and building footprint, as well as building envelope and interior construction. Once all the information for all steps is provided, the software generates a model with a summary of energy demands of the building in a year. This model is based on the building form defined during the wizard information input (step 2).

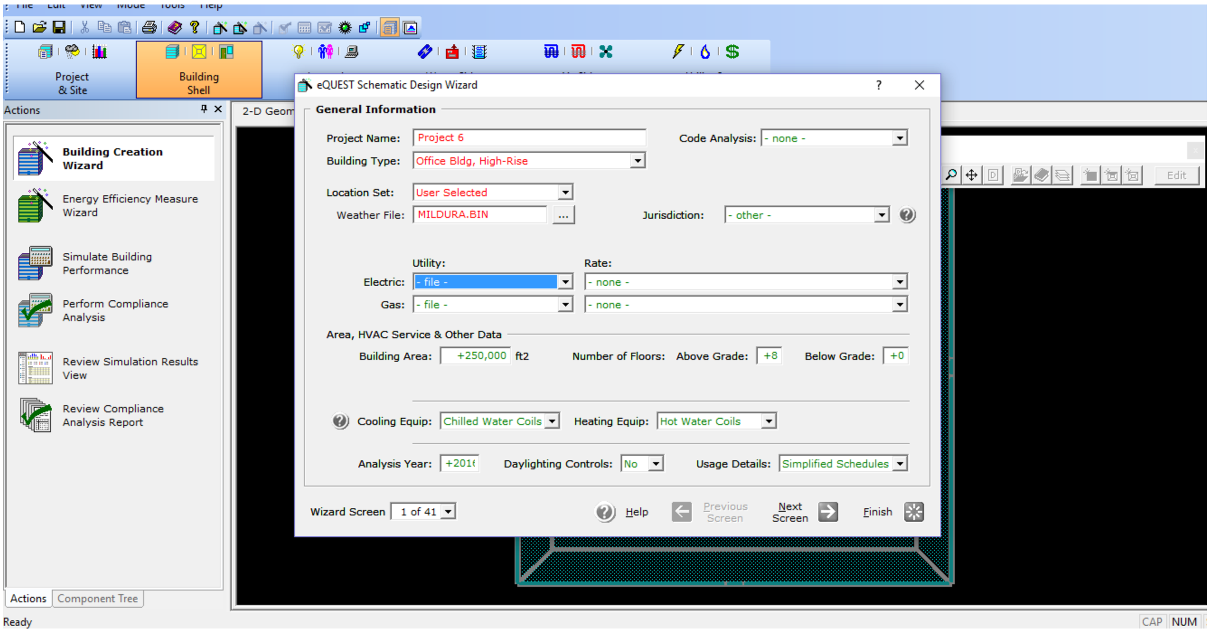


Figure 19: Schematic wizard design in eQuest

Revit

Revit is a building modelling software package, developed by Autodesk. Building Information Modelling software includes architectural, structural, mechanical, electrical, and plumbing (MEP) features. Modelling with Revit allows the designer to have a holistic design where features of design have attributes that are linked together. In its recent versions, Revit has incorporated the analytical functions of Ecotect that enables the software to carry out energy-related modelling, such as solar radiation analysis. These features are part of a tool called Insight360. Solar radiation analysis visualises and quantifies the distributions of solar radiation on many surfaces. The modelling is based on a building's location, orientation, and form. Ecotect was initially chosen as the tool for solar radiation analysis, which is the first step towards the calculation of potential energy production of a building. It was later identified that Ecotect software was discontinued by Autodesk and previous versions were inaccessible to the researcher. The main functions of Ecotect, including its Solar Radiation Analysis, were then introduced as a new feature in the Revit software. Therefore, Revit was used for the purpose of solar radiation analysis.

In order to run the analysis, the 3D model of the urban form needed n to be imported from CityEngine to Revit. This required an additional process in which incompatible file formats needed to be converted into the format compatible with Revit. If this process succeeded and the model form remained compatible within the Revit environment, then the next steps – allocation of local weather files and running the solar radiation analysis – could be processed.

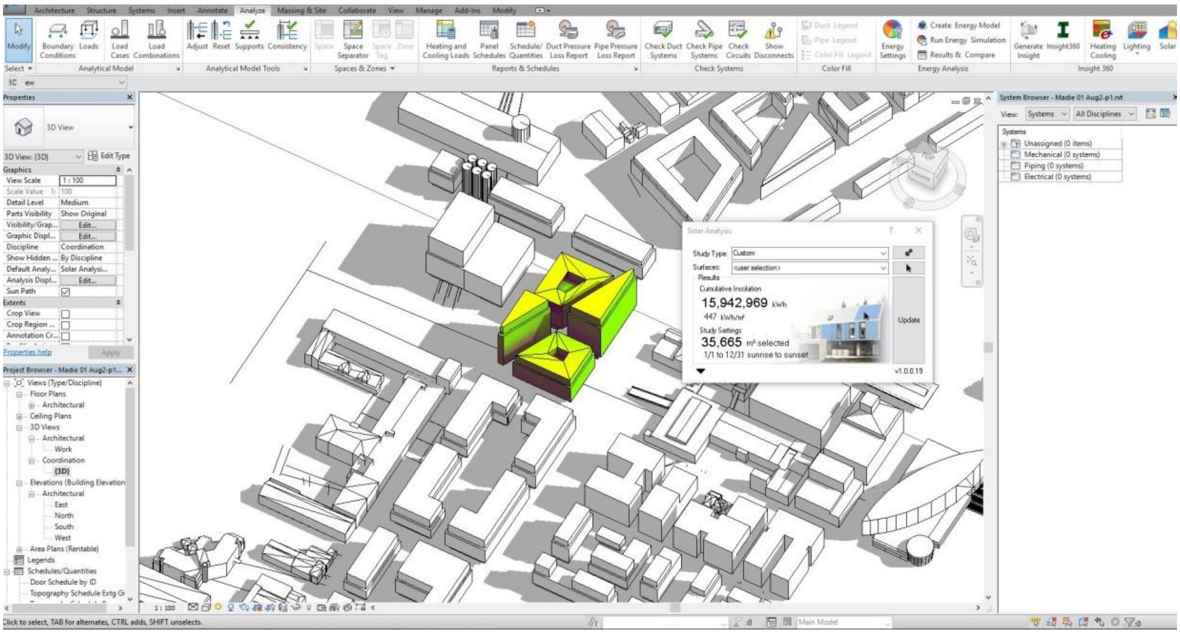


Figure 20: Solar analysis in Revit

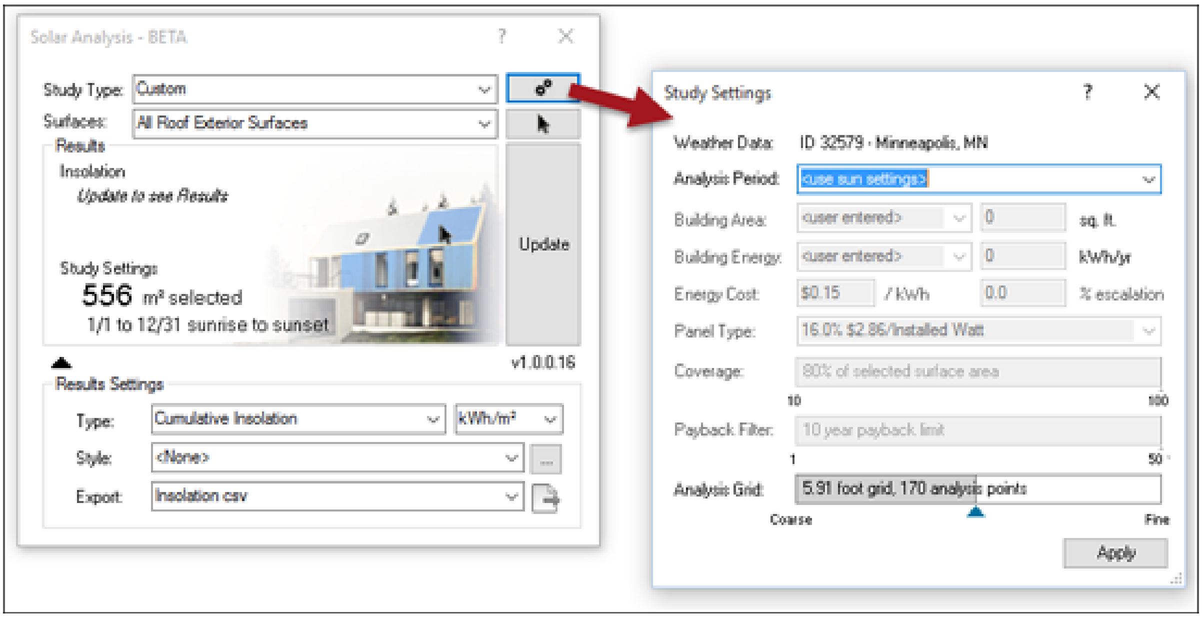


Figure 21: Solar analysis in Revit

Table 2: Summary of Software Opportunity and Challenges

Software	Outcome	Issues/ challenges
CityEngine	Create models to be used for: • Solar radiation analysis • Energy demand analysis. Therefore, the 3D modelling as well as the quantitative data are both essential. Model the urban form. Use the quantitative data of the built environment for energy demand modelling of the buildings.	Parametric modelling requires the knowledge and experience of coding in a Python environment. The difficulty in accessing the original coder of the model and the same-time learning of coding has been time-consuming and required a lot of trial and error. At the end, with changing some codes in the original model, it became possible to model the new footprint and buildings according to the latest Urban Design Framework feasibility study.
Sketch-up	Considering the difficulties in the CityEngine modelling process, sketch-up was used to do manual modelling changes that could have taken longer time in CityEngine. The 3D modelling was then used for the solar radiation analysis.	The challenges in this step were to replicate the same model that was created in CityEngine. This was required as the model created in CityEngine was not compatible with some solar radiation analysis software. This will be discussed further below.
ArchiCAD	This software has a solar tool that was expected to be useful for the solar radiation analysis.	However, trailing the software showed that it was not the most suitable and accurate tool for this research.
Ecotect	According to the literature, Ecotect was identified as the most suitable software for carrying out the solar radiation analysis. It was freely available prior to 2015 and a large amount of research had used it before.	It was identified that the software was discontinued since March 2015 as Autodesk had incorporated its functionality into another software, which was Revit 2016. Revit was not freely available, so ArchiCAD was initially explored to identify whether it was a suitable substitute. The reason for this decision was that ArchiCAD was available through Auckland Council and AUT. However, Revit 2017 was used as the software for solar radiation analysis as Autodesk granted access to the software through a student account.

Software	**Outcome**	**Issues/ challenges**
Revit	Solar radiation analysis was carried out in this software, using its new functions that had substituted Ecotect's.	In order to perform the solar radiation analysis, Revit required importing the 3D modelling. The 3D model created in CityEngine was not compatible with the software, which was contrary to other research that used both software. This resulted in re-creating the model in a sketch-up environment, so it could be imported into Revit easier. This process was not straightforward either, but it worked out in the end.
eQuest	This software is particularly used for energy demand calculation of a building. According to the literature, eQuest provides the most accurate estimation of the energy required for a building. The simulation engine within eQUEST is derived from the latest official version of DOE-2. DOE-2 has been widely reviewed and validated using the ASHRAE/BESTEST evaluation protocol.	This software was primarily developed for the U.S., which means that all the details required for the software needed to be converted into the appropriate units. This included weather systems, material specifications, and other details.

This concludes discussion on the design methodology and methods. The following chapter outlines in detail the analyses of the case study in the Wynyard Quarter, and presents the findings and more generalisable interpretations from those findings.

CHAPTER THREE

Findings / Analysis / Discussion

Introduction

This chapter presents and discusses the results produced by the development scenarios generated in CityEngine, based on the UDF 2007 and the UDF 2014, the energy demand models of buildings, and the solar analysis of buildings conducted in Autodesk Revit. The results for each of these models were then tied together to present the full energy performance for the UDF 2007 and the UDF 2014. First, the CityEngine models are presented along with the building reports, including their total GFA. Then the eQUEST model results for the given two building scenarios are presented. The results include a number of diagrams and charts demonstrating the total energy consumption, along with peak demands of energy with further details of energy consumption. Views are shown of the building models created, and the buildings' energy consumption data by end use is presented. Next, the solar analysis of the two scenarios is presented, which explains the capacities for on-site energy generation for each scenario. The models were produced in Autodesk Revit. Figures are also shown for this modelling. Once the overall energy performance of the two scenarios is presented, the contributing factors will be discussed. The discussion will explore urban design parameters, and their impact will be examined. The discussion will also examine the role of policies in the implementation of energy efficient urban forms.

Preparing the models

The modelling of different scenarios for the case study was carried out first in CityEngine, for 3D modelling purposes, and afterwards in eQuest for simulation of energy demands for each of the scenarios. In order to understand the potential of each scenario for energy production, solar radiation analysis for each scenario was carried out in Revit. The case study area is 7,705m^2 and was included in the Urban Design Frameworks of 2007 and 2014. The documents were published in their respective years, outlining possible scenarios for the development of city blocks in Wynyard Quarter.

In the UDF 2007, two types of height limit were proposed for the case study. The proposals were categorised in pairs for a total of four buildings on the site. The height limits were 31 metres and 52 metres.

Figure 22: Height and FAR limits according to the UDF 2007 (Waterfront Auckland, 2014)

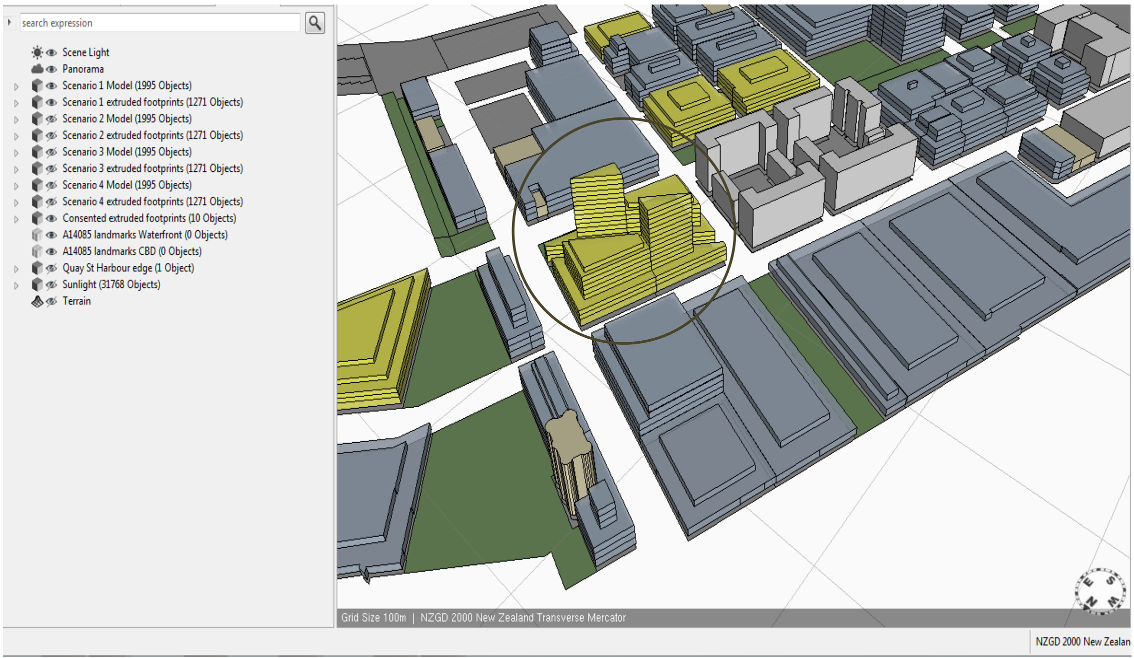


Figure 23: A CityEngine simulation based on the UDF 2007

Table 3: Block Report from CityEngine

Report	N	%	Sum	%	Avg/Mod.	Min/Mod.	Max/Mod.
FAR	32	0	31.38752	0	7.846881	5.999992	9.693973
Parcel Area	4	0	5168.292	0	1292.073	731.9443	1862.062
Building Height	32	0	96.00005	0	24.00001	18.00001	30.00002
GFA Residential	32	0	36440.66	0	9110.164	7095.146	11172.36

The UDF 2014 provides some flexibility in terms of the development controls (height and GFA) in order to achieve the best outcome for the site. This report suggests a 39 metre height instead of 31 metres (contrary to the UDF 2007 suggestion) and a courtyard shape for the block typology.

Figure 24: The plan and height limit based on the UDF 2014 (Waterfront Auckland, 2014)

Figure 25: A CityEngine simulation based on the UDF 2014

Table 4: Block Report from CityEngine

Report	N	%	Sum	%	Avg/Mod.	Min/Mod.	Max/Mod.
Building Height	41	0	123.0002	0	24.60004	21.00001	30.00002
GFA_Residential	41	0	40202.4	0	8040.48	6555.108	10282.25
FAR	41	0	37.65303	0	7.530607	6.088216	9.687605
Parcel Area	5	0	5379.5	0	1075.9	1004.458	1128.927

Modelling the energy performance of buildings in eQuest

This section describes the design parameters used in the eQuest software to model the energy simulation of the different scenarios for the case study. The details include envelope construction, interior construction, lighting, and HVAC design.

Envelope

The envelope elements include roof surfaces, wall construction, ground floor details, and below-grade walls.

Roof surfaces details

Roof surfaces details include material of construction, exterior finish and colour, exterior insulation, and additional insulation.

Wall construction

The different layers inside to outside, their thickness and materials and insulation are the most important questions in wall construction detailing.

Ground floor details

The materials and properties of different layers of the slab on grade, from ground to inside and insulation are other details that should filled.

Window and doors
Different information about the doors and windows type, dimensions, orientation, construction, and insulation details should be considered in this part.

The following models were generated after each of the variables for the above building information categories were entered:

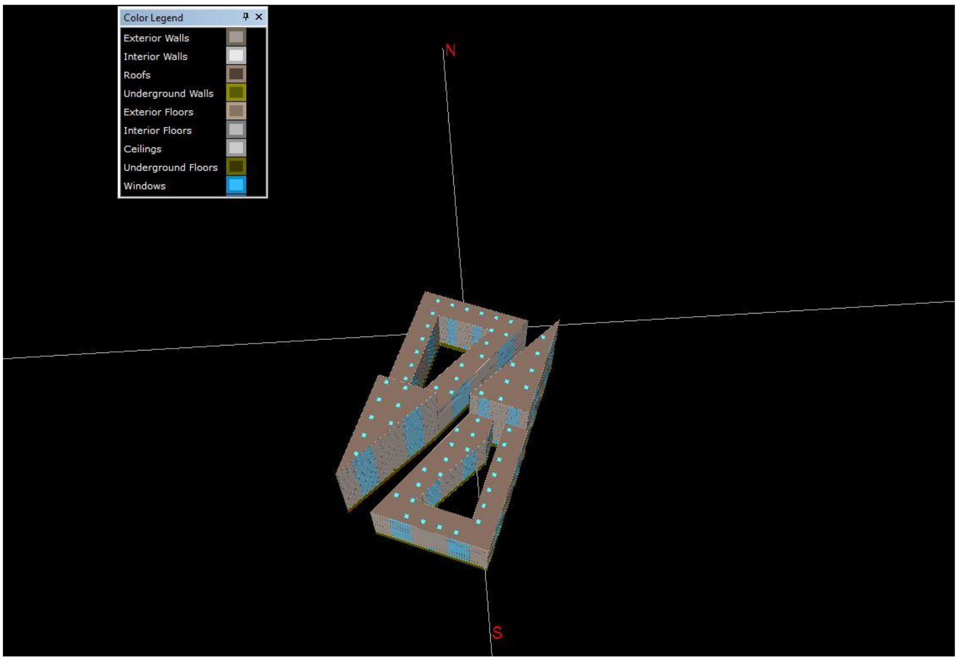


Figure 26: The eQuest modelling based on the UDF 2007

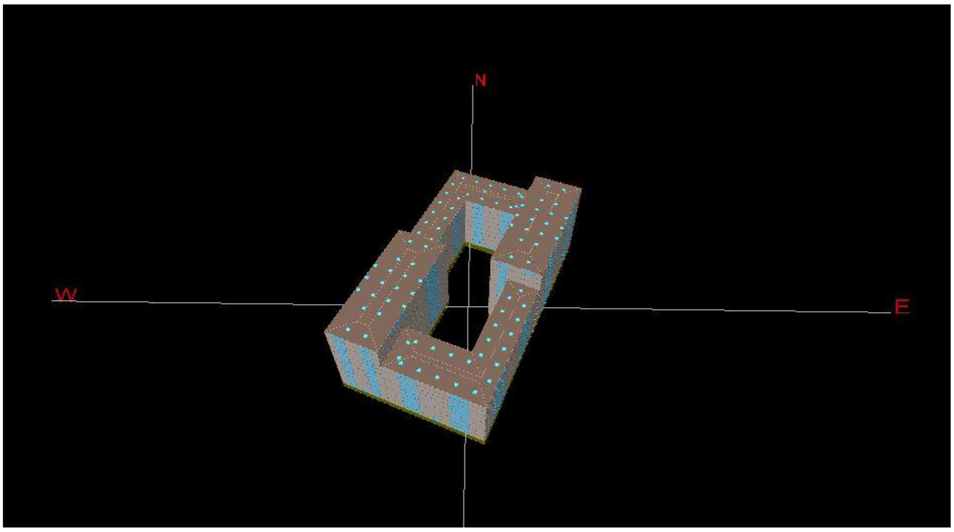


Figure 27: The eQuest modelling based on the UDF 2014

HVAC system
Two HVAC systems were defined for each of the scenarios. The system specifications were the same in each of the scenarios. The need for differing systems was due to different

requirements for heating, cooling, and ventilation in different building configurations. The first system was defined as a DX Coils single-zone heat pump, applied to each floor above grade (ground). The second HVAC system is a unit ventilator (no heating and cooling) applied to the underground floors (basements and carparks).

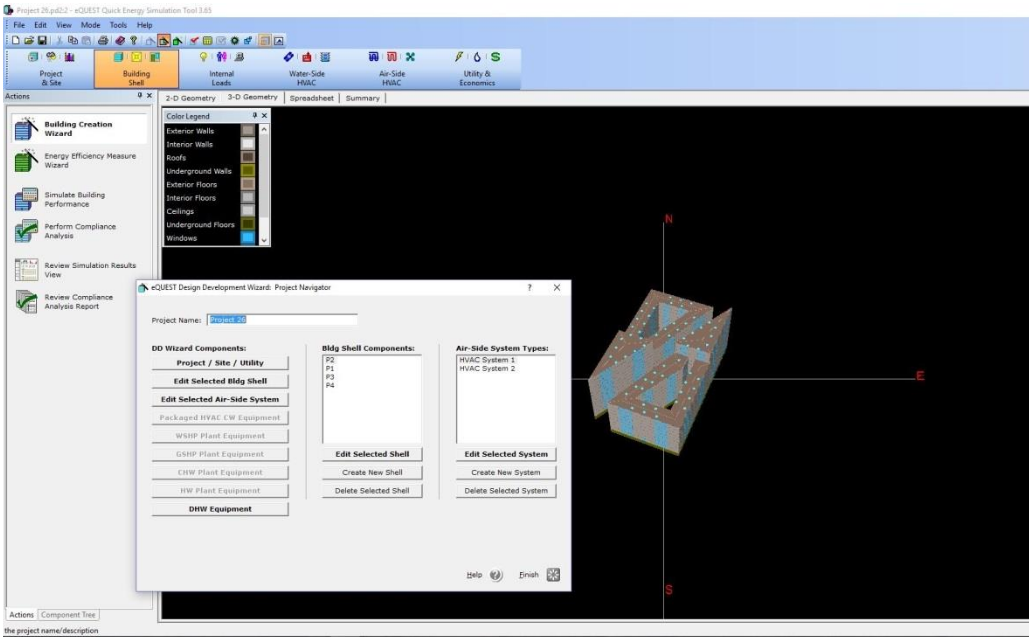


Figure 28: The eQuest modelling and HVAC systems for UDF 2007

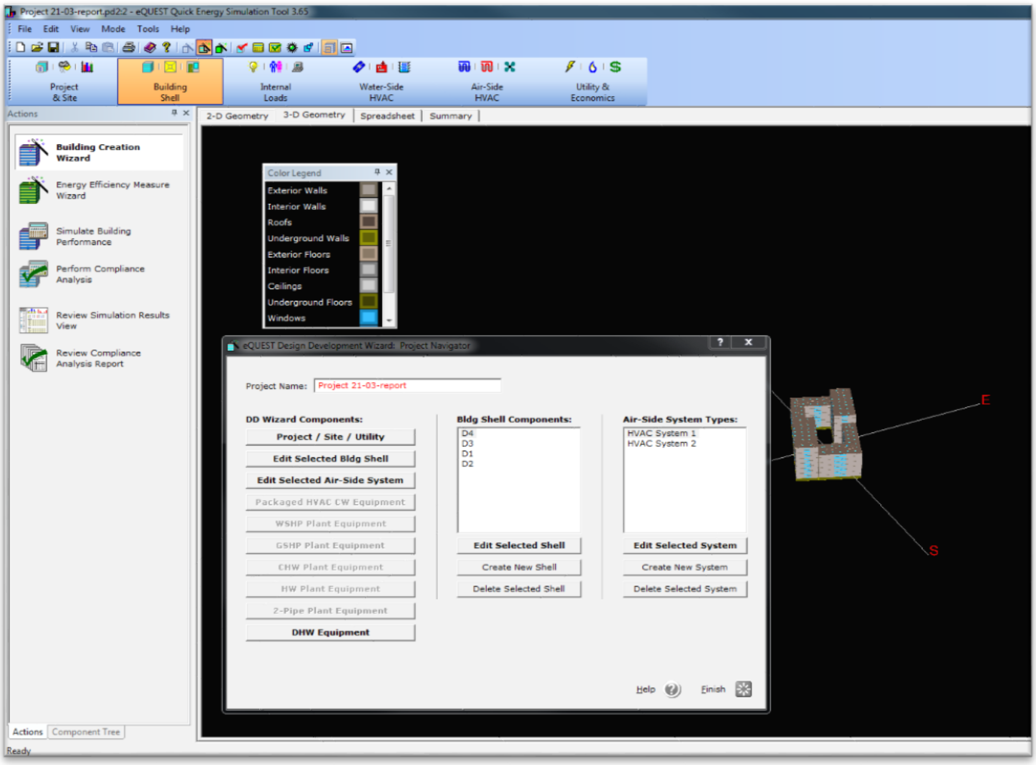


Figure 29: The eQuest modelling and HVAC systems for UDF 2014

The energy simulation outcome

In this section, the results of the energy simulation for each scenario are explained. The results can be categorised in two broad strands of energy consumption and power demand. The energy consumption (kWh) is for the period 1 January 2016 to 31 December 2016. The overall energy consumption results are for the year as well as for each month. The power demand (kW) is for the same period and follows the same breakdowns. It should be noted that the weather profile of Auckland, which was prepared by NIWA, was inserted as a variable in the software before it carried out the simulation.

Annual energy consumption by enduse

The results showed that ventilation had the largest impact on annual energy consumption, followed by area lighting and exterior usage. Exterior usage consists of any energy used on the exterior of the building, such as lighting in parking areas. Energy consumption for area lighting equals the overall energy consumed for combined space heating and cooling. According to the simulation results, the majority of the energy used in the building was for water heating, almost three times the energy used for ventilation of the building. After normalising the figures, gas energy used for water heating was almost equal to the overall electricity energy use in the building. Compared with the UDF 2014, it is clear that the UDF 2007 consumed far less energy in total. As well, there were some changes in the patterns of energy consumption. For example, space cooling consumed less energy in the UDF 2014, whereas it consumed almost the same amount in the UDF 2007. Also, the amount of energy for exterior usage was larger than the energy used for ventilation of the buildings in the UDF 2014. This was primarily because the ventilation load decreased in the UDF 2014 compared to the UDF 2007.

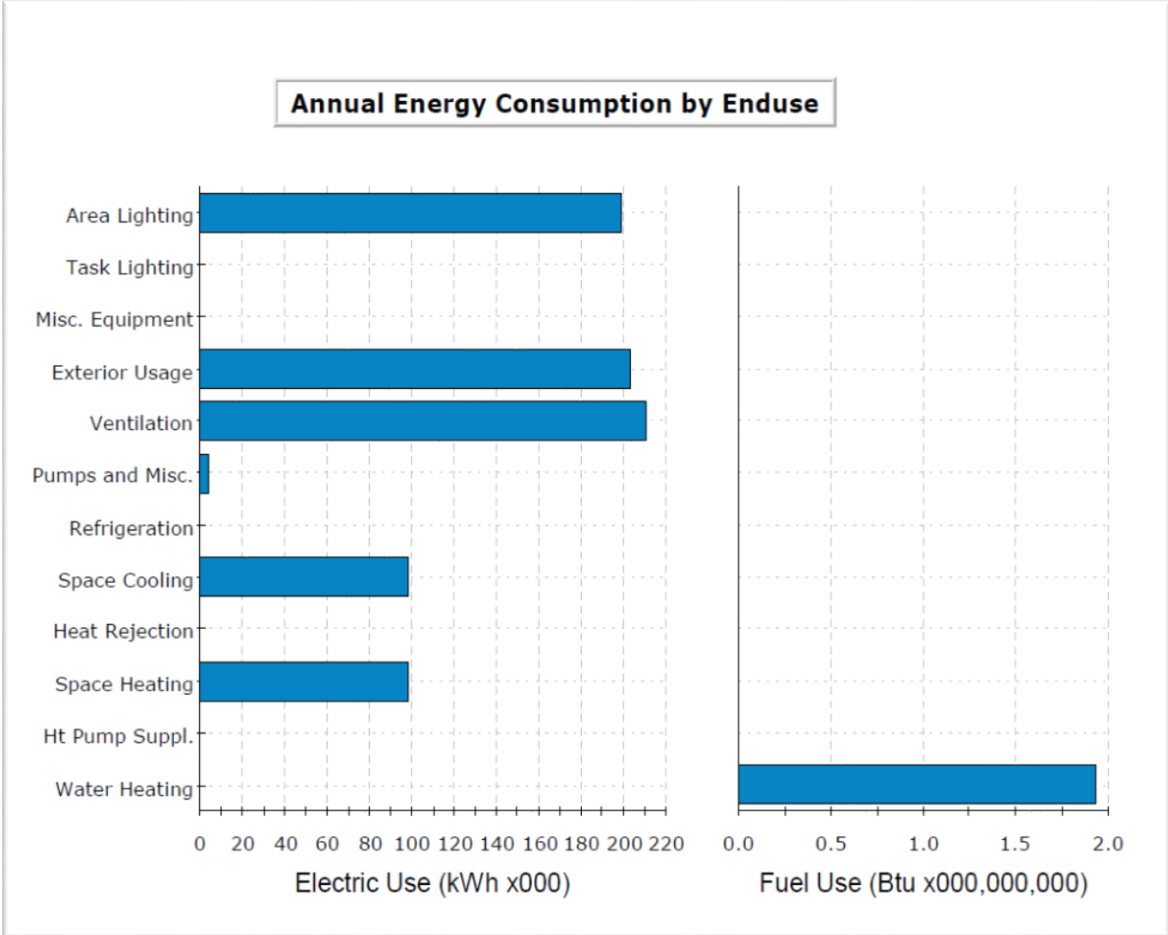


Figure 30: The Annual Energy Consumption By Enduse based on the UDF 2007

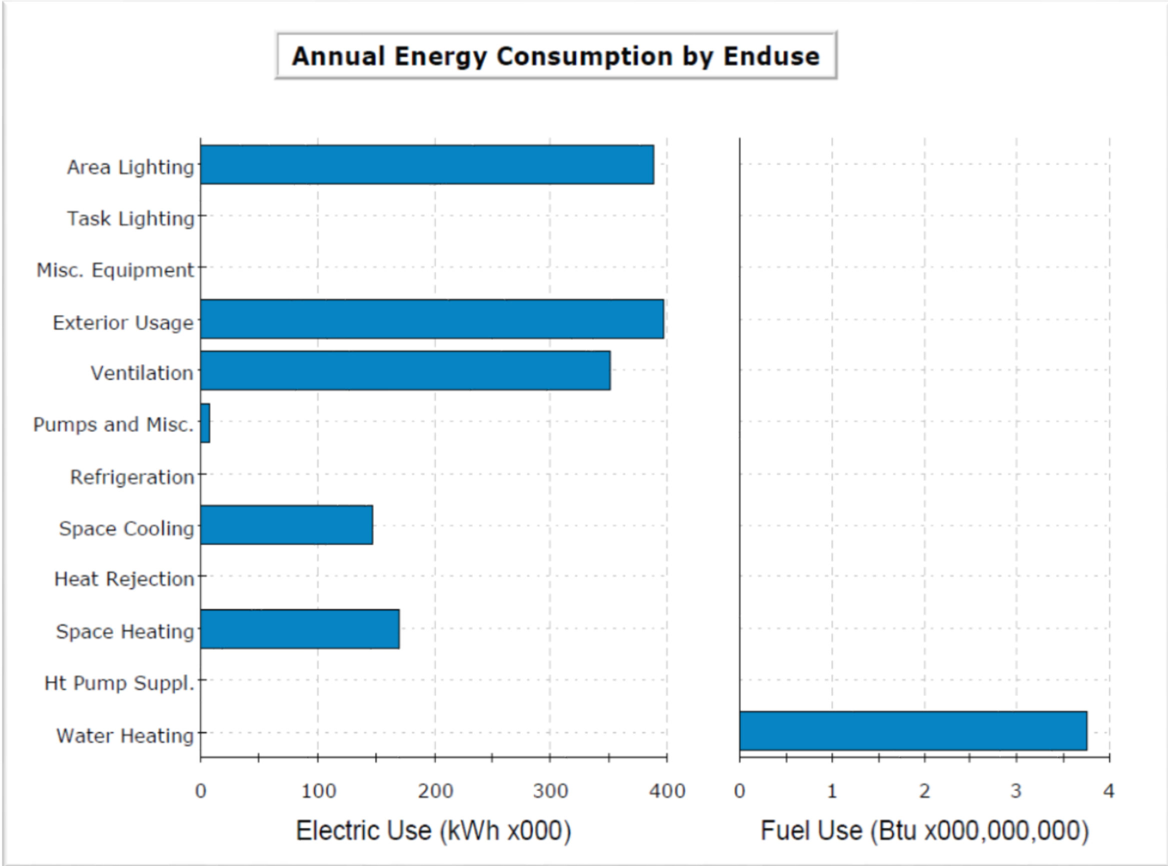


Figure 31: The Annual Energy Consumption By Enduse based on the UDF 2014

Annual electricity consumption

The overall electricity energy used per year exceeds 800,000 kWh in the buildings. The majority of the electricity was used for area lighting, exterior usage, and ventilation, with almost the same amount for each of them. The amount of electricity used for space heating and cooling was almost equal, each accounting for 100,000 kWh per year. The UDF 2014 simulation showed that annual electricity consumption was significantly higher in each category of energy consumption than the UDF 2007 levels, amounting to less than double. Therefore, the Annual Electric Consumption of the UDF 2014 was greater than 1,400,000 kWh for the same period.

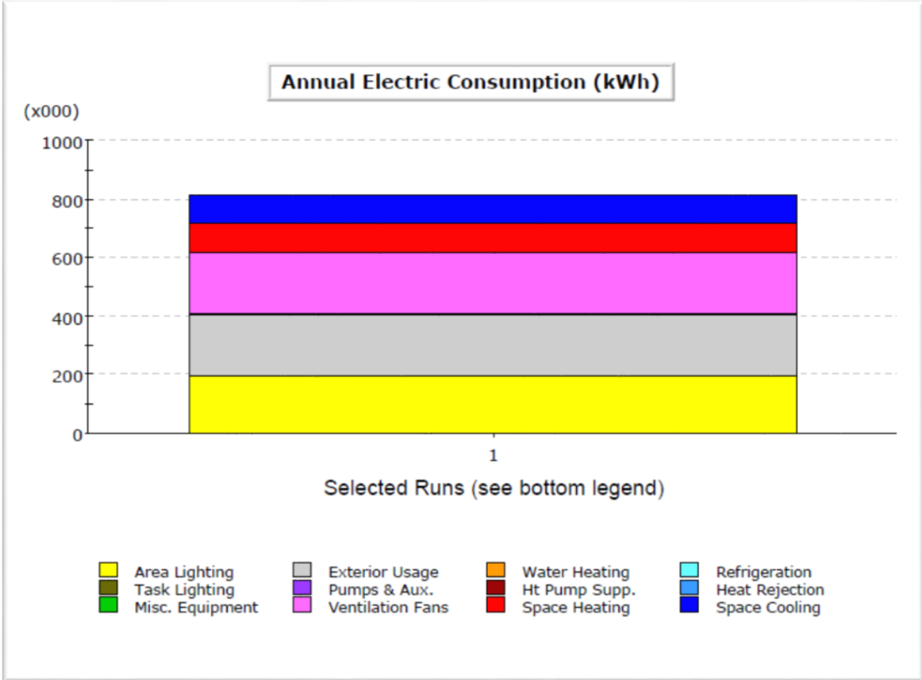


Figure 32: The Annual Electric Consumption (kWh) based on the UDF 2007

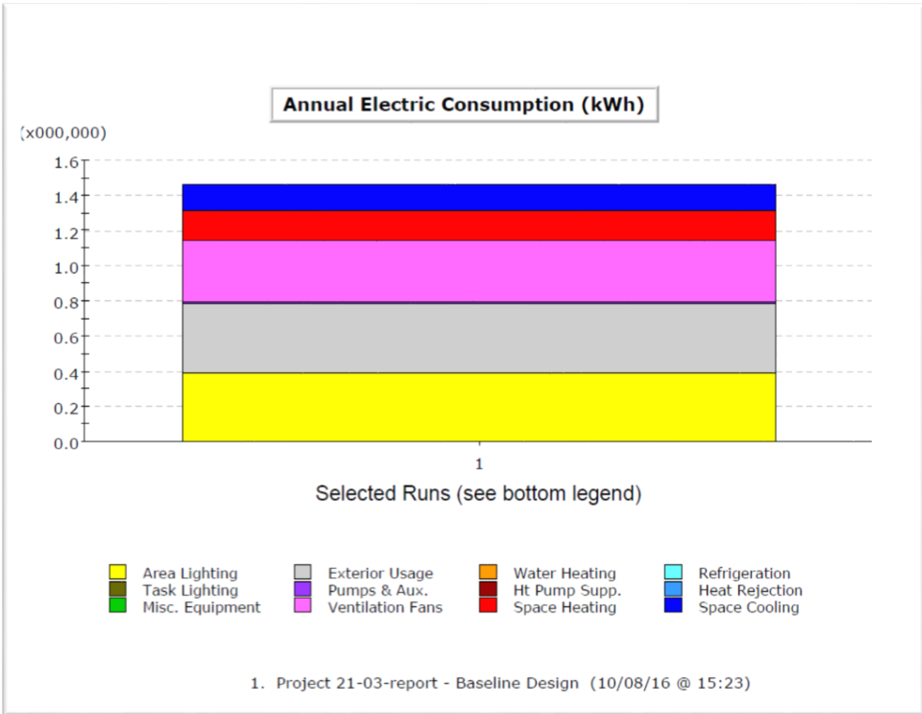


Figure 33: The Annual Electric Consumption (kWh) based on the UDF 2014

Annual Peak Demand by Enduse

The annual peak demand chart for the UDF 2007 showed that space cooling used almost 50% of overall electricity while almost all of the natural gas was used for water heating. Area lighting was the second most energy intensive category, using almost half of the electricity used for space cooling. The UDF 2014 energy modelling showed that the amount of energy used would increase compared with the UDF 2007. The electricity used for space cooling surged over 50%, from 177.4 kW in the UDF 2007 to 272.3 kW in the UDF 2014. The rise in electricity used for other purposes was at almost the same rate, too. Although the amount of energy use would increase in the UDF 2014, the overall share of each category use was slightly different between the UDF 2007 and 2014. Compared with the UDF 2014, space cooling was still expected to use most electricity, although less than 50% of all electricity used in the buildings. The UDF 2014 used 10% less on space cooling while the energy used for area lighting and exterior usage increases by 4% and 2% respectively. There was no significant difference in the natural gas usage, being almost all used for water heating in the buildings.

Annual Peak Demand by Enduse

	Electricity kW	Natural Gas Btu/h (x000)	Steam Btu/h	Chilled Water Btu/h
Space Cool	+177.39	-	-	-
Heat Reject.	-	-	-	-
Refrigeration	-	-	-	-
Space Heat	-	-	-	-
HP Supp.	-	-	-	-
Hot Water	-	+611.74	-	-
Vent. Fans	+38.81	-	-	-
Pumps & Aux.	-	-	-	-
Ext. Usage	+41.42	-	-	-
Misc. Equip.	-	-	-	-
Task Lights	-	-	-	-
Area Lights	+82.58	-	-	-
Total	+340.19	+611.74	-	-

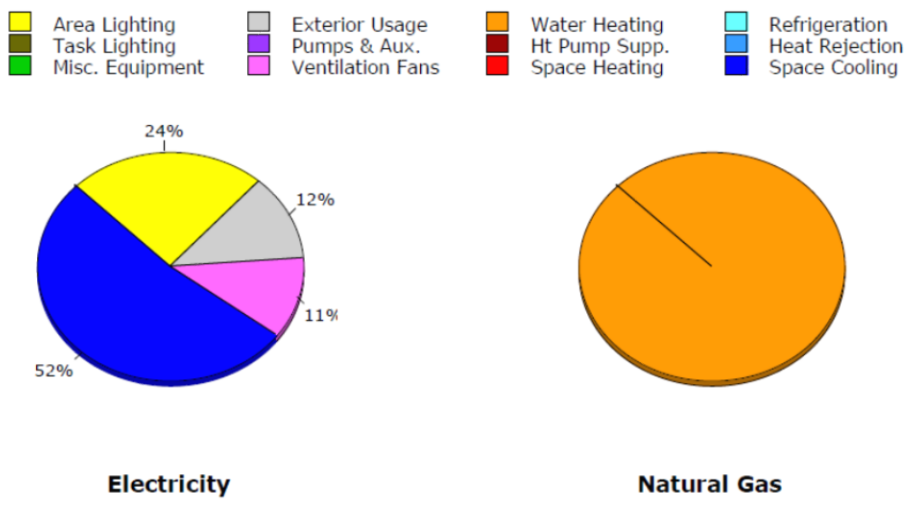
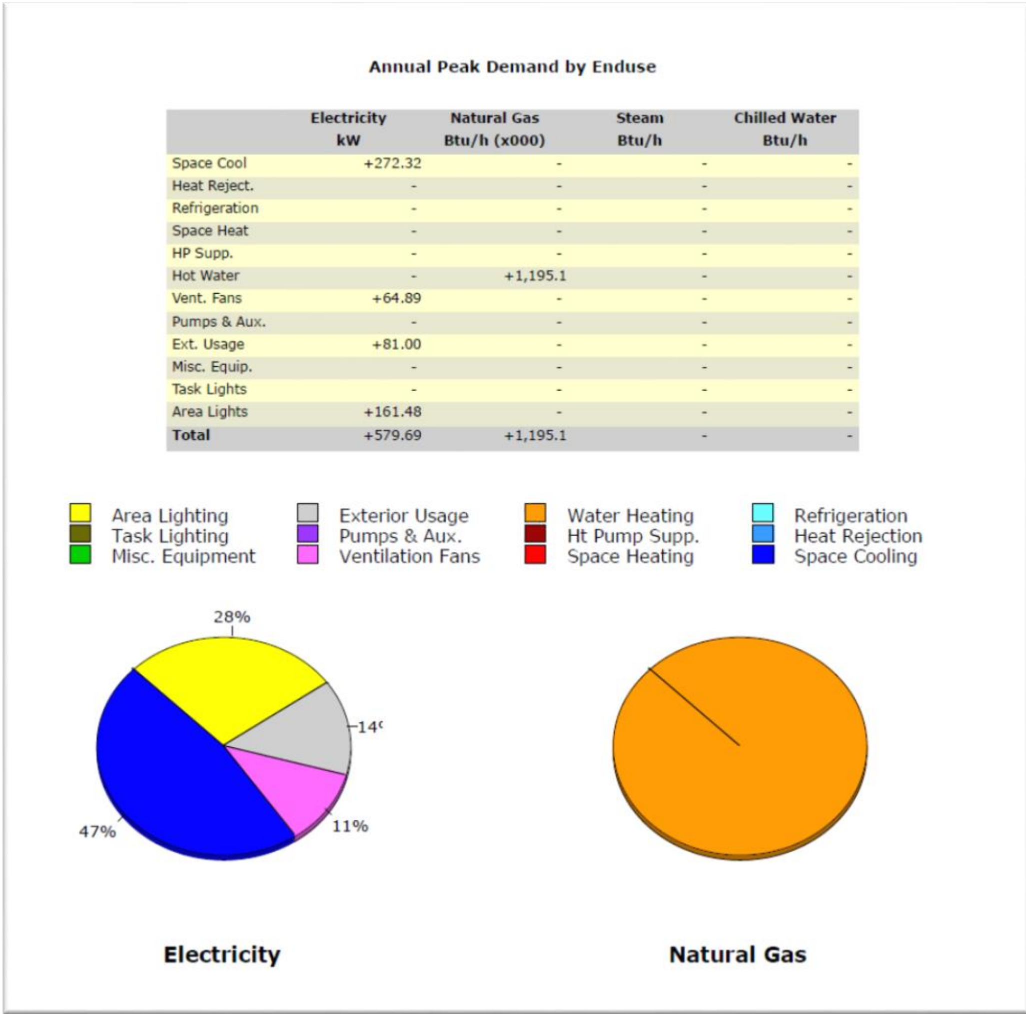


Figure 34: The Annual Peak Demand by Enduse based on the UDF 2007



Annual Peak Demand by Enduse

	Electricity kW	Natural Gas Btu/h (x000)	Steam Btu/h	Chilled Water Btu/h
Space Cool	+272.32	-	-	-
Heat Reject.	-	-	-	-
Refrigeration	-	-	-	-
Space Heat	-	-	-	-
HP Supp.	-	-	-	-
Hot Water	-	+1,195.1	-	-
Vent. Fans	+64.89	-	-	-
Pumps & Aux.	-	-	-	-
Ext. Usage	+81.00	-	-	-
Misc. Equip.	-	-	-	-
Task Lights	-	-	-	-
Area Lights	+161.48	-	-	-
Total	+579.69	+1,195.1	-	-

Figure 35: The Annual Peak Demand by Enduse based on the UDF 2014

Annual Energy Consumption by Enduse

The simulation results showed that annual electricity energy consumption by enduse was slightly different between the UDF 2007 and 2014. This difference was beyond the different levels of energy use of each of the UDFs. In fact, the pie charts showed that almost the same amount of energy was used for heating and cooling of the buildings, while the UDF 2014 showed the energy used for cooling is 2% less than the UDF 2007. The percentage of energy used for the heating of the buildings was 12%, which was the same ratio for both the UDF 2007 and 2014. In the UDF 2014, less energy was spent on ventilation compared with its 2007 alternative. Although the difference was 2%, almost a quarter of the total used in the buildings would be consumed by ventilation fans. A similar trend was also true for the area lighting. In the UDF 2014, 27% of total energy was consumed for area lighting, which was 3% more than the UDF 2007. It is possible to conclude that the orientation of the buildings had an impact on the level of solar radiation accessibility within the building, with reductions in the amount of energy consumed for space heating, but increased the need to light the internal space.

Annual Energy Consumption by Enduse

	Electricity kWh (x000)	Natural Gas MBtu	Steam Btu	Chilled Water Btu
Space Cool	+146.6	-	-	-
Heat Reject.	-	-	-	-
Refrigeration	-	-	-	-
Space Heat	+170.6	-	-	-
HP Supp.	+0.3	-	-	-
Hot Water	-	+3,764.1	-	-
Vent. Fans	+352.2	-	-	-
Pumps & Aux.	+6.4	-	-	-
Ext. Usage	+397.0	-	-	-
Misc. Equip.	-	-	-	-
Task Lights	-	-	-	-
Area Lights	+389.0	-	-	-
Total	+1,462.1	+3,764.1	-	-

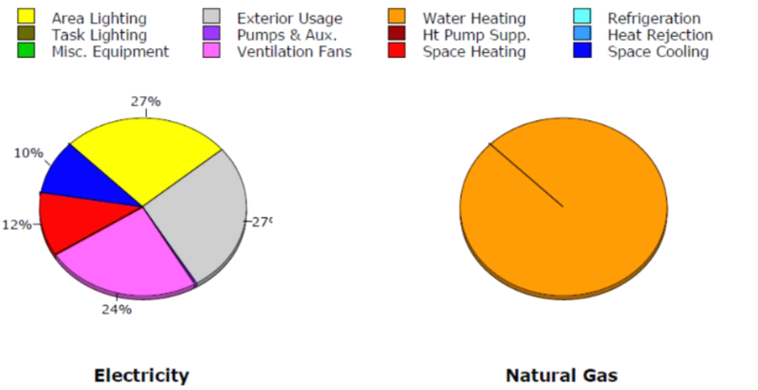


Figure 36: The UDF 2007 Annual Energy Consumption by Enduse

Annual Energy Consumption by Enduse

	Electricity kWh (x000)	Natural Gas MBtu	Steam Btu	Chilled Water Btu
Space Cool	+98.35	-	-	-
Heat Reject.	-	-	-	-
Refrigeration	-	-	-	-
Space Heat	+98.04	-	-	-
HP Supp.	+0.17	-	-	-
Hot Water	-	+1,926.6	-	-
Vent. Fans	+210.64	-	-	-
Pumps & Aux.	+4.05	-	-	-
Ext. Usage	+203.02	-	-	-
Misc. Equip.	-	-	-	-
Task Lights	-	-	-	-
Area Lights	+198.91	-	-	-
Total	+813.19	+1,926.6	-	-

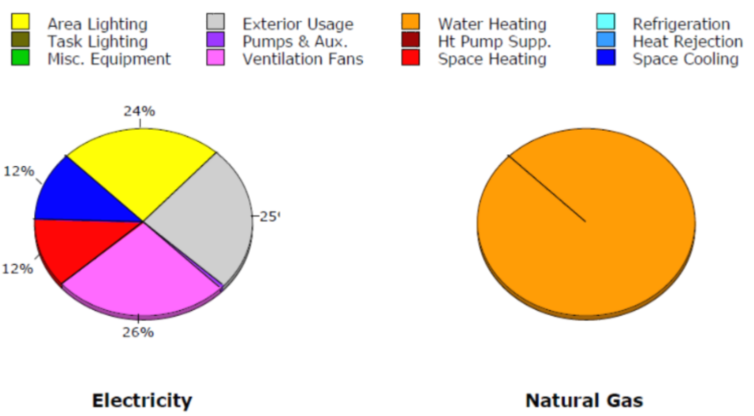
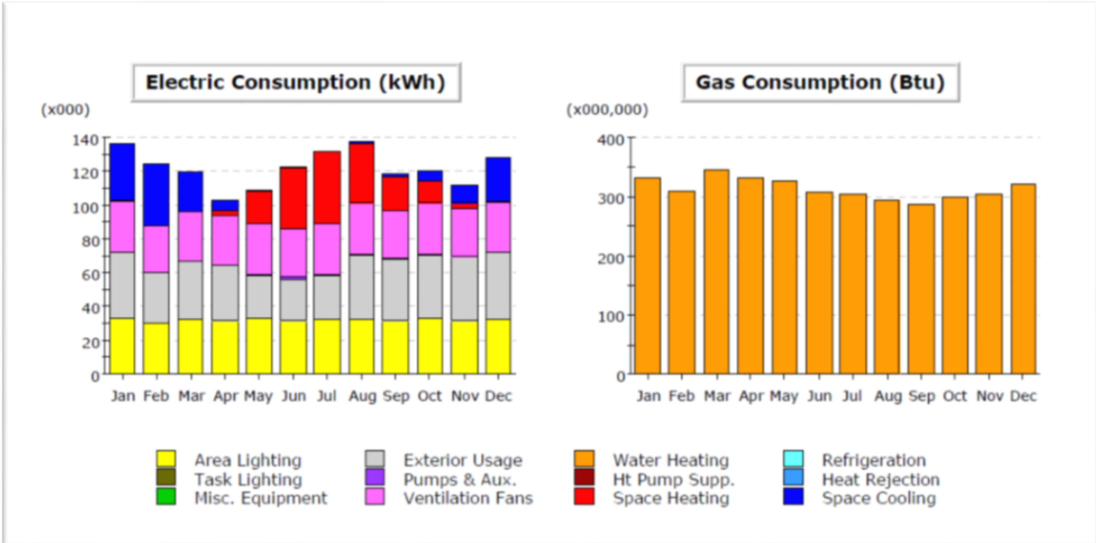


Figure 37: The UDF 2014 Annual Energy Consumption by Enduse

Monthly energy consumption by enduse

As expected, the overall monthly energy consumption for each enduse, particularly space heating, and cooling, matched seasonal changes. The overall energy consumption for heating started from April in both models and rose to a maximum in July. Thereafter, the demand for heating started to reduce and reached its minimum by the end of November. Energy consumption for exterior usage fluctuated between January and December, with the least during mid-autumn to mid-winter, between May and July. Maximum energy was consumed in August. Proportionately, the UDF 2014 consumed slightly less energy on space cooling than the UDF 2007. For example, for the month of April, the UDF 2007 consumed four times more energy on space cooling than heating, while the UDF 2014 consumed only slightly more energy on space cooling than heating for the same period.



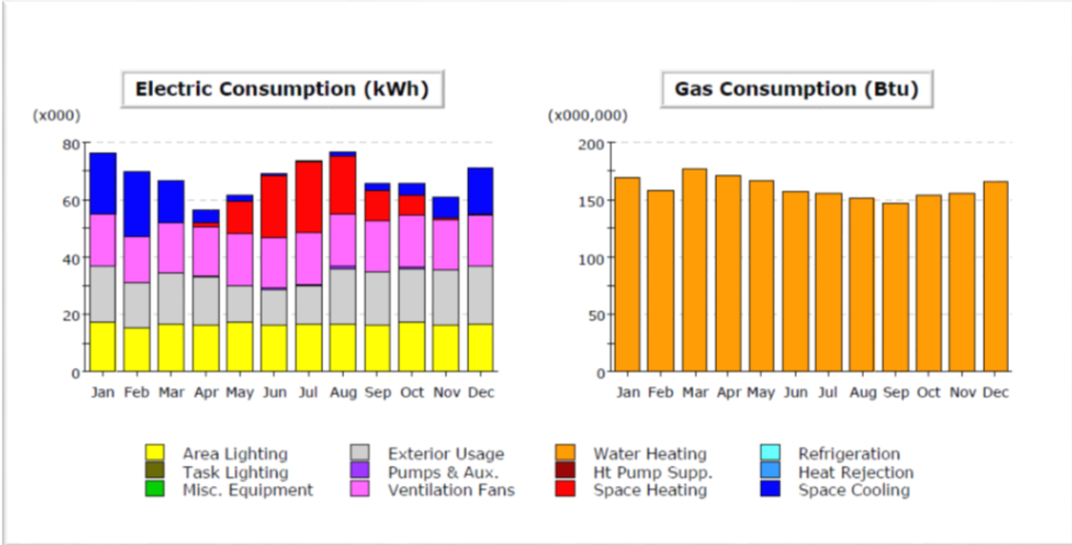
Electric Consumption (kWh x000)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Space Cool	+33.7	+36.8	+23.2	+5.7	+1.6	+0.3	+0.3	+0.7	+2.2	+6.0	+10.6	+25.5	+146.6
Heat Reject.	-	-	-	-	-	-	-	-	-	-	-	-	-
Refrigeration	-	-	-	-	-	-	-	-	-	-	-	-	-
Space Heat	+0.2	+0.0	+0.0	+3.4	+18.9	+36.0	+41.5	+35.0	+19.4	+12.9	+2.8	+0.5	+170.6
HP Supp.	-	-	-	-	-	+0.1	+0.1	+0.0	+0.1	+0.0	-	-	+0.3
Hot Water	-	-	-	-	-	-	-	-	-	-	-	-	-
Vent. Fans	+30.3	+27.0	+29.7	+28.8	+30.1	+28.8	+29.9	+29.9	+28.8	+30.1	+28.8	+29.9	+352.2
Pumps & Aux.	+0.0	-	-	+0.2	+0.5	+1.1	+1.5	+1.5	+0.6	+0.7	+0.1	+0.1	+6.4
Ext. Usage	+38.7	+30.6	+33.9	+32.8	+25.1	+24.3	+25.1	+37.1	+35.9	+37.1	+37.5	+38.7	+397.0
Misc. Equip.	-	-	-	-	-	-	-	-	-	-	-	-	-
Task Lights	-	-	-	-	-	-	-	-	-	-	-	-	-
Area Lights	+33.4	+29.8	+32.8	+31.8	+33.2	+31.8	+33.1	+33.0	+31.8	+33.2	+31.8	+33.0	+389.0
Total	+136.5	+124.3	+119.6	+102.7	+109.5	+122.5	+131.4	+137.4	+118.8	+120.2	+111.6	+127.7	+1,462.1

Gas Consumption (Btu x000,000)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Space Cool	-	-	-	-	-	-	-	-	-	-	-	-	-
Heat Reject.	-	-	-	-	-	-	-	-	-	-	-	-	-
Refrigeration	-	-	-	-	-	-	-	-	-	-	-	-	-
Space Heat	-	-	-	-	-	-	-	-	-	-	-	-	-
HP Supp.	-	-	-	-	-	-	-	-	-	-	-	-	-
Hot Water	+330.7	+309.6	+345.4	+331.9	+327.1	+306.6	+305.5	+294.9	+286.7	+300.2	+303.3	+322.4	+3,764.1
Vent. Fans	-	-	-	-	-	-	-	-	-	-	-	-	-
Pumps & Aux.	-	-	-	-	-	-	-	-	-	-	-	-	-
Ext. Usage	-	-	-	-	-	-	-	-	-	-	-	-	-
Misc. Equip.	-	-	-	-	-	-	-	-	-	-	-	-	-
Task Lights	-	-	-	-	-	-	-	-	-	-	-	-	-
Area Lights	-	-	-	-	-	-	-	-	-	-	-	-	-
Total	+330.7	+309.6	+345.4	+331.9	+327.1	+306.6	+305.5	+294.9	+286.7	+300.2	+303.3	+322.4	+3,764.1

Figure 38: The UDF 2014 Monthly Energy Consumption by Enduse



Electric Consumption (kWh x000)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Space Cool	+20.99	+22.87	+14.63	+4.40	+1.88	+0.73	+0.82	+1.20	+2.43	+4.86	+7.39	+16.15	+98.35
Heat Reject.	-	-	-	-	-	-	-	-	-	-	-	-	-
Refrigeration	-	-	-	-	-	-	-	-	-	-	-	-	-
Space Heat	+0.07	+0.00	+0.00	+1.47	+11.24	+21.69	+24.44	+20.45	+11.00	+6.61	+0.92	+0.14	+98.04
HP Supp.	-	-	-	-	-	+0.06	+0.04	+0.03	+0.03	+0.01	-	-	+0.17
Hot Water	-	-	-	-	-	-	-	-	-	-	-	-	-
Vent. Fans	+18.12	+16.14	+17.77	+17.23	+18.01	+17.23	+17.89	+17.89	+17.23	+18.01	+17.23	+17.89	+210.64
Pumps & Aux.	+0.02	-	-	+0.11	+0.32	+0.69	+0.91	+0.98	+0.39	+0.52	+0.08	+0.04	+4.05
Ext. Usage	+19.81	+15.66	+17.34	+16.78	+12.84	+12.43	+12.84	+18.99	+18.37	+18.99	+19.17	+19.81	+203.02
Misc. Equip.	-	-	-	-	-	-	-	-	-	-	-	-	-
Task Lights	-	-	-	-	-	-	-	-	-	-	-	-	-
Area Lights	+17.10	+15.25	+16.78	+16.28	+16.99	+16.27	+16.90	+16.88	+16.27	+17.00	+16.28	+16.89	+198.91
Total	+76.12	+69.91	+66.52	+56.27	+61.28	+69.10	+73.85	+76.42	+65.73	+66.00	+61.07	+70.93	+813.19

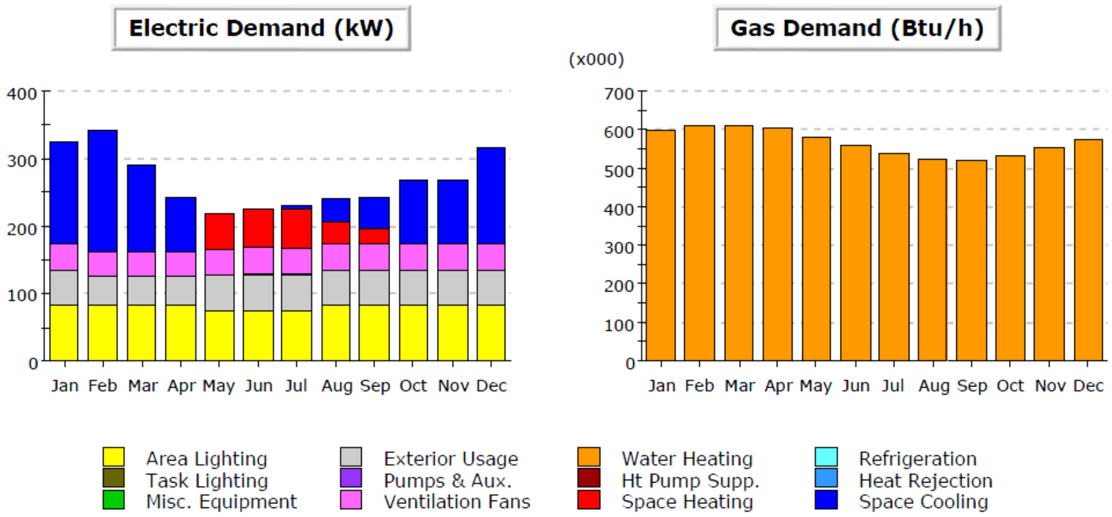
Gas Consumption (Btu x000,000)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Space Cool	-	-	-	-	-	-	-	-	-	-	-	-	-
Heat Reject.	-	-	-	-	-	-	-	-	-	-	-	-	-
Refrigeration	-	-	-	-	-	-	-	-	-	-	-	-	-
Space Heat	-	-	-	-	-	-	-	-	-	-	-	-	-
HP Supp.	-	-	-	-	-	-	-	-	-	-	-	-	-
Hot Water	+169.3	+158.4	+176.9	+170.0	+167.3	+156.8	+156.3	+150.9	+146.6	+153.6	+155.3	+165.1	+1,926.6
Vent. Fans	-	-	-	-	-	-	-	-	-	-	-	-	-
Pumps & Aux.	-	-	-	-	-	-	-	-	-	-	-	-	-
Ext. Usage	-	-	-	-	-	-	-	-	-	-	-	-	-
Misc. Equip.	-	-	-	-	-	-	-	-	-	-	-	-	-
Task Lights	-	-	-	-	-	-	-	-	-	-	-	-	-
Area Lights	-	-	-	-	-	-	-	-	-	-	-	-	-
Total	+169.3	+158.4	+176.9	+170.0	+167.3	+156.8	+156.3	+150.9	+146.6	+153.6	+155.3	+165.1	+1,926.6

Figure 39: The UDF 2007 Monthly Energy Consumption by Enduse

Monthly peak demand by enduse

These graphs show the demand peaked for each month of the year. As expected, the demand load of both UDF 2007 and 2014 were consistent with monthly energy consumption. The demands for energy for cooling and heating followed seasonal fluctuations. The only difference between electricity demand of UDF 2014 and UDF 2007 was the load for heat-pump supply for UDF 2014, which did not record for UDF 2007. This resulted in a significant reduction of ventilation load, reducing it to almost a tenth of the electricity demand for the previous and the following months. Also, the UDF 2007 model showed a surge in space cooling load, which was almost none in UDF 2014. In UDF 2014, space cooling and heating demands were almost equal in September, while space cooling load was nearly twice the space heating load in September for the UDF 2007.



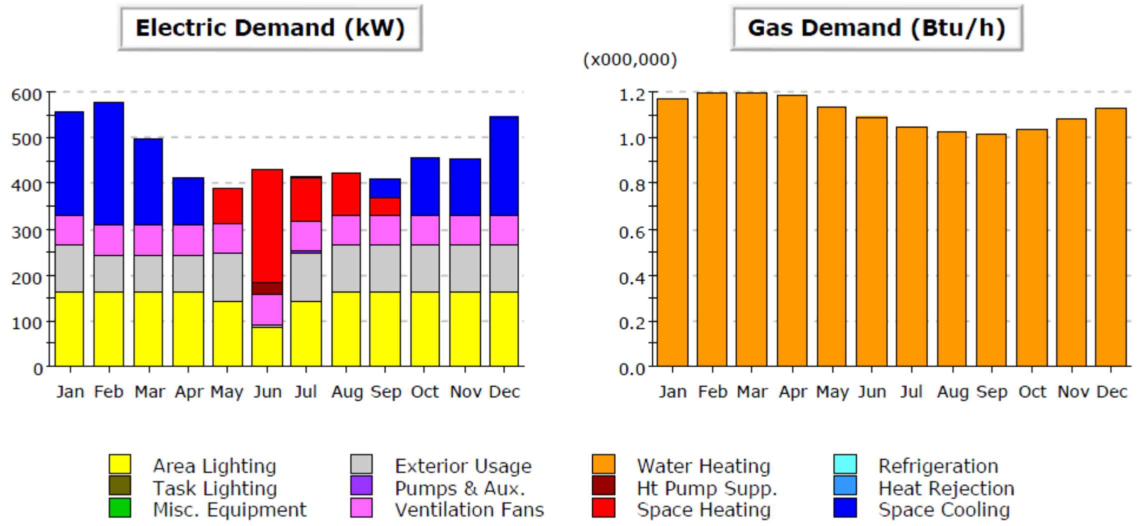
Electric Demand (kW)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Space Cool	+149.7	+177.4	+127.9	+79.6	-	+1.2	+2.8	+34.6	+46.6	+93.7	+93.2	+142.8	+949.6
Heat Reject.	-	-	-	-	-	-	-	-	-	-	-	-	-
Refrigeration	-	-	-	-	-	-	-	-	-	-	-	-	-
Space Heat	-	-	-	+0.1	+53.4	+56.9	+59.0	+32.3	+21.8	-	+0.4	-	+223.8
HP Supp.	-	-	-	-	-	-	-	-	-	-	-	-	-
Hot Water	-	-	-	-	-	-	-	-	-	-	-	-	-
Vent. Fans	+38.8	+38.8	+38.8	+38.8	+38.8	+38.8	+38.8	+38.8	+38.8	+38.8	+38.8	+38.8	+465.7
Pumps & Aux.	-	-	-	-	-	+2.7	+2.3	-	-	-	-	-	+5.0
Ext. Usage	+53.3	+41.4	+41.4	+41.4	+53.3	+53.3	+53.3	+53.3	+53.3	+53.3	+53.3	+53.3	+603.6
Misc. Equip.	-	-	-	-	-	-	-	-	-	-	-	-	-
Task Lights	-	-	-	-	-	-	-	-	-	-	-	-	-
Area Lights	+82.6	+82.6	+82.6	+82.6	+73.5	+73.5	+73.5	+82.6	+82.6	+82.6	+82.6	+82.6	+963.7
Total	+324.3	+340.2	+290.7	+242.5	+219.0	+226.3	+229.7	+241.5	+243.0	+268.3	+268.3	+317.4	+3,211.2

Gas Demand (Btu/h x000)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Space Cool	-	-	-	-	-	-	-	-	-	-	-	-	-
Heat Reject.	-	-	-	-	-	-	-	-	-	-	-	-	-
Refrigeration	-	-	-	-	-	-	-	-	-	-	-	-	-
Space Heat	-	-	-	-	-	-	-	-	-	-	-	-	-
HP Supp.	-	-	-	-	-	-	-	-	-	-	-	-	-
Hot Water	+597.9	+610.2	+611.7	+605.8	+580.7	+556.7	+534.9	+521.8	+519.6	+531.6	+552.3	+576.3	+6,799.5
Vent. Fans	-	-	-	-	-	-	-	-	-	-	-	-	-
Pumps & Aux.	-	-	-	-	-	-	-	-	-	-	-	-	-
Ext. Usage	-	-	-	-	-	-	-	-	-	-	-	-	-
Misc. Equip.	-	-	-	-	-	-	-	-	-	-	-	-	-
Task Lights	-	-	-	-	-	-	-	-	-	-	-	-	-
Area Lights	-	-	-	-	-	-	-	-	-	-	-	-	-
Total	+597.9	+610.2	+611.7	+605.8	+580.7	+556.7	+534.9	+521.8	+519.6	+531.6	+552.3	+576.3	+6,799.5

Figure 40: The Monthly Peak Demand by Enduse based on the UDF 2007



Electric Demand (kW)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Space Cool	+226.9	+272.3	+188.9	+105.6	-	-	+1.4	-	+39.8	+124.5	+120.1	+212.5	+1,292.0
Heat Reject.	-	-	-	-	-	-	-	-	-	-	-	-	-
Refrigeration	-	-	-	-	-	-	-	-	-	-	-	-	-
Space Heat	-	-	-	+0.2	+78.7	+244.1	+95.3	+93.9	+38.1	+0.3	+1.2	-	+551.6
HP Supp.	-	-	-	-	-	+27.6	-	-	-	-	-	-	+27.6
Hot Water	-	-	-	-	-	-	-	-	-	-	-	-	-
Vent. Fans	+64.9	+64.9	+64.9	+64.9	+64.9	+64.9	+64.9	+64.9	+64.9	+64.9	+64.9	+64.9	+778.6
Pumps & Aux.	-	-	-	-	-	+1.7	+4.6	-	-	-	-	-	+6.4
Ext. Usage	+104.1	+81.0	+81.0	+81.0	+104.1	+5.8	+104.1	+104.1	+104.1	+104.1	+104.1	+104.1	+1,081.9
Misc. Equip.	-	-	-	-	-	-	-	-	-	-	-	-	-
Task Lights	-	-	-	-	-	-	-	-	-	-	-	-	-
Area Lights	+161.5	+161.5	+161.5	+161.5	+143.7	+85.5	+143.7	+161.5	+161.5	+161.5	+161.5	+161.5	+1,826.3
Total	+557.4	+579.7	+496.3	+413.1	+391.4	+429.6	+414.1	+424.4	+408.4	+455.3	+451.8	+543.0	+5,564.4

Gas Demand (Btu/h x000,000)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Space Cool	-	-	-	-	-	-	-	-	-	-	-	-	-
Heat Reject.	-	-	-	-	-	-	-	-	-	-	-	-	-
Refrigeration	-	-	-	-	-	-	-	-	-	-	-	-	-
Space Heat	-	-	-	-	-	-	-	-	-	-	-	-	-
HP Supp.	-	-	-	-	-	-	-	-	-	-	-	-	-
Hot Water	+1.17	+1.19	+1.20	+1.18	+1.14	+1.09	+1.05	+1.02	+1.02	+1.04	+1.08	+1.13	+13.29
Vent. Fans	-	-	-	-	-	-	-	-	-	-	-	-	-
Pumps & Aux.	-	-	-	-	-	-	-	-	-	-	-	-	-
Ext. Usage	-	-	-	-	-	-	-	-	-	-	-	-	-
Misc. Equip.	-	-	-	-	-	-	-	-	-	-	-	-	-
Task Lights	-	-	-	-	-	-	-	-	-	-	-	-	-
Area Lights	-	-	-	-	-	-	-	-	-	-	-	-	-
Total	+1.17	+1.19	+1.20	+1.18	+1.14	+1.09	+1.05	+1.02	+1.02	+1.04	+1.08	+1.13	+13.29

Figure 41: The Monthly Peak Demand by Enduse based on the UDF 2014

Modelling of on-site energy generation through solar analysis in Revit

Wynyard Central Sustainability Standards set out the criteria and several metrics to determine the minimum requirements with which new developments should comply. It is expected that by complying with these standards, the sustainability objectives of the Auckland Plan will be achieved as well. As already mentioned, the 2007 and 2014 versions of the urban design framework for Wynyard Quarter proposed different scenarios for building form for the case study of this research. The 2007 framework proposed building forms that were aligned along a diagonal open space plaza, which schematically created two opposite facing triangular forms. In contrast, the 2014 framework proposed new building forms by removing the open space plaza. Instead, a central open space was proposed surrounded by buildings with rectangular forms. Solar analysis for each of the building forms was performed in Autodesk Revit 2017. In earlier stages of the research, reviewing the literature suggested that Ecotect software was suitable to perform this section of the analysis. However, Ecotect was no longer available as standalone software as its functionalities had been incorporated into the most recent versions of Revit.

Performance criteria for on-site energy generation

It was beyond the scope of this research to assess the results of each scenario against all criteria. Instead, the analysis includes the most relevant criteria against which the performance of each building typology was assessed. The standards require new developments to be able to generate energy onsite from their initiation and over the years, with this capacity improving gradually. The criteria regarding this is categorised in the climate mitigation section, under precinct renewable energy generation. The measures for these criteria specify that a building should be able to offset its energy consumption by generating at least 5% in the first year. This target should be doubled to 10% at year 10 and increased to 30% by year 30. In reality, a certain percentage of the rooftop surface would be used for PV panel installation. The WCSS requires this space to be maximised in each development. However, final design details were not available and the UDFs provided a generic building form. Based on this, it can be assumed that the allocated space would be of similar ratio for both scenarios. Therefore, it was possible to consider the gross rooftop space for the installation of PV panels.

Wynyard Central Sustainability Standards (WCSS) require buildings to maximise the generation of renewable energy onsite, which will be primarily from photovoltaic solar panels installed on rooftops. Although the document does not specify the minimum percentage of PV panels on rooftops, it outlines how much onsite energy should be generated from day one as well as a gradual increase over the years. It is expected that onsite energy generation will largely be dependent on the solar radiation that the buildings receive. Therefore, the amount of solar insolation per annum will demonstrate the capacity for each building to capture solar radiation and convert it to electricity. The sustainability standards for the precinct (WCSS) require buildings to maximise rooftop space for the installation of photovoltaic (PV) panels. It is conventional to use the rooftop space of buildings for onsite energy generation as it is usually the place with the highest exposure to the sun. Apart from the PV systems' technical designs, the geometry of a rooftop is a key factor as it dictates the amount of space dedicated to the PV panels. The greater space it provides, the more onsite energy generation it enables. Building form can influence this measure by the geometry of a rooftop, its overall area, and the portion of the rooftop area dedicated to PV systems. Yet, neither of the UDF documents specified the percentage of rooftop to be dedicated to the PV panels. Based on the sustainability standards mentioned above, the researcher assumed that the maximum ratio of rooftop space for each of the modelling scenarios would be the same. Therefore, the gross area of each rooftop could be used as a proxy to determine the rooftop space used by PV panels, thus the capacity for onsite energy generation.

It is important to mention that there are a number of qualities that will determine the efficiency of a PV system in converting solar radiation into electricity. The pace at which the technology is advancing can improve some limitations to efficiency, such as battery capacities. Since the modelling scenarios of the research were for one site, it is possible to assume the same technology would be used for the PV systems. Based on this, the highest efficiency level that was used in the analysis. The solar analysis calculations provided enough information to compare the two scenarios and understand which one captured a greater amount of solar radiation over the same period. However, the efficiency ratio of PV systems enabled the comparison of the results in order to assess how well the targets regarding onsite energy generation, outlined in the standards document (WCSS), was met.

The results indicated that the rectangular layout had a lower level of solar insolation. This was largely because a smaller amount of space was available for PV solar panels, despite the higher average insolation levels. This conclusion is based on the assumption explained earlier that the rooftop space was a determinant of the total space that buildings devoted to harvesting PV solar panels. The triangular building forms provided a larger rooftop space to install PV panels, almost 359m^2 more than the rectangular building forms. This additional rooftop space largely remedied the lower average insolation value of the respective building. Therefore, although rectangular buildings harvested additional solar radiation of almost 79 kWh per square metre, their overall annual solar insolation fell short of the triangular building form by almost 75,674 kWh. By only an additional 65m^2 of rooftop (dedicated to solar panels), the rectangular building form could equate the solar insolation of the triangular building form. However, this would not be adequate to render the rectangular building form as energy efficient as the triangular building form.

The overall difference of annual solar insolation of the buildings was not significant, as it only counted for less than 2% of renewable on-site energy generation. In order to understand the significance of this difference, it was important to consider the overall projected energy consumption of buildings in each scenario. The triangular building form consumed almost 1.5 times less energy compared to the other scenario. Therefore, the results indicated that even with greater on-site energy generation, the rectangular building form performs less efficiently than did the triangular building form. In order for the rectangular building form to be as efficient as the triangular building form, it needed to generate more onsite energy. In other words, it needed to convert at least 1.5 times more solar energy to electricity, which would be the equivalent of 6,194m^2 of rooftop on the rectangular building form.
In order to compare the results with the targets specified in the WCSS document, a high performance PV solar panel assumed to be used. The efficiency for such systems would be 20%. The coverage rate of the rooftop assumed as 70%. By knowing these two ratios, the following calculation was made.

Table 5: The Energy Beneration vs. Energy Consumption of the Urban Design Frameworks

	UDF 2014 (rectangular)	UDF 2007 (triangular)
The rooftop area	4,021m^2	4,381m^2
Average insolation value	1,173.7 kWh	1,094.8 kWh
Total insolation value	4,720,190 kWh	4,795,864 kWh
Total energy consumption (Based on eQuest models)	2,546,119 kWh	1,354,454 kWh
Onsite energy generation (Based on Revit models)	958,431	974,454
Generation vs. consumption ratio	37%	71%

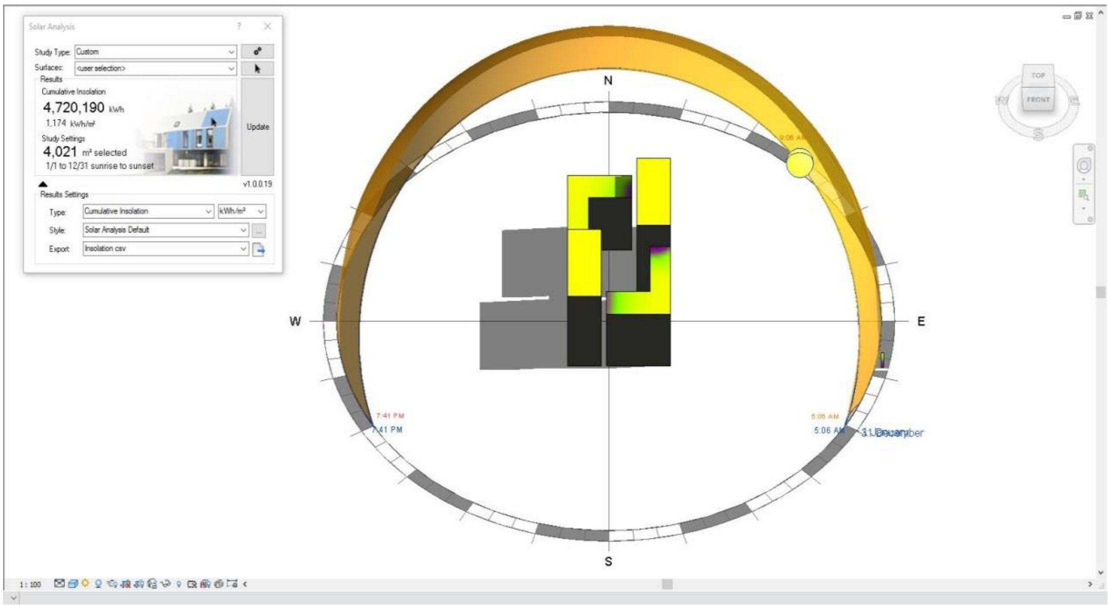


Figure 42: Solar analysis of rooftops for the UDF 2014

The edge of the low-rise buildings had lower insolation value due to shadowing by the adjacent high rise buildings. The figures revealed that, if the assumptions were correct, then the triangular building form could remedy its energy consumption plus almost 40% excess energy. At the same time, the rectangular building form could only recover just under 75% of the total energy it consumed per year. The results also showed that both the building forms provided enough potential for onsite energy generation such that WCSS targets could be met.

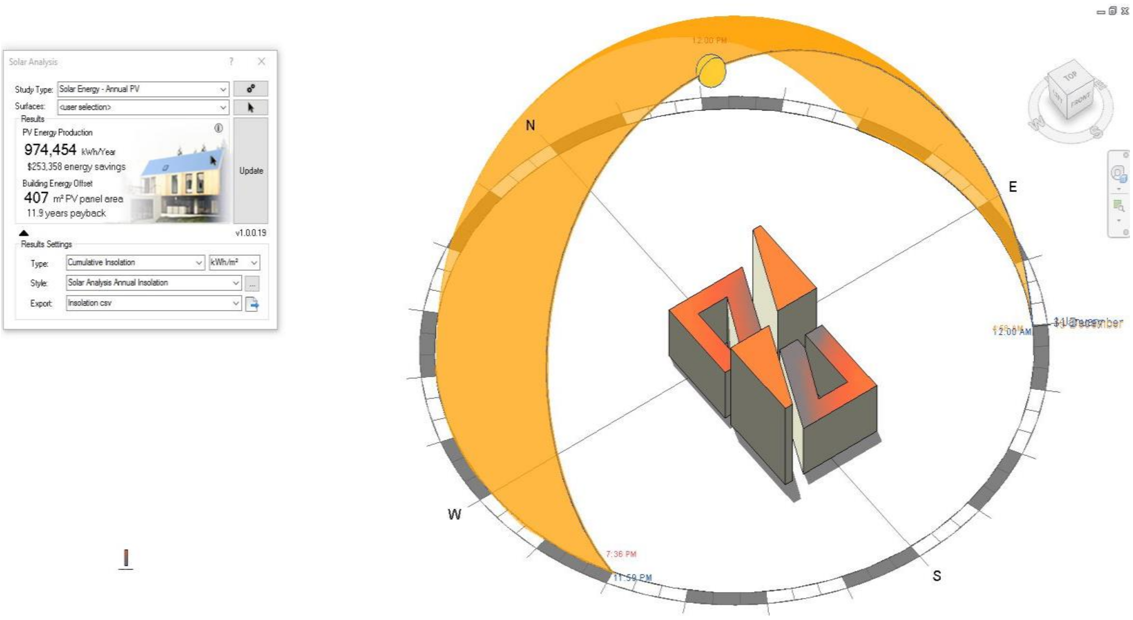


Figure 43: Potentials for solar PV energy generation of the UDF 2007, view 1. Brighter colours indicate a greater potential for solar PV energy generation.

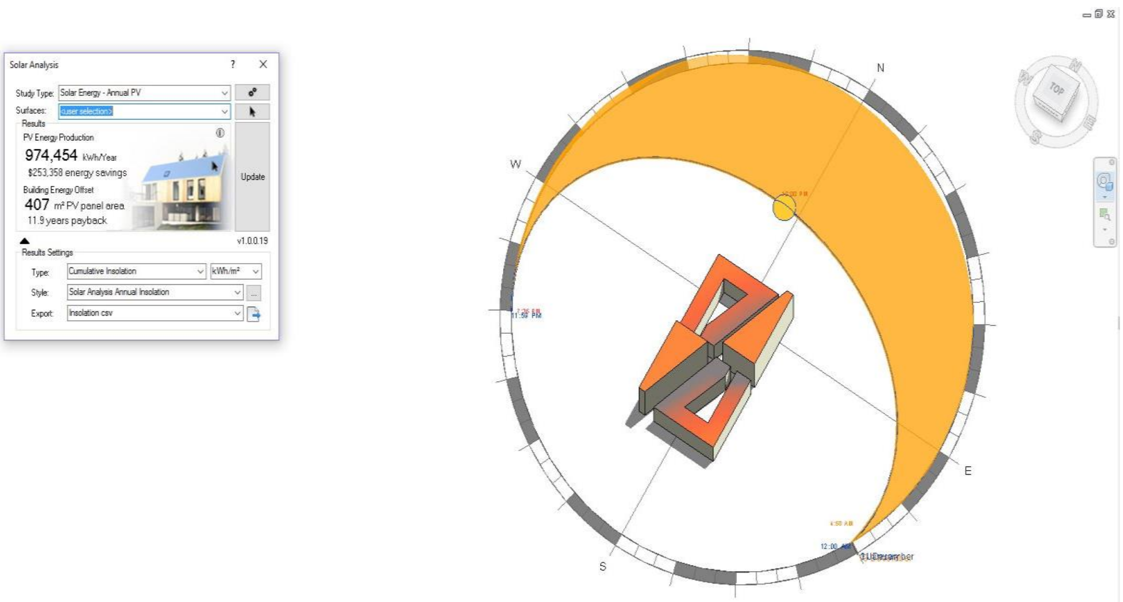


Figure 44: Potentials for solar PV energy generation of the UDF 2007, view 2. Brighter colours indicate a greater potential for solar PV energy generation.

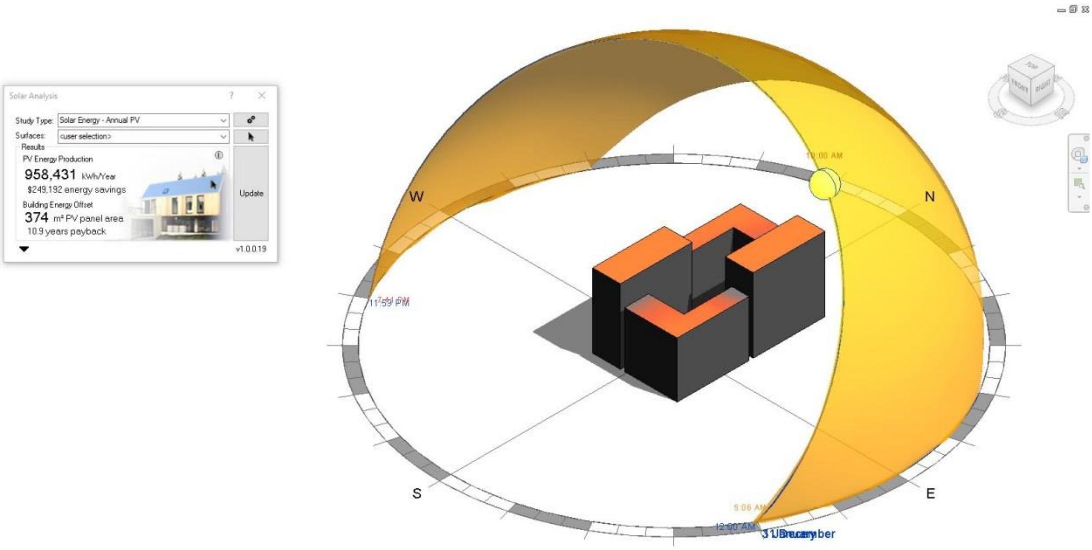


Figure 45: Potentials for solar PV energy generation of the UDF 2014, view 1. Brighter colours indicate a greater potential for solar PV energy generation.

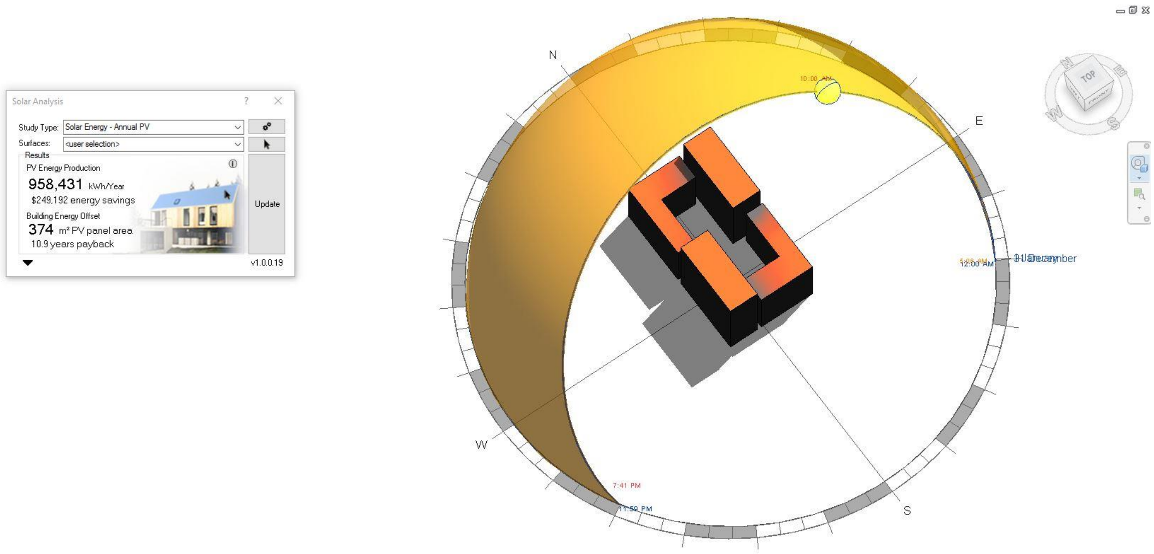


Figure 46: Potentials for solar PV energy generation of the UDF 2014, view 2. Brighter colours indicate a greater potential for solar PV energy generation.

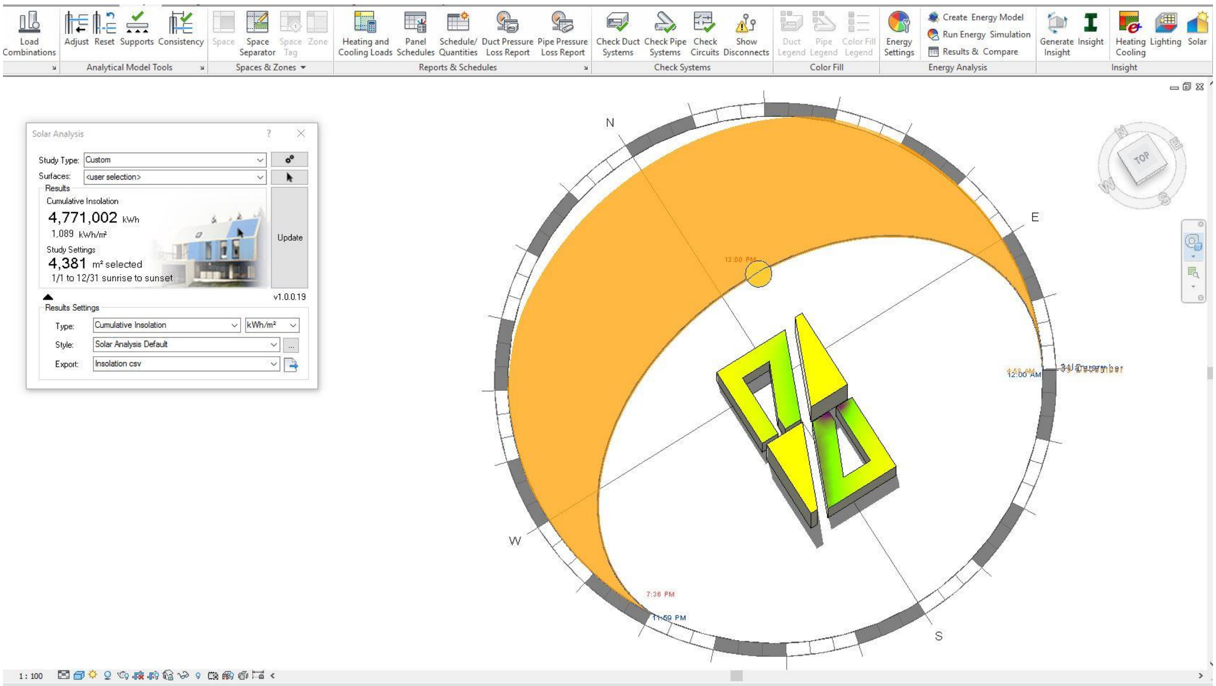


Figure 47: Annual cumulative insolation of the UDF 2007, view 1. Brighter colours demonstrate the highest solar insolation value.

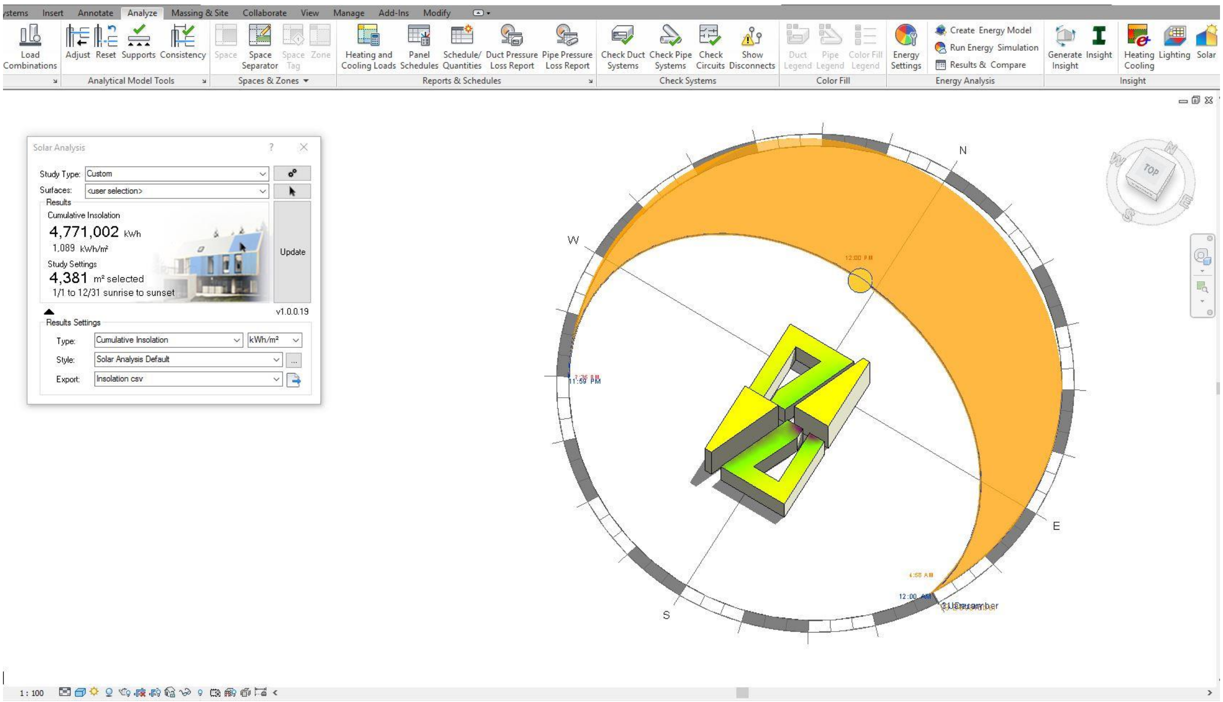


Figure 48: Annual cumulative insolation of the UDF 2007, view 2

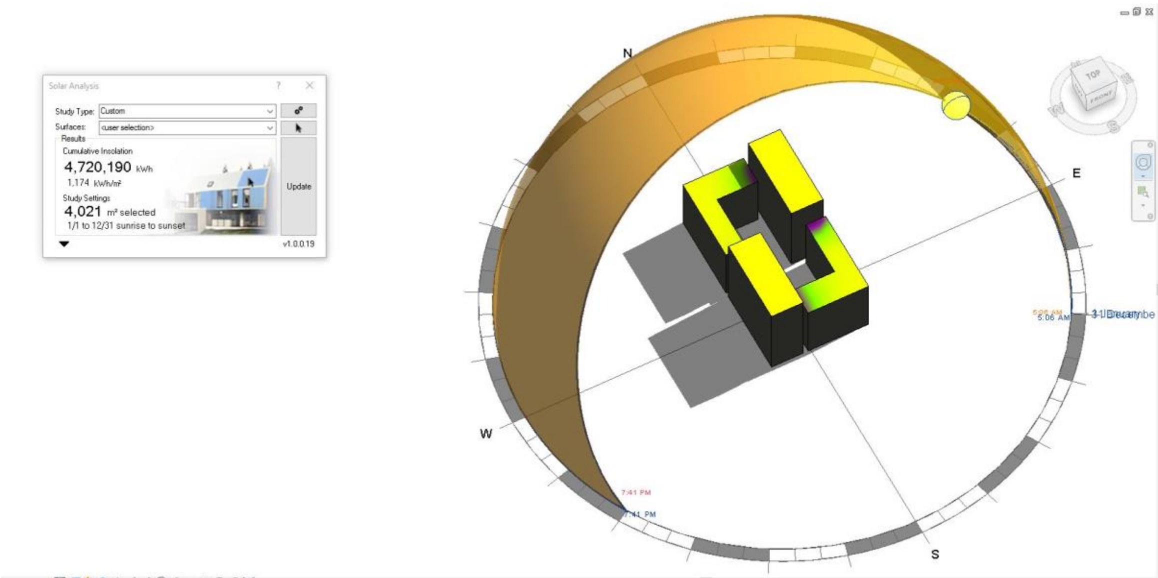


Figure 49: Annual cumulative insolation of the UDF 2014, view 1. Brighter colours demonstrate the highest solar insolation value.

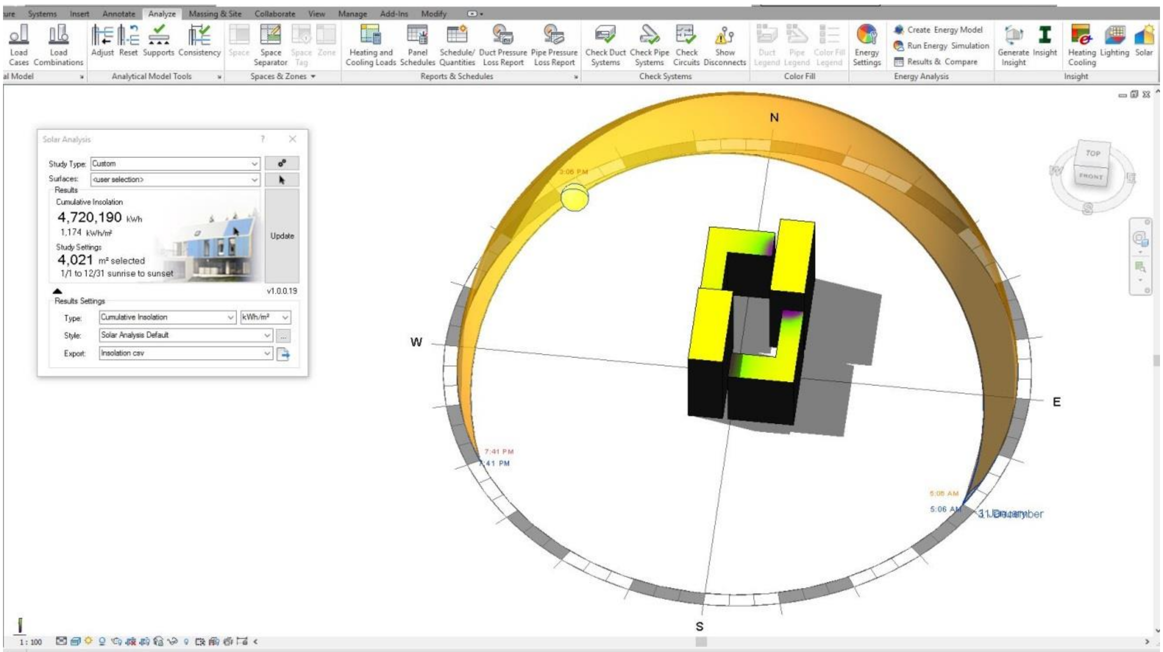


Figure 50: Annual cumulative insolation of the UDF 2014, view 2

Determining the energy performance of the two scenarios
According to the table below, the total achieved GFA for the UDF 2007 buildings was 35,830m^2. Based on the eQuest energy analysis for the UDF 2007, electricity consumption was 790,000 kWh and gas consumption was 1,926,000,000 Btu (British thermal unit). To convert the units from Btu to kWh, the Btu value should be multiplied to 0.000293.

$$1{,}926{,}000{,}000 \times 0.000293 = 564{,}454 \text{ kWh}$$

Therefore, total energy consumption (gas and electricity combined) was 1,354,454 kWh.

Table 6: Achieved Gross Floor Area in Each Urban Design Framework

Building Number	Achieved GFA (m^2) in the Urban Design Framework	
	2007	2014
19	11,030	11,488
19A	6,770	9,040
20	6,840	11,488
20A	11,190	9,040

Wynyard Central Sustainability Standards specify the target for energy consumption per square metre. The target value for residential development is 40 kWh/m^2. Therefore, the amount of the energy consummation should be divided by the total achieved Gross Floor Area (GFA) to realise the amount of energy used per square metre. Calculations showed that the UDF 2007 scenario achieved roughly 38 kWh/m^2/y. This result was below the specified target, which was a success for the scenario. According to the table, the total achieved GFA for UDF 2014 was 41,056m^2. The eQuest energy analysis demonstrated that electricity consumption for UDF 2014 was 1,440,000kWh and gas consumption was 3,764,000,000 Btu. As it is mentioned above, the conversion method is as below:

$$3{,}764{,}000{,}000 \times 0.000293 = 1{,}103{,}119 \text{ kW}$$

The total energy consumption for the UDF 2014 was 2,546,119 kWh and after dividing it by the total achieved GFA, the residential energy consumption of UDF 2014 was 62kWh/m^2/y, which exceeded the Wynyard Central Sustainability Standards. Thus, the overall energy consumption of the UDF 2007 (which had the diagonal open space plaza) was less than the target specified in the Wynyard Central Sustainability Standards.

Discussion on the building form
The results demonstrated that the UDF 2007 buildings performed more efficiently in terms of energy. This section investigates the possible contributing factors to this result. The main objective of this research is to identify the urban design parameters influencing the energy efficiency of the buildings in the case study. This research has approached the issue of climate change and sea-level rise from a mitigation perspective, so it is also important to understand the role that each of the urban design parameters play in further improvement of the energy performance of buildings, hence decreasing the amount of GHG emissions and moderating the pace at which climate change happens. Wynyard Quarter is due for inevitable redevelopment that will increase population in the area. In fact, this research

focuses on investigating the role of urban design parameters in conserving energy, which is usually generated off-site and delivered to each building.

New Zealand produces almost two thirds of its electricity using clean energy, such as hydro, geothermal, and wind power plants (The New Zealand Energy Strategy 2011-2021). However, almost one third of the electricity is generated in power plants burning fossil fuels, mainly coal. It is important to mention that most clean energy power plants are geographically located away from main users. Most of these power plants are located in the South Island while a significant number of users are in cities such as Auckland and Wellington, kilometres away from them. It is estimated that almost 30% of electricity is lost before reaching end-users in transmission and delivery. About the same percentage – one third of electricity generation – results in greenhouse gas emissions. In locations where natural gas is available, it is expected that activities such as water heating in buildings results in greater GHG emission. Therefore, the research objective to identify the most energy efficient urban form, by examining the different proposed building forms in the case study, can identify challenges and opportunities in conserving energy and the overall GHG emission from buildings. In recent years, research supports the idea that urban form has a direct impact on energy consumption, more clearly on GHG emissions. Generally, urban form is a result of various activities of a population in a certain location that are influenced by the social, economic, and environmental dynamics at play in a place. This overarching definition includes urban design parameters concerning the building form and shape.

According to the Urban Design Framework for Wynyard Quarter, this area has been undergoing massive redevelopment in recent years and will be in the future. In assessing the threats of climate change and sea-level rise to Wynyard Quarter, it is acknowledged that Wynyard Quarter is invaluable reclaimed land at a strategic place, with convenient access to the Auckland CBD, on the prominent edge of the Auckland waterfront. Therefore, the redevelopment of Wynyard Quarter is seen as the only way forward. The Wynyard Quarter Plan states that the current clearance between the ground and sea level can accommodate sea level rise over the next 100 years.

The impact of urban form parameters in energy performance

Building form, which refers to the geometrical characteristics of buildings, affects the solar gain and energy demand of buildings in the urban environment by changing the wall-to-volume ratio and the corresponding effects of over-shadowing (Lin, 2013). The 2007 proposed plan resembles a triangular geometry for the buildings and has a diagonal open space plaza between the two blocks. Based on the results of the simulation for energy consumption, the 2007 proposed plan consumed less energy than the 2014 proposed plan. In other words, it was more energy efficient. On the other hand, according to the Revit model and solar energy simulation, the UDF 2007 scenario was capable of greater on-site energy generation. The open space plaza in the UDF 2007 had a long-term impact on the overall energy efficiency of its surrounding buildings. Despite this, the enclosure ratio of the open space plaza in the UDF 2007 did not achieve the extent of its potentials due to it being long and narrow, which prevented more effective solar gains. The following considers a series of parameters contributing to energy efficiency levels.

Building height

The impact of building height on the energy demand of buildings mainly arises from its role as a practical obstacle in the urban environment. In particular, building height not only shapes the skyline of a city and alters the amount of open space at ground level, but it also affects sunlight accessibility and solar gain. The two case-study scenarios consisted of four buildings of which two had identical heights, 52 meters each. The other two buildings had different heights. The UDF 2007 buildings were shorter, at 31 meters, 8 metres from their counterparts in the UDF 2014. This difference resulted in different shading of the buildings or, in other words, being overshadowed. The lower average solar insolation value of the UDF2007 buildings could be attributed to this difference. Lower average solar insolation could result in less capacity for on-site generation contributing to the overall energy performance. However, the greater rooftop space in the UDF 2007 buildings compensated for this deficiency. Recent research suggests that the energy performance of a building improves if its residential density grows. The higher buildings of the UDF 2014 can increase their residential density as they provide bigger GFA, hence residential units. However, this variable was not measured or controlled. Without such details, it was difficult to quantify such impact on energy performance. In fact, the simulation results indicated that the overall energy demands, considering all building types together, increased as building height increased.

Orientation of the buildings

The orientation of a building is defined as the direction perpendicular to the main surface of the building. Clearly, the orientation of a building affects solar gain and energy demand by altering the incident angle and duration of sunlight. It is regarded as one of the most important parameters in housing design. Orientation is one the most important variables in the energy efficiency of a building. When the orientation of a building is laid out correctly, solar gain will be maximised, the building benefits from better quality daylighting, and the need for extra heating declines significantly. The orientation of buildings in both UDF 2007 and UDF 2014 was the same, aligning with the West North-west and East South-east orientation. The buildings were North-facing, meaning they can benefit from the North light. However, this was not the best orientation. In fact, an East-West direction is the best orientation for a building. This orientation allows for maximum possible solar gain during winter months. Research suggests that it also reduces the summer cooling energy demand (Ko, 2012). Site design solar gain should be investigated at the site design stage in order to maximise the energy conservation of a building, hence reducing its carbon footprint by reducing the GHG emission. Higher compactness in an area often results in a decrease in the PV potentials as building shading increases. This effect can be seen in UDF 2007 as the greater height differences between the neighbouring buildings resulted in a lower average solar insolation value compared with UDF2014.

Building configuration

The combination of irregular height and narrow streets results in a more compact environment, which reduces solar access and PV potential (Arboit, M., A. Diblasi, J. C. Fernández Llano, 2008). This issue can be avoided by designing an optimal building configuration that maximises solar access (Ko, 2012). The building configuration can reduce or increase the effects of shading on neighbouring buildings. With both UDF 2007 and UDF 2014, higher buildings cast shadows over the shorter buildings. This reduced solar accessibility of the shorter buildings and negatively impacted their solar PV potentials as their average solar insolation values decreased. As a result, the UDF 2007 buildings having a greater height difference demonstrated a lower average solar insolation value. The UDF 2014 buildings with a smaller height difference received better solar radiation that was demonstrated in their higher average solar insolation value. Apart from the impacts on the potential on-site energy generation, explained above, the shading of taller buildings over shorter ones becomes more critical in the winter months when objects cast shadows two to three times their height. Therefore, shorter buildings can be extremely overshadowed by taller buildings, which significantly limit their solar access.

Strategies for energy efficiency in buildings (Wynyard Quarter)
This section discusses the policies regarding energy efficiency that impact on developments in Wynyard Quarter. All the documents included in this section concern energy efficiency, mostly with a direct concern about improving energy efficiency primarily in Wynyard Quarter. The table below gives a summary of each document's priority and policy statement. The policy direction from Auckland Council and the New Zealand Government support improving energy efficiency. The New Zealand Government Energy Efficiency Strategy outlines the four main priorities for improving energy efficiency in the country. *Priority 3* concerns the efficient use of energy, with a focus on supporting warm, dry, energy efficient homes. Its focus concerns existing residential stock that performs poorly in terms of energy efficiency. Despite the fact that the policy addresses energy deficiency in terms of available housing, it does not specify targets for energy efficiency qualities. It only states a target concerning the number of houses that will be supported to become more energy efficient. The policy does not include performance criteria for energy efficiency of new housing and therefore no targets are presented. As a result, the redevelopment of Wynyard Quarter is hardly within the scope of this strategy document.

Low Carbon Auckland (A Year in Action) outlines a 30-year strategy for Auckland to become a low-carbon city. It also introduces a 10-year action plan in order to achieve the objectives of the strategy. The main objective of this strategy stems from the Auckland Plan, which is to reduce the greenhouse gas emission by 40% by 2040. The document identifies solar PV energy generation as a key to accelerate greater renewable energy generation. In contrast to the government's strategy, the Low Carbon Auckland strategy provides data on existing and future housing to increase levels of energy generation by solar PV panels.

The Auckland District Plan operative prior to the Unitary Plan emphasised the importance of sustainability and energy performance of the buildings at Wynyard Quarter. It specified the use of building design elements to ensure developments were assessed against those performance measures during the consenting process.

The sustainable development framework for Auckland's waterfront development outlines the priorities for developments within the waterfront. The key priority is for all development to be low-carbon. This includes building energy efficiency along with other measures; including onsite clean energy generation, sustainable transport modes, and minimising water to landfill. The framework introduces performance targets that are very specific in terms of building energy performance. It requires the energy efficiency of commercial buildings to be 80 kWh/m^2/y. This target is twice that for energy efficiency targets of multi-unit residential buildings, which is 40 kWh/m^2/y. The introduction of specific targets for the energy efficiency of buildings enables a better assessment of energy performance for proposed developments. The results show that UDF 2007 complies with this target by achieving 38 kWh/m^2/y while UDF 2014 exceeds this target as it achieves 62 kWh/m^2/y if these building complexes are multi-unit residential.

The above target demonstrates that UDF 2014 did not perform as efficiently as required by the standards. However, there were consequences of that development that might not have been captured. The UDF 2014 provided a greater GFA, which meant it could accommodate a larger number of residents. Although this greater population impacted on the buildings' energy performance, it was capable of conserving energy in other sectors, such as transportation. This is because it is more likely that residents in Wynyard Quarter have greater accessibility to more sustainable transport options as well as taking shorter commute distances between work and home. Therefore, a more complex system of targets should also be introduced, so as to capture the wider energy performance of developments as a whole.

The UDF 2014 asserted that a rectangular shape building provided the most efficient building footprint compared to a triangular building form. The proposed building form would complete the urban block. It also increased amenities for the residents of the building in terms of greater accessibility to daylight. Based on the results, the rectangular form performed less efficiently. Therefore, the last point about greater accessibility to daylight cannot be accepted on face value because it led to less energy efficiency. This study did not conduct an interior lighting assessment of the building models. It also did not consider any detailed interior design of the building forms. Therefore, there was not enough information available to assess how much greater the access to daylight would be for residents. Without having quantitative data, it was difficult to conclude whether the increased amount of access to daylight could rationalise the less energy efficient outcome of the proposed rectangular building form.

The Waterfront Plan acknowledges the fact that sea level rise is happening as a direct result of climate change. In response, it refers to the government guidelines (Ministry for the Environment, [2009]. Preparing for coastal change: a guide for local government in New Zealand) to demonstrate that the Wynyard Quarter ground level is adequately high enough to avoid being impacted by sea level rise in a 100-year period. The plan recognises that the waterfront can be impacted by climate change over time, but it finds solutions such as planned retreat or ground level raising unacceptable. The plan does not provide any rationale for this statement, except that being on the water's edge is the character of the place. This leaves it to the researcher to assume that the underpinning reason for development here could be the strong financial incentives to revitalise the Wynyard quarter. Such revitalisation will attract significant investments to the area, which will be coupled with increased population, amenities, and the vitality of the area. This intervention will likely rejuvenate a prime location close to the CBD which would be otherwise used for industrial activities.

The Unitary Plan policies regarding the built form, which includes maximum building height, the maximum gross floor area, and maximum site intensity are key to defining the urban form in the Wynyard Precinct. These policies are of great influence on how developments shape the precinct. These policies enable greater intensification within specified parameters that are key in informing the urban design framework and the proposition of the rectangular building form, which is studied in this research. These policies reinforce greater intensification for the precinct, hence greater GFA per developments. Therefore, it seems that they are at competition with the sustainability objectives of the precinct that are translated into standards at the development scale. They can diverge the focus from the sustainability objectives for the precinct. The real issue seems to be the lack of an assessment process at the precinct level. Although the sustainability objectives were translated into standards applicable to individual sites, there is no particular mechanism introduced to quantify the overall energy performance of the precinct. In other words, although this research demonstrates that the rectangular building form exceeds the standards for energy efficiency, there is no way to take into account the transport efficiencies that might have been gained as a result of a greater intensification.

Given that the assumption of the research is for the developments to use similar construction materials, in reality, it is still possible for the proposed rectangular built form to meet the standard for the residential energy consumption of 40 kWh/ m^2 /y, if only higher specified construction materials are used, which will likely increase construction costs.

Table 7: Strategies for energy efficiency in buildings

Report name	Agency	Priority	Policy
New Zealand Energy Strategy 2011-2021 (Ministry of Economic Development, 2011)	New Zealand Government	The strategy focuses on four priorities to support New Zealand to make the most of its energy potential: diverse resource development, environmental responsibility, efficient use of energy, and secure and affordable energy. Priority 3 primarily concerns energy efficiency in buildings and dwellings.	Areas of focus for this priority: • Warm, dry, energy efficient homes • An energy efficient transport system • Enhance business competitiveness through energy efficiency • Better consumer information to inform energy choices The policy regarding efficient homes is primarily about updating the already-built houses to improve their insulation and energy efficiency. Regarding the new developments, the policy states the Building Code will be updated to support energy efficiency by increasing requirements. The policy will also investigate market solutions to support energy-efficiency initiatives in new housing stock and will continue support so the industry can continue to support energy efficient building design through consenting process. The policy states that one of its targets is for the electricity system to be able to produce 90% of electricity from renewable sources by 2025, given the supply, security is maintained.
The Building Act 2004 (Ministry of Business Innovation and Employment, 2004)	New Zealand Government	Improving energy efficiency of building materials	The need to facilitate the efficient use of energy and energy conservation and the use of renewable sources of energy in buildings: the need to facilitate the efficient and sustainable use in buildings of

Report name	Agency	Priority	Policy
			• materials (including materials that promote or support human health) • material conservation
Auckland District Plan central area section – Wynyard Quarter (Auckland Council, 2012c)	Auckland Council	Sustainability	Encouraging low energy and sustainable building design including the use of durable, low maintenance materials, passive heating, passive cooling, and the use of solar energy. Buildings should be designed to be sustainable through the use of durable low maintenance materials, inert exterior cladding (avoiding the use of materials containing copper or zinc), maximising solar access and natural ventilation, and the incorporation of mechanical and electrical systems that optimise energy efficiency.
Low Carbon Auckland A Year in Action October 2015	Auckland Council	Low Carbon Auckland (LCA) is a 30-year strategy and 10-year action plan to guide Auckland's transformation into a prosperous, energy resilient, low carbon city. It delivers on bold targets set in the Auckland Plan to reduce greenhouse gas (GHG) emissions by 40% by 2040	Transforming the way we use and generate energy: The plan sets out a programme of 15 actions to meet and manage the increasing energy demands associated with Auckland's rapid growth. These will be achieved by improving energy efficiency and conservation, and accelerating greater use of Auckland's renewable energy resources including distributed solar photovoltaics (PV) and large-scale wind.
Becoming a Low Carbon Community An Action Plan 2015 (Waitematā Local Board, 2015)	Auckland Council	Transforming Auckland into an energy-resilient low carbon city	Implement programmes to support sustainable new buildings with energy efficient designs, use of low impact materials and less waste.

Report name	Agency	Priority	Policy
Sustainable Development Framework (Waterfront Auckland, 2013a)	Panuku Development	Waterfront Auckland's development expectations: All developments will be low carbon. This will primarily be achieved through being energy efficient, incorporating renewable energy, promoting sustainable transport modes, and minimising waste to landfill.	All developments will have a high level of energy efficiency and have energy efficient lighting and appliances Performance targets: Buildings will be required to meet high levels of performance in terms of energy efficiency, renewable energy, water reuse, and sustainable transport, as these have been identified as priority areas for the Wynyard Quarter. Building energy efficiency: Office/commercial – 80kWh/ m^2 /year Multi-unit residential – 40kWh/ m^2 /year
Wynyard Central sustainability standards (Waterfront Auckland, 2013b)	Panuku Development	Greenhouse gas emissions All developments will be low carbon. This will primarily be achieved through being energy efficient, incorporating renewable energy, promoting sustainable transport modes, minimising waste to landfill and selection and source of building materials.	No specific standard. Energy efficiency, renewable energy, transport, and waste standards will all contribute to reduction of greenhouse gas emissions. 45% reduction in CO2 emissions over BAU by 2030.

Report name	Agency	Priority	Policy
		Precinct passive design. Designs of new developments will maximise microclimate, solar access, natural ventilation, and natural light to minimise the need for heating, cooling, and artificial lighting.	All glazing to be double glazing as a minimum with performance characteristics to meet Green Star and Homestar requirements and energy targets (with the exception of some character buildings). Appropriate sun control and design for passive solar gain in winter. Minimise overshadowing and southerly aspect. Shallow floorplates to maximise cross-ventilation and light. Mixed mode ventilation to offices and other non-residential uses. Residential floorplates will combine a mix of deeper double aspect apartments and smaller single aspect apartments. Deep floorplates with long stretches of double-loaded corridors with single aspect apartments will be avoided.
		Building design optimises the roof space available for solar and makes this space available for installation of solar panels to maximise the provision of on-site renewable energy.	All developments (unless otherwise agreed with Waterfront Auckland) to be designed to accommodate solar photovoltaics (PV). Residential developments to incorporate a combination of solar PV and solar hot water heating panels. Alternatively, heat pump hot water systems can be used.

Report name	Agency	Priority	Policy
		Waterfront Auckland and a third party solar provider or consortium to work with development partners to facilitate the delivery of a precinct-wide solar system.	New developments to incorporate a roof design that optimises solar energy generation. This will mean giving consideration to roof slope, orientation, and solar access and avoiding locating plant or venting equipment on roof space if possible. If this is not possible, the space taken up by this equipment should be minimised, with a minimum of 70% of roof space on each building left clear for the installation of solar.
Auckland Waterfront Development Agency Limited (Waterfront Auckland) 2015 Annual Report	Panuku Development	No reference to sustainability objectives, GHG emission and mitigation approaches.	
Waterfront Auckland (state of intent) from 1 July 2015 to June 2018 (Waterfront Auckland, 2015)	Panuku Development	No reference to sustainability objectives, GHG emission and mitigation approaches.	

CHAPTER FOUR

CONCLUSION

LIMITATIONS & FUTURE RESEARCH

Research limitations

This section introduces the limitations experienced during the research process. One of the challenges encountered in this research was the presence of different maps of the case study site with different projected developments and building forms that were inconsistent. The inconsistencies included the various building shapes and forms, land cover areas, and bulk and open space ratios. The available maps were embedded in reports, often out of scale and dimensions. The projections of activities were not consistent despite the general assumption that the buildings will be mixed-use. There was no clear identification of the mixed-use ratio. CityEngine models of Wynyard Quarter provided the building reports in which some of the critical data, such as gross floor areas, were checked for the UDF 2007 and 2014. The modelling showed the possible setback for higher floors of buildings based on the Unitary Plan rules. However, the amount of setback modelled by CityEngine was different to the UDF 2014. In particular, the UDF 2014 showed setbacks for the highest floors of the building. The UDF 2014 and its flexibility studies did not demonstrate any setback for the 2007 building forms in the case study.

Despite significant time spent on the CityEngine model, the modelling tools could not be easily changed such that more accurate models could be generated for other sections of analysis. The models generated in CityEngine developed compatibility issues when transferring to other software. Case in point was transferring to Revit in order to conduct solar analysis. This issue required another approach in which the models for solar analysis were prepared in Sketch-Up before being imported into Revit. Another limitation of the study was that the energy consumption levels were highly dependent on several building characteristics, such as the level of glazing. With different levels of glazing or even window shapes, the results could have varied. This highlights the opportunity for further detailed design guidelines that specify the relevant quantities that can improve energy efficiency of a building within the range of energy demand targets for sustainability standards. The other limitations encountered were:

- Lack of up-to-date maps, scale, and land-use concerning the study area
- Difficulties in accessing information about the energy performance of local construction materials
- The differences between software default details and units (as the software was U.S. based)
- Inconsistent information, particularly the plans of proposed building forms in the UDF 2007
- Time constraints for simultaneous learning of different software packages during the research project
- Different building typologies presented in different maps. For the triangular building, there were different versions and shapes in terms of it being a solid triangular block or a semi-open court.

Conclusions
The results of all the simulations done in the present study have already been analysed in the previous chapter. Based on the analyses, the following conclusions are drawn:

The triangular and open-court shape blocks, which were proposed for the case study site in the UDF 2007, could improve the energy efficiency of a building by up to 50%. This form improved the energy efficiency by increasing the building's capacity to gain more solar energy. Both scenarios that were based on the UDF 2007 and the UDF 2014 could benefit from better orientation that would improve their solar gain and daylighting accessibility. It was better to construct the buildings based on maximum height limitation as compactness with correct building configuration could lead to a more energy efficient building. The energy simulation tools utilised in this research, that is, eQUEST, have used the Design Development wizard. This modelling approach can be later upgraded to the Energy Efficiency Measure (EEM). The EEM wizard provides a stronger control over the variables, such as roof insulation, exterior wall insulation, window exterior shading, and ground floor insulation, which can generate energy efficiencies for more accurate modelling.

The results of the simulations showed that the greatest energy load in both the UDF 2007 and the UDF 2014 comprised artificial lighting. This proved that a better orientation of buildings could improve daylighting in the buildings and reduced the need for extensive artificial lighting. The introduction of targets in the guidelines or standards documents provides a baseline by which the new developments can be assessed or evaluated. This provides greater confidence in design efficiency and governance agency to monitor the compliance of new developments with expected energy efficiency outcomes. The energy efficiency standards introduced for an area should include individual measures, such as residential average energy used per square metre per year. The standards should also incorporate other measures that can capture the overall energy efficiency of an area in order to provide an in-depth understanding of the policy impacts.

Recommendations

The sustainability standards should provide measures for individual developments as well as integrated measurements of energy efficiency of developments. This means that the overall energy efficiency of a precinct should be assessed by considering the impact of developments in other energy-intensive sectors such as transportation. By having this model, standards that are more flexible can be produced, which will focus more objectively on energy efficiency of the built environment and the long-term mitigation of greenhouse gas emission. The other recommendation concerns the building heights proposed in either of the urban design frameworks. An urban design guideline should specify the range for height difference between buildings on the same site so that the capacity for on-site solar energy generation is not significantly impacted. Results show that a greater height difference between adjacent buildings on the same site can result in a lower average solar insolation value, which reduces the capacity for on-site energy generation. Hence, this results in less reduction of greenhouse gas emission. The urban design guidelines should identify a range of building configurations, shapes, and orientations that provide the most energy efficient urban forms. The range provides a variety of options from which designers can choose and indicates the levels of compliance with energy efficiency standards and targets. It also provides the opportunity to include other best practice urban design approaches that combine with and support energy efficiency targets.

Future research

This research has studied the impact of urban form parameters on the energy efficiency of buildings based on two scenarios for a case study. The research used eQUEST as the energy modelling software. Despite the valuable findings of the research, the researcher experienced a number of limitations. This research considered solar PV panel installation on rooftops as the means for clean energy generation. Future research can consider the solar gain by façades as a means for additional on-site clean energy generation. The scope of the research was limited to an urban block. Future research can expand its scope to the neighbourhood level, so it can include a variety of building forms and typologies. This research focused on urban design parameters and their impact on energy efficiency, hence a focus on mitigation of adverse impacts on climate change. Future research can study urban planning parameters, such as the impact of socio-economic variables, including population density, on achieving more energy efficient urban forms. The eQUEST software was developed in the U.S. As a result, its setting is configured to U.S. units, default standards, and values. Future research utilising eQUEST outside the U.S. should be wary of the time required for the adaptation of local information to the software parameters, unless it is decided to use software more compatible with specific locales.

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