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Urban Net Zero Energy Commercial Buildings (NZEB), are they possible?

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PREFACE

This research paper was submitted in partial fulfilment of the requirements of the Bachelor of Building Science (Honours) degree at Victoria University of Wellington School of Architecture and Design in 2009.

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EXECUTIVE SUMMARY

This paper examines the feasibility of refurbishing an existing office building to be a Net Zero Energy Building (NZEB) in the Wellington City Central Business District. Takes, as a case study, an existing low energy refurbishment project in Wellington and determines what building re-design measures are still needed to lower the annual energy consumption below the energy generation capabilities of the site. Measured energy data from 2008 is compared with the Energy Plus simulation of the existing building to calibrate a 'Truth Model'. The truth model is then altered with energy efficient design measures and energy generation technologies to achieve net zero energy.

The goal of the project was to answer the question: are zero energy buildings currently possible in New Zealand? The project is one of New Zealand's contributions to an International Energy Agency collaborative research project which are targeting production of design guidance and a source book of international buildings and technologies that demonstrate such projects are feasible anywhere. The IEA project has thus far revealed that although they are not a common way to build, there are examples of NZEB's around the world. It has also begun the work of standardising the definitions of 'Net Zero' to permit transparent inter-country comparisons.

New Zealand's contribution to the IEA NZEB project is a small part of the BRANZ Building Energy End-use Study (BEES). This project focuses on end-uses of energy in non-residential buildings. The approach adopted is a microcosm of the general BEES philosophy: to base the research analysis on data on the performance and end-uses of energy in real buildings. It is understood that if a zero energy design strategy becomes the standard way of building, then two of the more urgent aspects of a sustainable future – reduced carbon emissions and greater energy independence – have been addressed. Should buildings over time become not merely net zero but energy generators, then they may serve to be a healing influence on the environment.

The analysis presented in this paper focuses on several key issues relating to the feasibility of sustainable Net Zero energy non residential buildings: the role of the urban context in the feasibility of 'Net-Zero' because of over-shadowing and interference with wind flow patterns; the balance between building design and applied 'green' technologies; the split between lighting energy use, space conditioning energy use and electrical appliance energy use in a typical non-residential building.

ACKNOWLEDGEMENTS

I wish to acknowledge the following people who have contributed to the completion of this report. First my supervisor Michael Donn for all his guidance, knowledge, ideas and support throughout this year, and for being the course coordinator; Nigel Isaacs for all his help and encouraging words; and David Alcock for his help, walk through and knowledge of Conservation House. I also acknowledge the three institutes that have made all this possible; BRANZ/BEES for the financial support through scholarships; Department of Conservation for the use of Conservation House in my research; and Victoria University of Wellington. Lastly I thank my fellow Building Science students who have made this year great and bearable.

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LIST OF DEFINITIONS AND ABBREVIATIONS

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

BMS: Building Management System

BTU: British Thermal Units

CBD: Central Business District

CCT: Correlated Colour Temperature

CIBSE: Chartered Institution of Building Services Engineers

CRI: Colour Rendering Index

DALI: Digital Addressable Lighting Interface

DOC: Department of Conservation

EECA: Energy Efficiency and Conservation Authority

EIA: Energy Information Administration

EPA: Environmental Protection Agency

GWh: Giga Watt hours

HAWT: Horizontal Axis Wind Turbines.

IEA: International Energy Agency

kWh/m^2-yr: kilo Watt hours per square metre, per year

LPD: Lighting Power Density

MJ/m2: Mega Joules per metre squared

MWh/yr: Mega Watt-hours per year

NZBC: New Zealand Building code

NZEB: Net Zero Energy Building

NZS: New Zealand Standards

PJ: Peta Joules

PV: Photovoltaic

R-value: Insulation's resistance to heat flow.

US DOE: United States Department of Energy

VAV: Variable Air Volume

VAWT: Vertical Axis Wind Turbines.

CHAPTER 1- ENERGY DILEMMA

1.1 Study Aim

The aim of this project is to demonstrate that it is possible to refurbish an existing office building to be a Net Zero Energy Building (NZEB) in the Wellington City Business District (CBD). The purpose of this project is to determine how close New Zealand is to being able to refurbish buildings to NZEB status. On a national scale this could help facilitate some major changes in the building industry. Money could be invested into refurbishing commercial buildings around New Zealand to make them zero energy buildings to free up energy demand. A revision in the building code to cater for NZEBs could be introduced to create a new building refurbishment guide/code that buildings must comply with. Both of these changes would help lead New Zealand to a much more independent and secure future.

This study not only applies to refurbishing commercial buildings in the Wellington CBD but also to new construction. "New construction projects offer the greatest opportunity to achieve zero energy and retrofitting buildings is often difficult because of the lack of freedom in integrating the design" (Media 2009). If it is possible to refurbish to zero energy, it should also be possible for new buildings to achieve this performance. Another aspect is the Wellington climate. Wellington is an average climate for New Zealand in terms of temperature and sunlight hours. The main climatic difference when comparing Wellington to other towns and cities is the very strong wind environment.

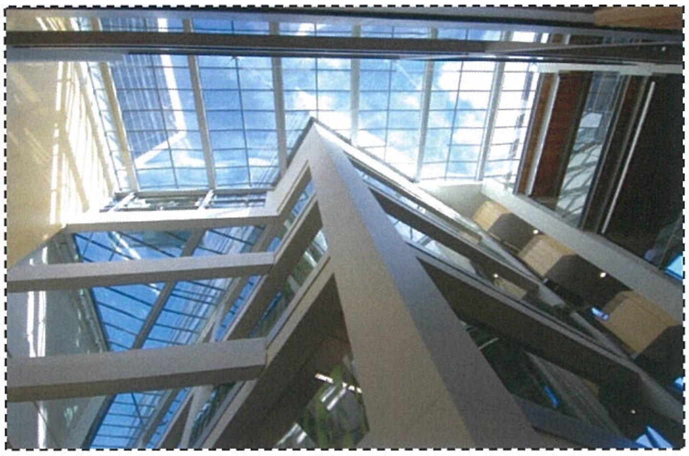
1.2 Global Energy Crisis

The easiest method to slow the effect of climate change would be to use less energy. For buildings this would be achieved firstly through energy efficiency and eventually using zero energy. The concept of NZEBs is that it produces as much renewable energy as that consumed by the building, so on an annual basis it consumes zero energy (Torcellini, et al. 2006).

The total global energy consumption in 2006 was 138.38 Billion kilo Watts (kW) ((EIA) 2006). A large portion of this energy is consumed by buildings. The building sector in the USA accounted for 38 percent of the total energy use and the commercial sector is responsible of 13 percent of the total energy consumption (U. D. (DOE), 2005 Buildings Energy Databook 2005). In New Zealand, commercial buildings account for approximately 10 percent of the total consumer energy consumption and in 2008 they used approximately 51.9Peta Joules (PJ) (14,417Giga watt hours) ((MED) 2009, 24-25).

Picture 1 – Conservation House Active Chilled Beam (Photo: 12/06/2009)

Picture 2 - Conservation House Atrium (Photo: 18/06/2009)



There are existing examples of NZEB's around the world and some are in relatively similar climates to Wellington. One example of a NZEB that is in a similar climate to Wellington is the Environmental Technology Centre at Sonoma State University (ETC) located in California. Wellington's average daily maximum temperature in mid-winter is 5.9°C and the average daily maximum temperature in mid-summer is 20.3°C ((WCC) 2009). ETC is located in Rohnert Park, California. Rohnert Park has an average winter temperature of 9°C and an average summer temperature of 20°C (T. W. Interactive 2009). This is closely comparable to the Wellington temperatures. ETC is a Laboratory in use and is of new construction completed in July 2001. It is in an urban setting with a floor area of 204m^2 and has an annual net energy consumption of -4.6kWh/m^2-yr (IEA, Environmental Technology Center at Sonoma State University 2008). This shows that it is possible to build NZEB's in New Zealand's climate.

Table 3 highlights the main differences between existing NZEBs around the world. The buildings displayed are from the International Energy Agency (IEA) NZEB database and are those entered into the database as of 17th of October 2009. These buildings are shown because they demonstrate that there is no specific climate or building use that is ideal for getting to zero energy. It is noteworthy that the building floor areas are relatively small. Also, none of the buildings are located in a densely urban environment; these two factors may have a large impact on achieving zero.

Table 3 – Existing NZEB's and High-Performance Office Building (As of 16 September 2009)
(Department of Energy 2009)

NZEB Building Name	Location	Building Use	Floor Area (m²)	Annual Energy Consumption (kWh/m²-yr)	Intrinsic Energy Consumption (kWh/m²-yr)
Aldo Leopold Legacy Center	Baraboo, Wisconsin	Commercial office; Interpretive Center	1100	-6.36	49.1
Audubon Center at Debs Park	Los Angeles, California	Recreation; Interpretive Center;	467	0	54.2
Challengers Tennis Club	Los Angeles, California	Recreation	325	-3.03	28.6
Environmental Techology Center, Sonoma State	Rohnert Park, California	Higher education; Laboratory	204	-4.64	7.3
Hawaii Gateway Energy Center	Kailua-Kona, Hawaii	Commercial office; Interpretive Center; Assembly; Other	334	-10.9	87.2
IDeAs Z2 Design Facility	San Jose, California	Commercial office	609	0	77.5
Oberlin College Lewis Center	Oberlin, Ohio	Higher education; Library; Assembly; Campus	1260	-13.3	101.7
Science House	St. Paul, Minnesota	Interpretive Center	142	0	55.6
Steinhude Sea Recreation Facility	Steinhude, Germany	Recreation	296	0	202
Highest Performing Commerical Building	**Location**	**Building Use**	**Floor Area (m²)**	**Annual Energy Consumption (kWh/m²-yr)**	**Intrinsic Energy Consumption (kWh/m²-yr)**
Wind NRG Partners Manufacturing Facility	Hinesburg, Vermont	Commercial office; Industrial	4320	47.9	47.9

2.31 Intrinsic Energy Consumption

The intrinsic energy consumption of a NZEB is the annual energy consumption of the building before the energy generated, by generation technologies, is deducted. This value is useful when considering how low the energy demand needs to be before attempting to offset it to zero. It is recommended to aim for an annual energy consumption of 63kWh/m^2-yr (20,000BTU/ft^2-yr) (Media 2009). However, the average energy consumption of the eight NZEBs in the IEA NZEB Database is 73.6kWh/m^2-yr (Department of Energy 2009). This value is higher than the recommended and is not indicative of the intrinsic energy consumption needed to get to zero energy. This is due to each NZEB having a different use, size and surrounding site context (See Table 3 for an overview of each NZEB).

CHAPTER 3- NET ZERO ENERGY DESIGN PRINCPLES

The following chapter assesses the potential of energy generation technologies and energy lowering measures in NZEBs.

3.1 Energy Generation Technology

Some energy generation technologies are suited to different situations than others. In highly built-up areas there is limited site area and significant over-shadowing around the buildings due to the dense nature of the urban environment. The climate must also be assessed because different weather activities and variations can play an influential role in the energy generation potential.

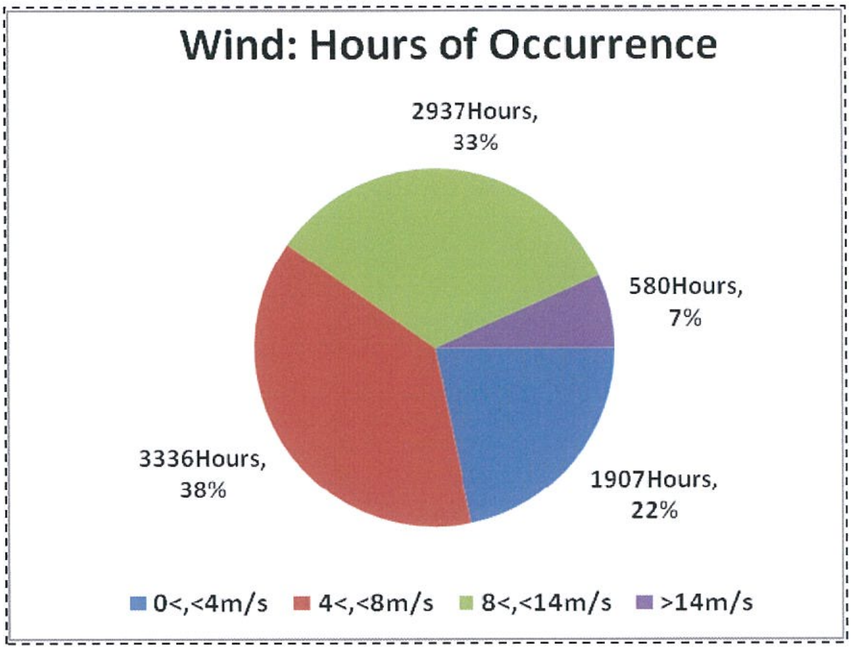
3.11 Wellington CBD Generation

The most common and available sources of energy for generation in the Wellington CBD would be solar and wind energy. Due to the restrictions on site area and the majority of the empty site space is on the rooftops, rooftop mounted Photovoltaics (PV) and Wind turbines will be investigated as the energy generation technologies for the large commercial building refurbishment.

A Typical Meteorological Years hourly direct and diffuse solar radiation data was gathered for Wellington (Liley 2007). Wellington receives 1,482kWh/m^2/yr of direct solar radiation, 586kWh/m^2/yr of diffuse radiation and the total amount of radiation is 2,086kWh/m^2/yr.

A Typical Meteorological Years hourly wind speed data was gathered for Wellington (Liley 2007). Figure 6 displays the percentage breakdown of the total number of wind hours for four wind speed intervals in Wellington. The four way breakdown is to highlight the different wind turbine generation steps: no generation wind speeds (0-4m/s); cut-in wind speeds (4-8m/s); maximum generation wind speeds (8-14m/s); stable generation and cut-out wind speeds (>14m/s). A large majority of hours exceed 4m/s which indicates that wind will be a good option for generating energy. This is due to most wind turbines having a minimum wind speed threshold of approximately 4m/s. The maximum wind speed threshold differs between wind turbine efficiencies. A standard high-efficiency rooftop mounted wind turbine has a cut-out wind speed of approximately 25m/s (Everwind and Inc 2009). The hourly maximum Wellington wind speed for a Typical Meteorological Year is 21.6m/s; this is outside of the cut-out wind speed range.

Figure 6 – Wellington Wind Hours of Occurrence



3.12 Photovoltaic Cells

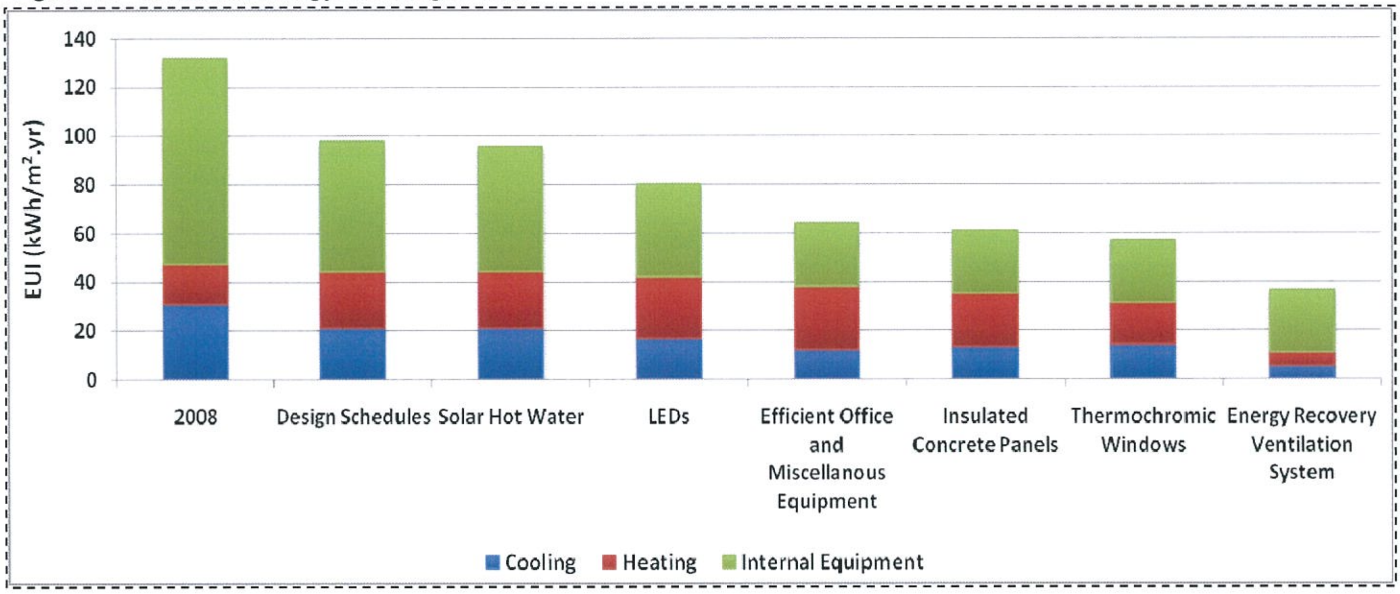
Photovoltaic (PV) cells convert solar radiation into electricity that can be used directly by a building, stored in a battery for later use or sold directly to a power grid. The PV cells are connected together to create a PV module and make up a PV system. PV modules are rated on wattage of energy generated basis or efficiency, e.g. a 150 watt cell will generate 150 watts in the 1000W incident standard test conditions or it has an efficiency of 15 percent. As the sun is the energy source, the more direct the PVs face to the sun; the more energy can be generated. PVs can be situated flat or tilted towards the sun on a building's roof or façade and can be connected to a sun tracking system that follows the sunpath throughout the day. PV can generate energy in direct and diffuse sunlight, "although their output is diminished. Flat PV modules do not need direct sun to work and can generate 50 to 70 percent of their rated output under bright overcast conditions" (SEANZ 2008). Thus, factors to be considered when designing PV systems are:

- the module size;
- the shape;
- the efficiency (efficiency ratings are based on a test in standard conditions of 1000W/m^2 at 25°C);
- the solar climate;
- solar shading;
- orientation;
- climate temperature; and
- energy production needs.

5.3 Lowering Techniques

Each individual energy efficient design and technology used in lowering the existing Conservation House energy consumption towards zero was simulated in Energy Plus. The energy lowering techniques were simulated in a step by step process starting with the existing calibrated model and then the first lowering measure. Figure 15 displays the simulation results from Energy Plus. It shows the energy consumption changes throughout the different energy lowering techniques. The green represents the internal electrical loads, the red is the heating and the blue is the cooling. The design changes were simulated to firstly improve the internal electrical energy consumption (e.g. domestic hot water, lighting and electrical equipment) and once that was lowered the space conditioning energy consumption was lowered (heating, cooling and ventilation). This process was completed because the internal loads have an impact on the space conditioning consumption.

Figure 15 – Simulated Energy Lowering Results



The first change was not a design change. It was applying the design schedule inputs from the engineer's energy performance model to the existing calibrated model. This change was made to bring the building back to a standardised schedule for design analysis purposes. The change of schedules significantly lowered the internal electrical loads. Due to this, there was less internal heat gains, the cooling consumption dropped and the heating consumption increased. These results prove the model is reliable because the consumption is between the designed 89 to 102kWh/m^2.yr. The overall energy consumption reduction was 34.5kWh/m^2.yr.

Solar hot water reduces the domestic hot water energy consumption by '75 percent' (EECA 2009) and lowers the annual consumption by 2.25kWh/m^2.yr (Refer to Appendix 11.3 for calculation).

50W, 14W, 12W, 6.7W and 5W LED lamps were used to replace the existing fluorescent lighting in Conservation House. The correlated colour temperatures (CCT) of the lamps are between 2700 and 3000 Kelvin (K) and the Colour Rendering Indices (CRI) were between 80 and 95 (Refer to Appendix 11.4 for full lamp specifications). The LED lighting reduced the consumption of the internal electrical loads by 15kWh/m^2.yr.

Efficient computers, printers, fax machines and miscellaneous equipment were installed to replace the existing internal electrical equipment. The existing computers were replaced with high efficiency 28W desktops and 18W monitors, while the other office and miscellaneous equipment were replaced with various more energy efficient equipment (Refer to Appendix 11.5 for equipment specifications). The change in equipment reduced the electrical equipment consumption by 16kWh/m^2.yr.

Due to the newly lowered internal heat gains from the more efficient internal equipment, the heating has increased. To lower the heating, Insulated Concrete Panels were attached to the exterior of the shaded facades. The current R-value of the external walls is 1.55m^{2o}C/W. A variety of R-values were tested and it was found that any value over an additional 3.0m^{2o}K/W has a minor effect on reducing the space conditioning energy consumption. With the additional 3.0m^{2}K/W added to the exterior, the annual consumption is reduced by 3kWh/m^2.yr. Table 6 displays the simulation results of the four additional ICP insulations that were tested.

Table 6 – Tested Additional ICP Insulation

End-use	50mm Foam Insulation - R1.5	75mm Foam Insulation - R3.0	145mm Foam Insulation - R5.6
Internal Equipment	25.68kWh	25.68kWh	25.68kWh
Heating	12.64kWh	13.15kWh	13.59kWh
Cooling	22.74kWh	22.05kWh	21.60kWh
Total	**61.06kWh**	**60.88kWh**	**60.87kWh**

The heating was still the majority of the space conditioning consumption. To lower this, Thermochromic windows replaced the existing tinted single glazing used on the Manners and Willis double facades, as well as the atrium roofs (Refer to Appendix 11.6 for Thermochromic modeling details). Thermochromic windows lowered the annual consumption by 4kWh/m^2.yr.

The Energy Recovery Ventilation System converted decreased the heating consumption by 70 percent and the cooling consumption by 60 percent. With the Energy Recovery Ventilation System installed the annual energy consumption would be lowered by 20kWh/m^2.yr (Refer to Appendix 11.7 for ERV details).

The newly refurbished Conservation House annual energy consumption is 274.4MWh. This results in an EUI of 36.4kWh/m^2.yr. This was achieved largely through efficient internal equipment and an Energy Recovery Ventilation System. These two energy lowering measures are vital in achieving such low energy consumption. The energy efficient internal equipment reduced the annual energy consumption by 33 percent and the Energy Recovery Ventilation System reduced it by a further 36 percent.

The LEDs and Thermochromic windows are experimental/leading edge technologies. Due to this, there is a question of whether they are current or cost viable options for the refurbishment. If they were not used in the redesign of Conservation House the lowered energy consumption would be approximately 52kWh/m^2.yr. This still achieves the aimed reduction of 50 percent of the New Zealand best practice energy standard; this proves that with technically mature and cost viable energy efficiency design techniques there can be a significant reduction in energy consumption. It also suggests that the New Zealand energy standards could be changed to aim for a maximum annual energy consumption similar to or below the figure set for the Green Star rating scheme.

CHAPTER 6 –ENERGY GENERATION

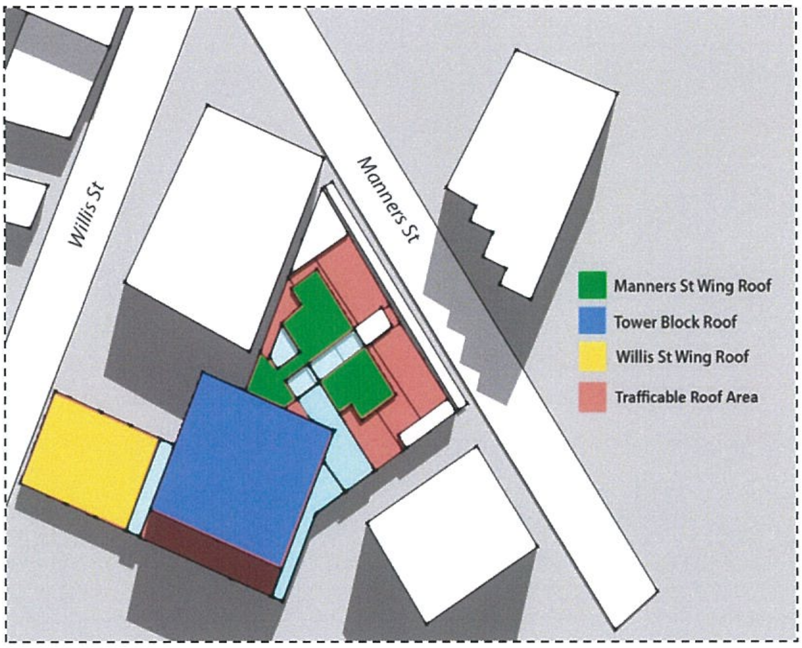
The following chapter examines the current DOC site's energy generation capabilities for rooftop wind turbines and photovoltaic systems.

6.1 Existing Urban Site Shading Study

Conservation House is situated in the city centre; because of this it has external shading from solar radiation, wind directions and wind velocity. To assess the shading at the existing site, a site analysis was completed of the sun path, solar shading, wind accessibility and the boundary layer.

6.11 Solar Shading

Figure 16 – Non-trafficable Roof Plan



A solar shading study was undertaken to determine the direct and diffuse exposure to solar radiation at the DOC site. This was achieved by creating a 1:1 model of the site, building and external shading sources in Sketch-up (Google 2009), and using a plug-in named SunTools (Technology 2009) to generate the shading. Wellington's longitude and latitude were input into the program to create an accurate representation of the suns position. A plan view of the non-trafficable roof was exported as a JPEG at hourly intervals for the relevant summer and winter solstices sunshine hours (Refer to Figure 16 for a roof plan). An approximate shading percentage of non-trafficable roof area for the Manners wing, Willis wing and Tower block was estimated and totalled for each day (Refer to Figure 17a and 17b for an example solar shading image). The two percentages were averaged to produce a yearly shading factor for each rooftop. The Manners wing is shaded for 57 percent of the year, Willis wing is shaded for 54 percent of the year and the Tower is not shaded at all throughout the year (Refer to Appendix 11.8 for solar shading study).

Figure 17a – 9am Summer Solstice Solar Shading

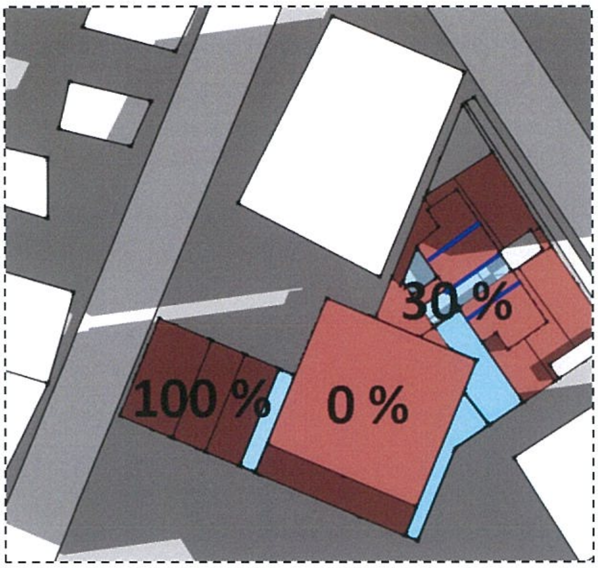
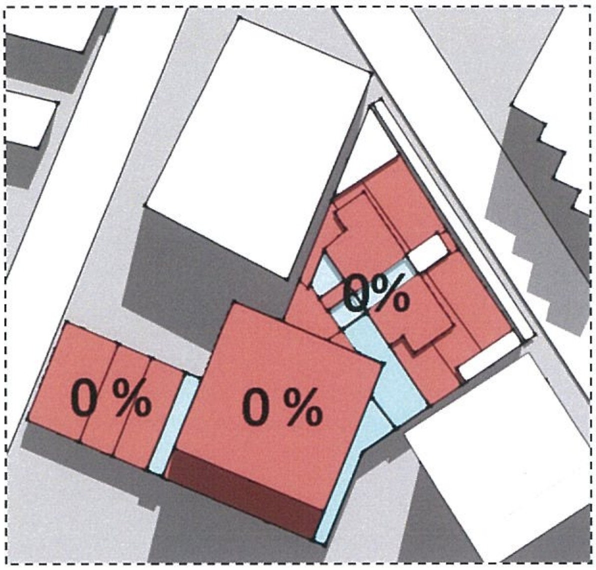


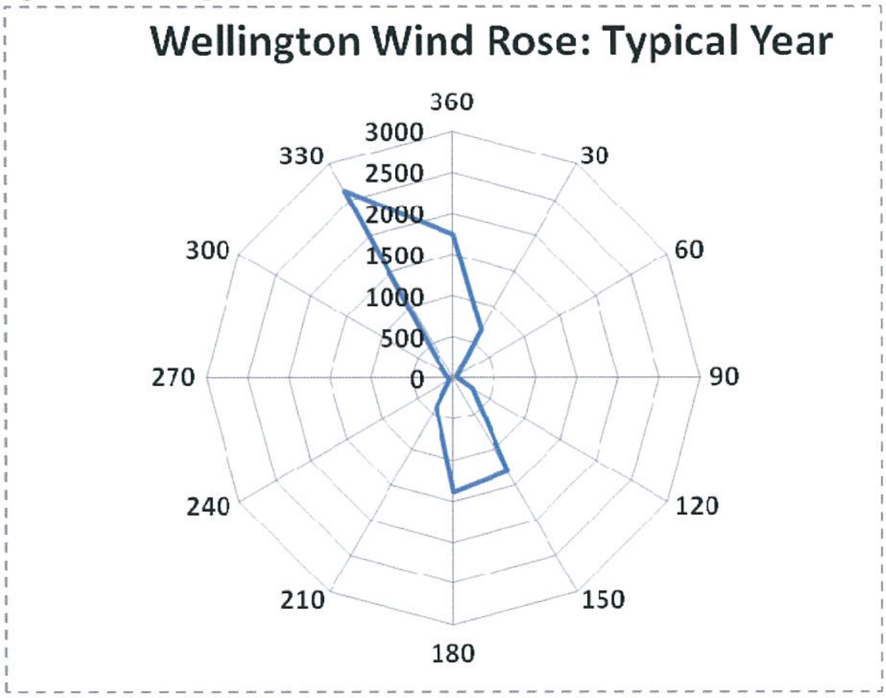
Figure 17b – 12pm Summer Solstice Solar Shading



6.12 Wind Shading

Each of the three rooftops are sheltered differently from the wind, due to the surrounding urban environment. A study into which wind directions will be accessible to the separate roofs was undertaken as well as a boundary layer study to determine the effect of the urban setting on the wind speeds. Figure 18 displays the wind rose for a typical Wellington year, this indicates which wind directions are prominent (the outside scales) and the hours of occurrence (the vertical scale).

Figure 18 – Wellington Wind Rose



An assessment of the site and surrounding streetscape was completed by examining the surrounding building heights and a street map of Wellington (Refer to Figure 19a and 19b).

It was determined that the Tower block roof is exposed to all wind directions as it is equal to or above all immediate surrounding buildings. The Manners wing roof has exposure to northerlies from the winds travelling up Willis St and down Boulcott St into Manners St. The Willis wing roof is exposed to northerlies and southerlies that funnel through Willis St.

Figure 19a - Surrounding Streetscape and Building Heights

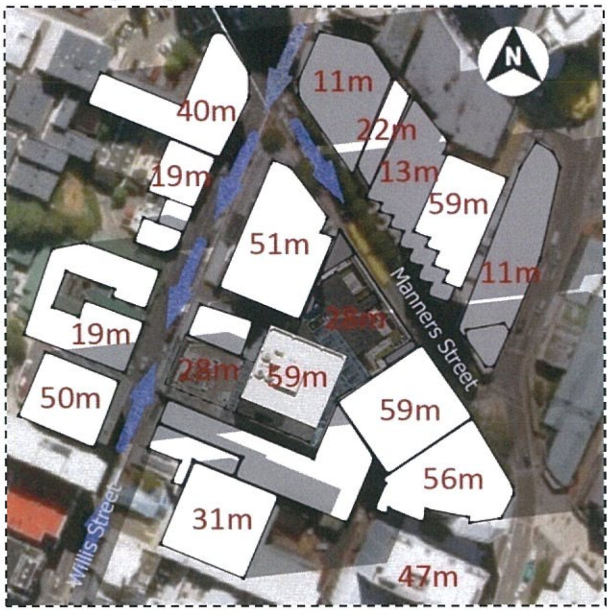


Figure 19b - Rooftop Level Wind Speeds

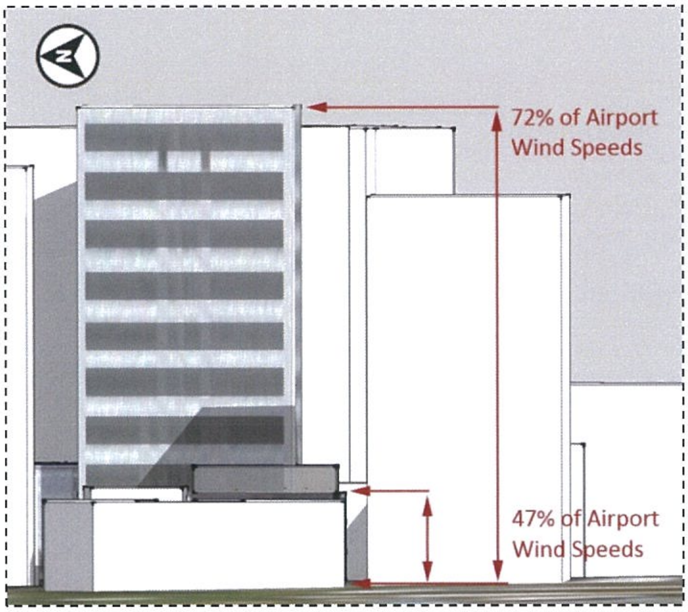


Figure 19b displays the effect of the high-rise urban setting on the different rooftop level wind speeds. The percentages on the right are the total wind speed percentages when compared to the weather data gathered at the Wellington airport (i.e. 72 percent of the Wellington Airport recorded wind speeds). This shows that all of the roof tops are affected from wind shading. The Tower rooftop is the least effected with a factor of 0.28 and the podium rooftops are the most effected with a factor of 0.53.

From these studies it is concluded that the podium level is the most affected by the surrounding environment from both solar and wind shading. The Manners wing roof wind and sun accessibility is the most affected by the urban setting. The Willis wing roof is approximately the same height as the Manners wing and is affected by the boundary layer in the same manner, but it is not sheltered as severely from all wind directions and solar radiation. Due to these factors, PV will be utilised on all three rooftops, however wind turbines will not be placed on the podium and only the Tower rooftop (For a wind turbine generation analysis comparing the Podium and Tower placements, see Appendix 11.9).

6.2 Energy Generation Scenarios

There are many positions the wind turbines can be placed on the building's rooftops. The aim was to situate the turbines in locations that would have the least shading impact on the PV system. The PV arrays were tilted to improve the efficiency and collect more solar radiation. Figure 20a and 20b display the two energy generation scenarios with layouts for the wind turbines and the PV arrays. The two energy generation scenarios were examined to assess the effect of the urban environment on PV and wind turbines. The scenarios were chosen because each one is optimised for an energy generation technology. The Split Scenario is optimised for maximum output from the wind turbines and the Mixed Scenario is optimised for the PV.

Split Scenario

The Tower Block roof can incorporate seven 10kW turbines around the facade edges and three within the perimeter of the rooftop. The Manners rooftop can contain 176m^2 of tilted PV arrays and the Willis rooftop can provide space for 249m^2 of PV arrays.

Mixed Scenario

The Mixed Scenario has a higher PV to wind turbine ratio. The Tower Block roof can incorporate six 10kW turbines around the facade edges and will have little shading impact on the PV arrays. The Tower can contain 220m^2 of tilted PV arrays, the Manners rooftop can contain 176m^2 of PV arrays and the Willis rooftop can provide space for 249m^2 of PV arrays.

Figure 20a – Split Energy Generation Scenario

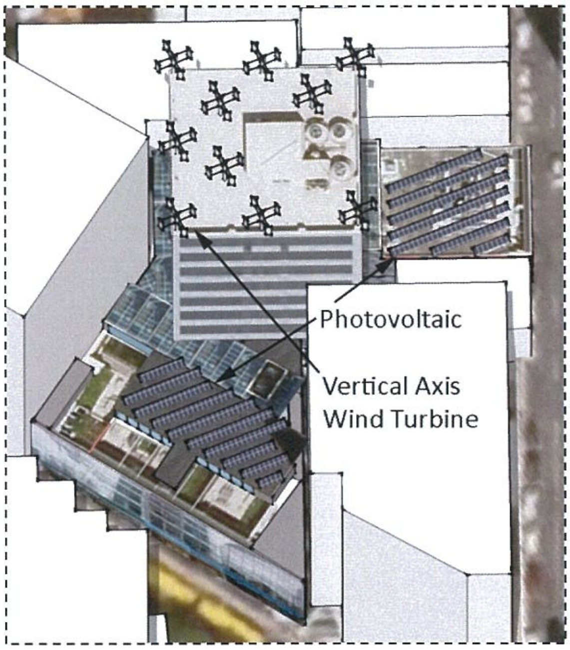
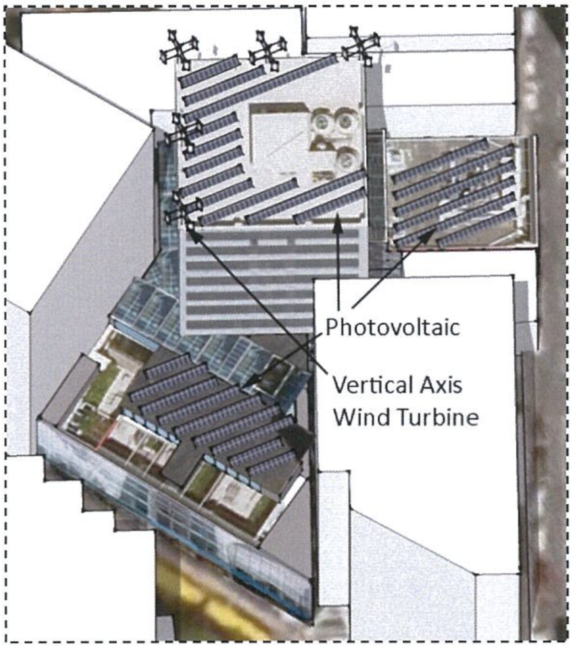


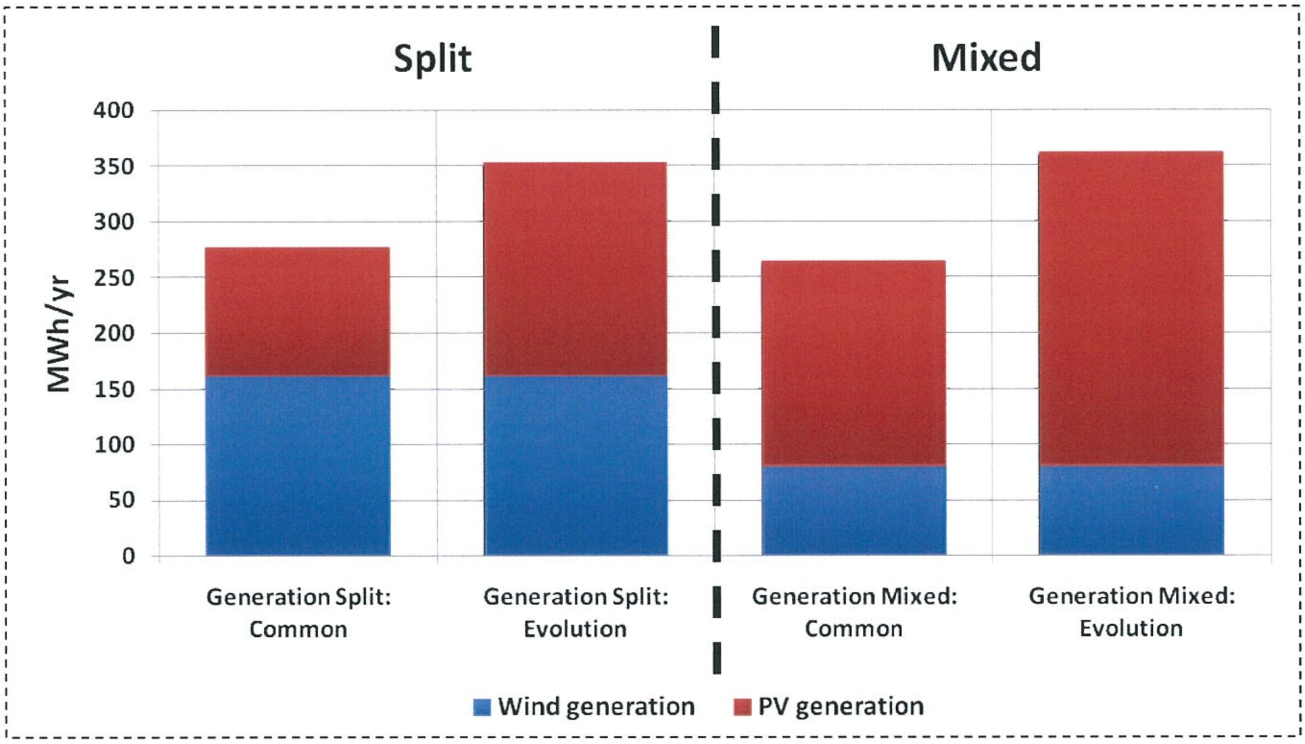
Figure 20b – Mixed Energy Generation Scenario



The two scenarios were tested and calculated to examine two PV circumstances. The first being labeled Common and is the current high efficiency PV that is widely available. The Evolution scenario is the efficiency that is on the cutting edge of the PV technology. It is tested and proven currently, but is not mass produced. This is to demonstrate what could be possible in the near future.

The results in Figure 21 are calculated using the wind generation and solar generation equations found in chapter 3, the Typical Meteorological Years Wellington weather data (Liley 2007), the wind shading study, solar shading study, the Everwind 10kW rooftop mounted generation ratings and the PV's generation efficiency (Refer to Appendix 11.10, 11.11 and 11.12 for Calculations).

Figure 21 – Energy Generation Calculation Results



The graph above shows a typical year's generation from wind turbines in the blue, and PV in the red for both the split scenario on the left and the mixed scenario on the right. In Figure 21, having more turbines on the tower will currently produce more than a mixed PV and turbine set up. But, as the PV efficiency increases, this changes and the mixed set up will produce more in the future. The common split scenario can generate 36.6kWh/m^2.yr while the mixed generates 35kWh/m^2.yr (The EUI is the energy generated divided by the total floor area of Conservation House). The evolution split scenario can generate 46.8kWh/m^2.yr and the mixed generates 47.9kWh/m^2.yr. Wind turbines placed on the podium generate 73 percent less energy due to the shading from the surrounding buildings (Refer to Appendix 11.9 for calculations and a comparison to the Tower placement). This proves that it is not a viable option to generate energy from wind in low lying positions of an urban area.

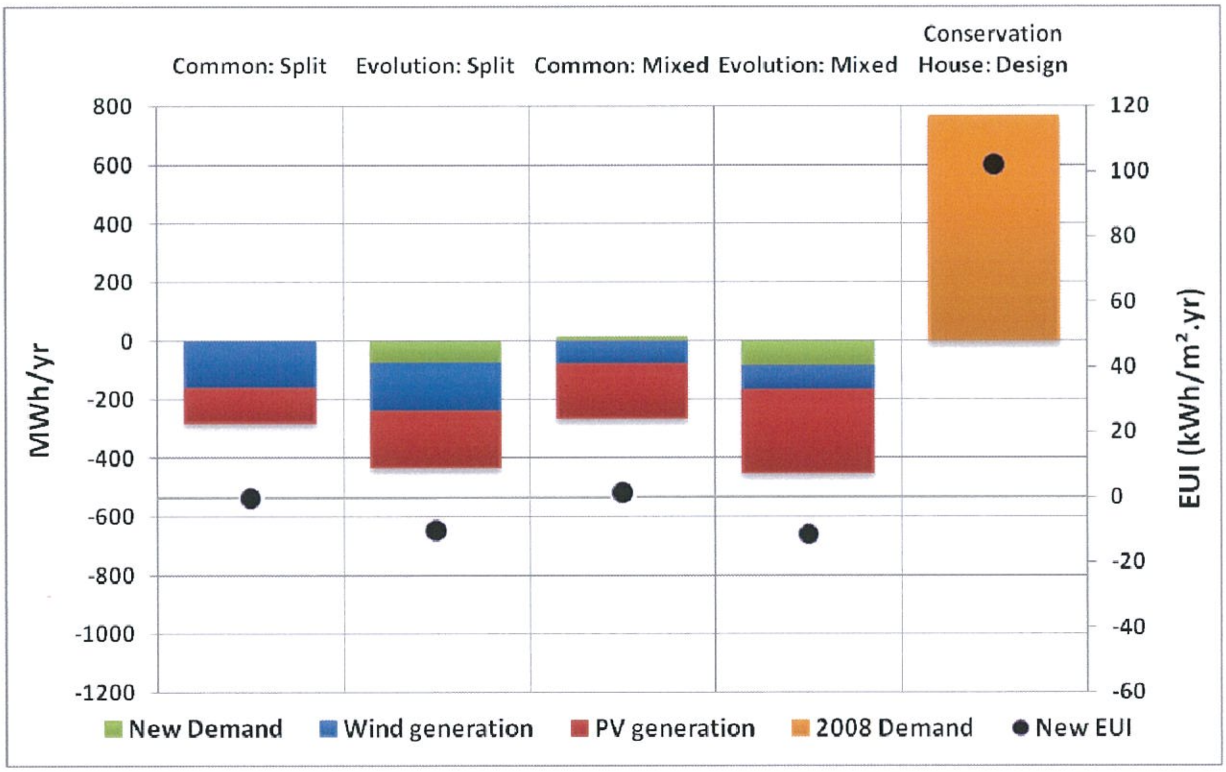
CHAPTER 7 – ENERGY BALANCE

The following chapter examines the balance between energy lowering of the refurbished Conservation House and the energy generation capabilities. The building is also assessed in an open site with no surrounding shading.

7.1 Current Urban Site

In order to be net zero energy, the energy consumed must at least equal the energy generated. Conservation House consumes 36.5kWh/m^2.yr and this must be equalled by the energy generated by the PV and VAWTs. Figure 22 below shows the energy generated by the VAWTs in the Blue, the PV in the red. The new annual energy consumption, with the energy generated subtracted to give the net demand, is in the Green and the new EUI's are the black dots (with generation subtracted). For a comparison, the Conservation House design energy consumption has been added and is the orange (Refer to Appendix 11.13 for energy balance equations).

Figure 22 – Overall Refurbished Conservation House Energy Balance



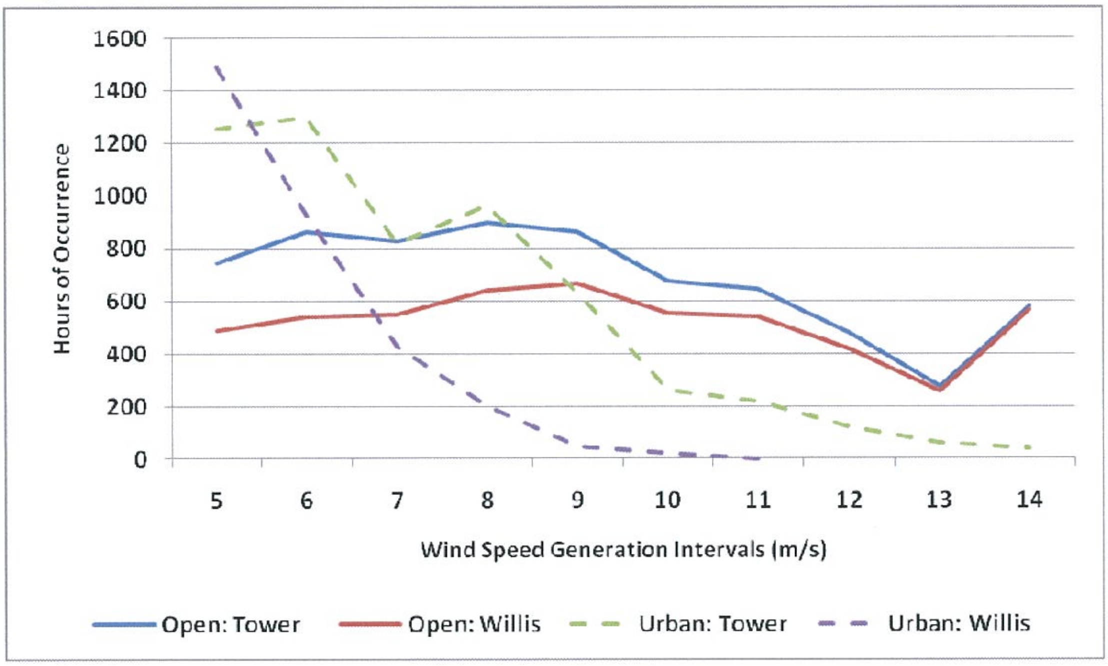
In Figure 22, the new annual net energy consumption is 0kwh/m^2.yr, and in the near future it is predicted the building could generate 11kWh/ m^2.yr of excess energy. This proves that it is currently, or in the very near future it will be, possible to refurbish existing commercial office buildings to be NZEBs in the Wellington CBD, and in the future urban buildings could be energy producers.

If the wind turbines were placed on the podium of Conservation House, the resulting affect of the boundary layer would result in 58 percent of the annual energy being offset (Refer to Appendix 11.9 for energy balance calculations). This highlights the effect that the urban environment has on achieving zero energy.

7.2 Open versus Current Urban Site

The refurbished Conservation House was calculated and simulated in Energy Plus on an open site in Wellington with no surrounding environmental shading. In an open site in Wellington it is possible to generate more energy than the current site. The boundary layer and urban setting has a very large impact on the wind generation capabilities. The difference in wind hours of occurrence between site location and wind turbine location can be seen in Figure 23. As can be seen, the occurrence of higher wind speed hours decreases rapidly due to the boundary layer for both the Tower and Willis wing rooftops.

Figure 23 – Wind: Hours of Occurrence between Site and Wind Turbine Location

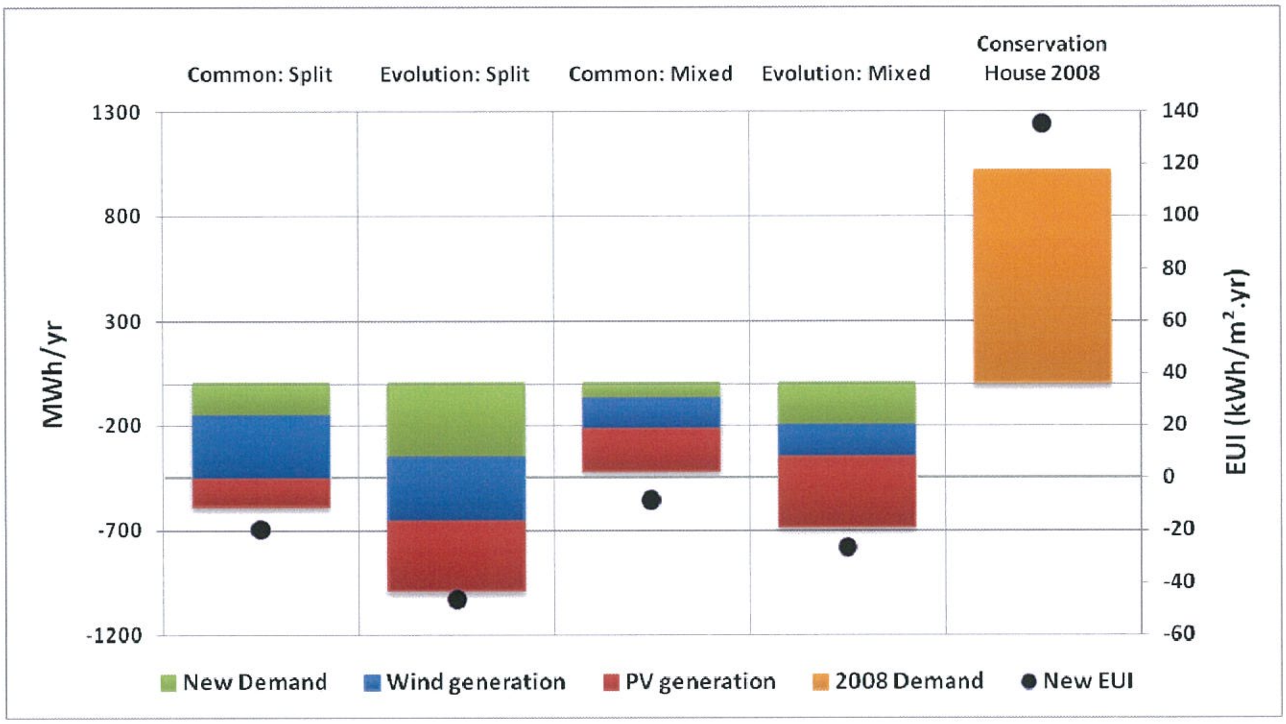


External solar shading from the neighbouring buildings and terrain causes the current urban site to produce 87 percent of the energy available at an open Wellington site. The change in PV generation is the decrease in direct radiation hours within the urban setting. Despite this, the primary energy generator changes from solar in an urban setting, to wind in the open site.

Figure 24 displays the results of the common and evolution energy balance between consumption and generation for an open Wellington site (Refer to Appendix 11.14 for energy balance equations). Energy Plus simulated that the refurbished Conservation House, on an open site, consumed more energy annually due to the increase in solar radiation leading to more overheating. If this building were really to be built on an open site this might be dealt with by a redesign incorporating more solar shading. The annual energy consumption is 291.1MWh.

However in an open site the energy generation technologies produce more energy than the urban site because of less shading from the surrounding environment. Conservation House can currently be an energy producer in either generation scenario, with the Common: Split scenario currently having a net energy consumption of -20kWh/ m^2.yr. This proves it is more economical to place energy generation technologies in an open area, due to it generating more than an urban site does currently.

Figure 24 – Open Wellington Site: Overall Refurbished Conservation House Energy Balance



This also indicates that wind and sun energy generation for a region or neighbourhood that is feeding into the grid may well be more suited placed in an open site rather than a dense urban area. The reduction in the overall effectiveness is:

- Common: Split – 37 percent less energy generated on an urban site.
- Common: Mixed – 25 percent less energy generated on an urban site.

If the energy generation was to be placed on an open site it would be more beneficial to deploy HAWTs instead of the VAWTs because they have higher efficiencies.

CHAPTER 8 - NET ZERO ENERGY INFERENCE

It has been demonstrated that it is currently possible within the site boundaries to refurbish existing office buildings, even in a high-rise city centre, to be NZEBs in Wellington. In the future, these urban buildings could be energy producers. Efficient internal loads and an Energy Recovery Ventilation System play a pivotal role in achieving net zero energy. The LEDs, energy efficient computers, and other electrical equipment reduced the annual energy consumption by 33 percent. The Energy Recovery Ventilation System reduced it further by 36 percent. Another important conclusion is the building use hours. A change from the current 6.00am to 11.00pm building hours, to an 8.00am to 6.00pm schedule restored Conservation House to the designed annual energy consumption. As expected, the way that the building is being used has a large impact on the annual energy consumption. This is significant because this operational change wipes out all the surplus energy generated by the PV and wind turbines. The way people use a theoretically zero energy building clearly has a huge potential impact on whether or not it achieves zero status.

It was shown that it is not a viable option to generate energy from wind in low lying areas of a densely built up environment. If the wind turbines were placed on the podium it would result in only 58 percent of the annual energy consumption being offset. It has also been found that more energy is generated from PV and wind turbines when placed on an open site. There was a 25 to 37 percent increase in energy generation when the two generation scenarios, tested in this study, were placed on an open site. This proves it is more economical to place energy generation technologies in an open area, due to it generating more than an urban site currently does.

Net zero energy is not restricted to buildings in an open site context. It was proven that a large commercial office building in a high-rise city centre can achieve a net zero energy status. This is an important finding as there are many large non-residential buildings in a downtown area that are shaded by a variety of surrounding buildings. In addition, because Conservation House is a refurbishment of the 1980s Mid-city Theatre, it can be assumed that common non-residential buildings can be refurbished to be NZEBs. This suggests that it is possible for these other large non-residential New Zealand buildings to be refurbished with current technology to be NZEBs. This means that if needed, money can be used to refurbish current buildings to consume zero, if not produce excess energy in New Zealand to increase energy security and independence.

The current energy efficiency code requirements can be more stringent towards the whole building design. A simple change in the energy standards can have a large impact, for example every new building requiring an Energy Recovery Ventilation System. It has been shown that a standard building can be refurbished well inside the maximum Green Star rating energy consumption of 105kWh/m^2.yr with technically mature energy efficient design alterations. This suggests that energy standards could be changed to aim for a maximum annual energy consumption similar to or below the figure set for the Green Star rating scheme. If this was undertaken, the national energy consumption would lower substantially with associated increases in New Zealand's energy security and independence.

CHAPTER 9 – FUTURE WORK

In order to extend this research to the wider New Zealand community it is necessary to test some of the assumptions built into this methodology.

- There is a need to assess different building sizes and types.
- Need to assess other climates to prove it is not unique to the Wellington weather. This would be achieved by applying the study to the rest of NZ to see if it is possible in other regions. The rest of NZ has different weather, and it would be interesting to see this impact on achieving zero.
- Are the building design technologies used to lower the energy consumption the only technologies that can be used? Or is there a suite of solutions that can be incorporated into a building's design.
- Is it cost viable to reach net zero energy? Can it be an economical method of building? Can it be a standard way to building currently? A cost analysis and cost effectiveness analysis study of getting to zero would answer these questions.

Other work would be to look into the actual wind accessibility in urban areas. This is important because the current method of factoring in the wind shading is theoretical. It would be good to measure the actual wind speeds at the different rooftop levels with an anemometer or such device and compare the two methods.

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CHAPTER 11 - APPENDICES

11.1 2008 Conservation House Measured Energy Use Index (EUI)

Equation Used

Energy Use Index = Annual Energy Consumption / Total Floor Area

Tenant

Energy Use Index = 685,013kWh/7549m^2

Energy Use Index = 90.74221751

= 91kWh/m^2.yr

Landlord

Energy Use Index = 335,690kWh/7549m^2

Energy Use Index = 44.46814148

= 44kWh/m^2.yr

11.2 Conservation House and Energy Plus Model Assumptions

Materials

The materials observed at Conservation House are as follows. The specific materials information was gathered from the engineer's simulation model of the energy performance for the Conservation House design analysis. ((SKM) 2006)

Material Information	Name	Roughness	Thickness	Conductivity	Density	Specific Heat	Thermal Absorptance	Solar Absorptance	Visible Absorptance	Thermal Resistance
Units			m	W/m-K	kg/m3	j/kg-K				m2-K/W
	AcousTile	Medium Smooth	0.015	0.058	288	586	0.9	0.5	0.7	
	ConcStruct150	Rough	0.15	0.87	1800	920	0.9	0.65	0.65	
	ConcScre	Medium Rough	0.05	1.28	2100	1000	0.9	0.65	0.65	
	CarpFini	Very Rough	0.01	0.6	186	1360	0.9	0.7	0.8	
	ConcIntFlr	Rough	0.275	1.13	2000	920	0.9	0.65	0.65	
	ClinkConcBlck	Rough	0.105	0.6	1520	1059	0.9	0.65	0.65	
	MinWlBord50	Medium Rough	0.05	0.048	240	1050	0.9	0.6	0.6	
	PlastBord12	Smooth	0.012	0.16	960	837	0.9	0.4	0.92	
	TerrazTile	Smooth	0.025	1075	2400	850	0.9	0.65	0.65	
	ConcStruc125	Medium Rough	0.125	0.87	1800	920	0.9	0.65	0.65	
	Aggregate	Very Rough	0.075	0.55	1580	1057	0.9	0.65	0.65	
	Soil	Very Rough	1	0.329	1515	796	0.91	0.76	0.76	
	Steel	Smooth	0.01	43	7800	500	0.25	0.53	0.5	
	Metal	Smooth	0.005	43	7800	500	0.25	0.53	0.5	
	MinWlBord90	Medium Rough	0.09	0.048	240	1050	0.9	0.6	0.6	
	Plaster	Smooth	0.02	0.42	1200	837	0.9	0.4	0.92	
	plastBord25	Smooth	0.025	0.16	960	837	0.9	0.4	0.92	
	ConcStruc275	Medium Rough	0.275	0.15	400	925	0.9	0.65	0.65	
	200mmAIR	Smooth					0.8	0.5	0.5	1.4
	100mmAIR	Smooth					0.8	0.5	0.5	0.71
	50mmAIR	Smooth					0.8	0.5	0.5	0.35

Glazing

The glazing materials observed at Conservation House are as follows. The specific glazing information was gathered from the engineer's simulation model of the energy performance for the Conservation House design analysis and what information was missing was input from the NREAL Energy Plus example buildings materials of two glazing options (e.g. Spectral Data, Dirt Correction Factor and Solar Diffusing). ((SKM) 2006)

Window Material: Glazing Information	**Units**		
Name		**4mmClear**	**6mmClearLowE**
Optical data type		SpectralAverage	SpectralAverage
Thickness	m	0.004	0.006
Solar transmittance at normal incidence		0.5952	0.4264
Front side solar transmittance at normal incidence		0.3548	0.5236
Back side solar transmittance at normal incidence		0.3548	0.5236
Visible transmittance at normal incidence		0.6092	0.44
Front side visible transmittance at normal incidence		0.3408	0.51
Back side visible transmittance at normal incidence		0.3408	0.51
Infrared transmittance at normal incidence		0	0
Front side infrared transmittance at normal incidence		0.999	0.999
Back side infrared transmittance at normal incidence		0.999	0.999
Conductivity	W/m-K	3.3687	3.3687
Dirt correction factor		1	1
Solar diffusing		No	No

Construction

The current constructions that were observed at Conservation House are as follows. The specific construction layers were gathered from the engineer's simulation model of the energy performance for the Conservation House design analysis. ((SKM) 2006)

Wall Name/Type	Outside Layer	layer 2	layer 3	layer 4	layer 5
Aceiling	ConcStruc275	ConcScre	200mmCav	ACousTile	
Cceiling	ConcStruc275	ConcScre			
IntWall	PlastBord12	50mmCav	PlastBord12		
CExtWall	ClinkConcBlck	MinWlBord50	PlastBord12		
MExtWall	metal	MinWlBord90	Metal		
CVExtWall	Plaster	ClinkConcBlok	50mmCav	PlastBord12	
GroFloor	Soil	Aggregate	ConcStruc125	ConcScre	TerrazTile
IntFloor	CarpFini	ConcScre	ConcStruc150		
Vent	Steel				
Opti4mm	4mmClear				
6mmClearLowE	6mmClearLowE				

Type of Lamps, Office Equipment and Miscellaneous Equipment

While undertaking the energy audit of Conservation House the types of lamps/luminaries, electrical equipment, miscellaneous equipment and occupancy were recorded from observations. The following tables show the results. The luminaries were established from the lighting schedules from the building specifications. (SKM and Plus 2005)

Lamps and Luminaries

Fitting Type 1

REXEL - Eluci Suspended Luminaire: Between Chilled Beams in Offices

Fitting Type 2

REXEL Dibuchi DOT 2000 Luminaire: Kitchens, Circulation spaces and Outside Bathrooms

Fitting Type 3

REXEL Slimpak Luminaire: Meeting rooms and Printer areas

Fitting Type 4

REXEL Slice recessed Luminaire: Labratories, Library and Reception

Fitting Type 5

REXEL Prisma Mask Luminaire: Ground Floor Meeting rooms

Fitting Type 6

Reflected Plan

REXEL Slimpak Luminaire: Emergency Lighting

		Total Fitting Load
Fitting Type	Lamp Type	(Watts)
1	1 x 49W Compact Fluorescents	49
2	1 x 26W Compact Fluorescents	54
3	1 x 49W Compact Fluorescents	49
4	Fluorescent T5 4 x14W	60
5	1 x 26W Compact Fluorescent	26
6	Fluorescent T5 1 x 49W	49
7	1 x 80W Incandescent	80
8	1 x 14W Compact Fluorescent	450
9	2 x 14W Fluorescent T5	28
10	Fluorescent T5 4 x 26W	200
11	1 x 50W MR16	50

Fitting Type 7

REXEL Luminaire: Bathrooms

Fitting Type 8

REXEL Lite Compact Luminaire: Reception

Fitting Type 9

REXEL Luminaire: Ground Floor and Reception

Fitting Type 10

REXEL Defender Luminaire: Ground Floor Storage and Labratories

Fitting Type 11

Ground Floor Meet-ing rooms

The office equipment manufacturers were recorded from the observations made and loads were gathered from the product specifications.

Office Equipment

Office Equipment	Equipment Name	Peak on Demand	Sleep Mode Demand	Number of Units
Computer	DELL and HP 19" Monitors	0.117	0.078	390
	DELL Core 2 Duo and HP Pentium 4 Desktops	0.117	0.006	353
Laminator	Ibico IL-19VT Laminator	1.38	-	1
Shredder	Prima Opera 35 Shredder	0.23	-	1
Printers	Konica Minolta Bizhub 6450	2.00	0.12	12.00
	Konica Minolta Bizhub 7255	2.00	0.12	1.00
	HP Deskjet 1220c	0.48	0.11	1.00
	HP Laserjet 8150n	0.69	0.11	1.00
	HP Buisness Inkjet 2600	0.07	0.02	1.00
Fax	Cannon Fax L900	0.78	0.05	2
	Cannon Fax L500	0.78	0.05	1
	Cannon Fax L350	0.78	0.05	1
	Brother Fax 2850	0.94	0.07	1
	Brother Multi-Function Centre MFC 970mc	0.94	0.07	1

The miscellaneous equipment was recorded from the observations made and the loads are based on the average load of the specific item use. (Carter 2009)

Miscellaneous Equipment

Office Equipment	Peak Demand	Stand-by Mode Demand	Number of Units
Refridgerator	0.30	N/A	15
Oven	3.00	0.0050	2
Microwave	1.10	0.0028	3
Coffee Machine	0.80	0.0010	2
Television	1.60	0.0064	1

Count of Lamps, Occupancy, Office Equipment and Miscellaneous Equipment per Zone

While undertaking the energy audit of Conservation House the lamps/luminaries, office equipment, miscellaneous equipment and occupancy were counted and observed.

Luminaire Count

Floor/Zones	Lamp Number											
Ground Floor	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**Total**
1stMan	12											**12**
1stManAtriumN												
1stManAtriumS												
1stTower	20	11	29		18	6		6	21		18	**129**
1stWillAtrium												
1stWill		10	29	35		6	6			32		**118**
2ndFloor	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**Total**
2ndMan	94	69	61		2	9						**235**
2ndManAtriumN			4									**4**
2ndManAtriumS												
2ndTower	53	3	18	39			3					**116**
2ndWillAtrium												
2ndWill												
3rdFloor	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**Total**
3rdMan	94	21	29		3	11						**158**
3rdManAtriumN			4									**4**
3rdManAtriumS												
3rdTower	71	29	38	30		3	3					**174**
3rdWillAtrium												
3rdWill	60	14	7		3	8						**92**
4thFloor	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**Total**
4thMan	94	33	37		6	29	2					**201**
4thManAtriumN			8									**8**
4thManAtriumS												
4thTower	71	29	38	30		3	3					**174**
4thWillAtrium												
4thWill	60	14	7		3	8						**92**
Total	**629**	**233**	**309**	**134**	**35**	**83**	**17**	**6**	**21**	**32**	**18**	**1517**

The office equipment from left to right correspond to the equipment names on page 55 from top to bottom.

Office Equipment

Floor/Zones	Office Equipment Types														
Ground Floor	Computer		Laminator	Shredder	Printers					Fax					Total
1stMan															
1stManAtriumN															
1stManAtriumS															
1stTower	6	6													12
1stWillAtrium															
1stWill	10	10													20
2ndFloor	Computer		Laminator	Shredder	Printers					Fax					Total
2ndMan	61	61			3										125
2ndManAtriumN															
2ndManAtriumS															
2ndTower	3	3													6
2ndWillAtrium															
2ndWill															
3rdFloor	Computer		Laminator	Shredder	Printers					Fax					Total
3rdMan	61	76			2										139
3rdManAtriumN															
3rdManAtriumS															
3rdTower	47	53						1	1		1				103
3rdWillAtrium															
3rdWill	31	31			2					1					65
4thFloor	Computer		Laminator	Shredder	Printers					Fax					Total
4thMan	62	72	1	1	3							1			139
4thManAtriumN															
4thManAtriumS															
4thTower	47	53				1	1						1		102
4thWillAtrium															
4thWill	31	31			2								1		64
Total	359	396	1	1	12	1	1	1	1	1	1	1	2	0	775

Miscellaneous Equipment

Floor/Zones	Miscellaneous Equipment Types					
Ground Floor	Refridgerator	Oven	Microwave	Coffee Machine	Television	Total
1stWill						20
2ndFloor	Refridgerator	Oven	Microwave	Coffee Machine	Television	Total
2ndTower	1				1	2
3rdFloor	Refridgerator	Oven	Microwave	Coffee Machine	Television	Total
3rdTower	2					2
4thFloor	Refridgerator	Oven	Microwave	Coffee Machine	Television	Total
4thMan	8	2	3	2		15
4thTower	2					2
Total	13	2	3	2	1	21

The occupancy was calculated from the observations made while completing the energy audit.

Occupancy

Ground Floor	People
1stMan	
1stManAtriumN	
1stManAtriumS	
1stTower	4
1stWillAtrium	
1stWill	2

2ndFloor	People
2ndMan	59
2ndManAtriumN	
2ndManAtriumS	
2ndTower	8
2ndWillAtrium	
2ndWill	

3rdFloor	People
3rdMan	59
3rdManAtriumN	
3rdManAtriumS	
3rdTower	48
3rdWillAtrium	
3rdWill	29

4thFloor	People
4thMan	59
4thManAtriumN	
4thManAtriumS	
4thTower	48
4thWillAtrium	
4thWill	29

Total	345

Lamp, Office Equipment and Miscellaneous Equipment loads per zone

From the observations and count recording, the electrical load for each zone was calculated for the lamps, office equipment and miscellaneous equipment. The following table displays the results from the calculations.

Ground Floor	Lamps (Watts)	Equipment(Watts	Misc (Watts)	Total
1stMan	588			588
1stManAtriumN				
1stManAtriumS				
1stTower	7945	1404		9349
1stWillAtrium				
1stWill	11235	2340		13575

2ndFloor	Lamps	Equipment	Misc	Total
2ndMan	11232	20274		31506
2ndManAtriumN	196			196
2ndManAtriumS				
2ndTower	6221	702	600	7523
2ndWillAtrium				
2ndWill				

3rdFloor	Lamps	Equipment	Misc	Total
3rdMan	7778	20809		28587
3rdManAtriumN	196			196
3rdManAtriumS				
3rdTower	9094	13170	600	22864
3rdWillAtrium				
3rdWill	4509	12034		16543

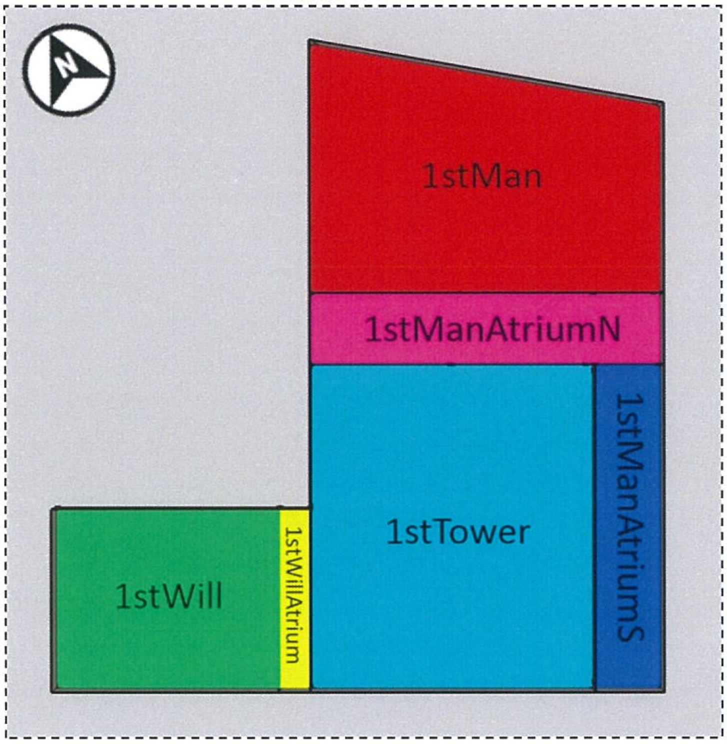
4thFloor	Lamps	Equipment	Misc	Total
4thMan	9938	24068	13300	47306
4thManAtriumN	392		Lift=22000	392
4thManAtriumS				
4thTower	7526	15120	600	23246
4thWillAtrium				
4thWill	4509	12194	0	16703

Total	**81359**	**122115**	**15100**	**218574**

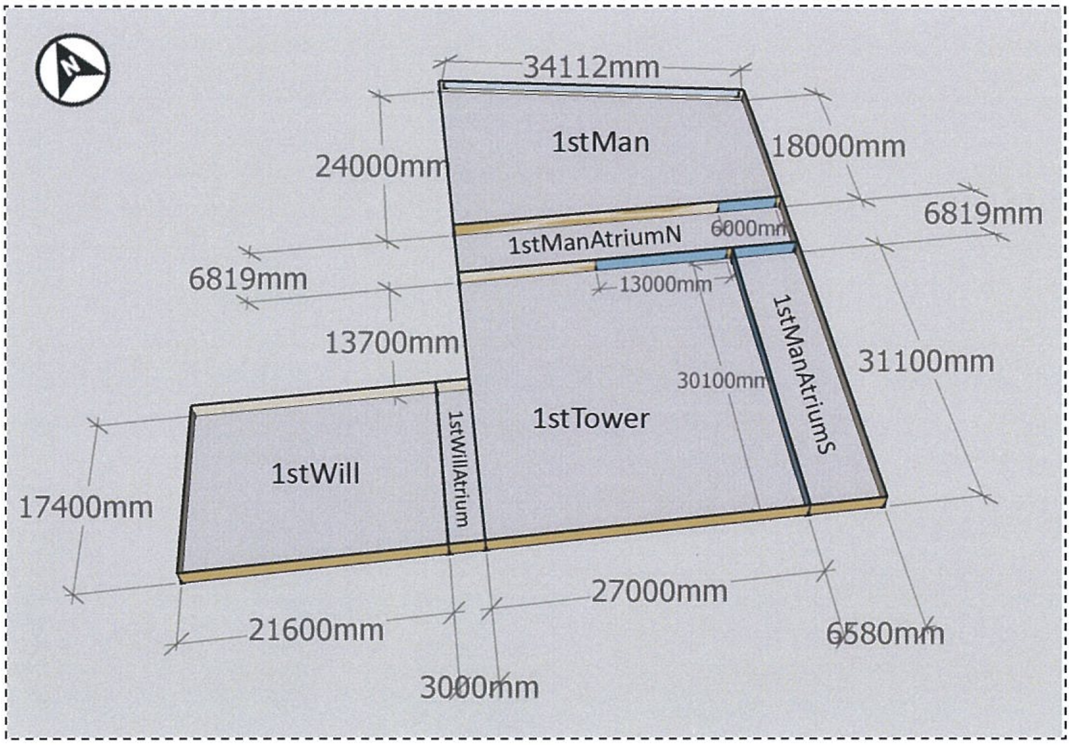
Modelled Zones

The ground floor zones modelled are as follows. They are drastically simplified when compared to the plans, but achieved the same result as if every room were modelled (Refer to section 11.15 for Conservation House building Plans).

Ground Floor Zones



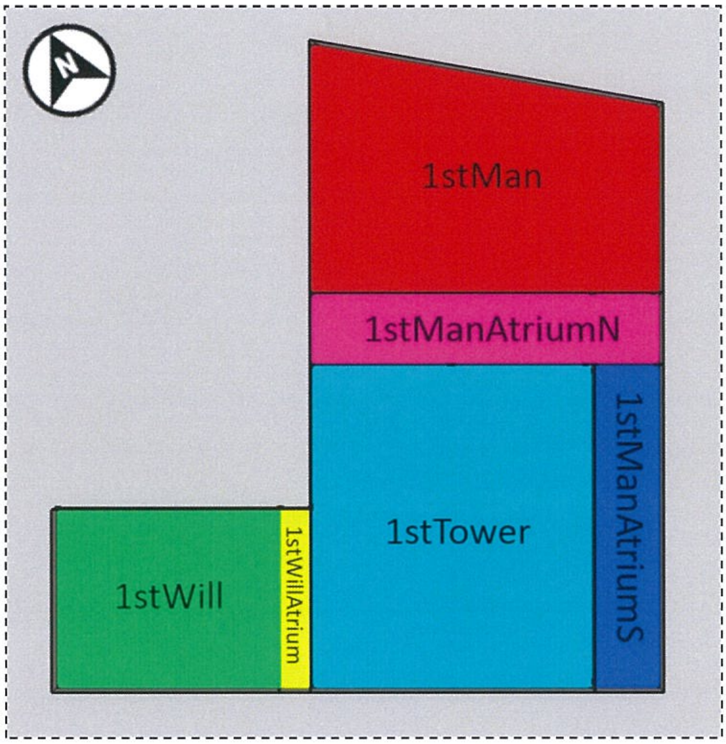
Ground Floor Dimensions



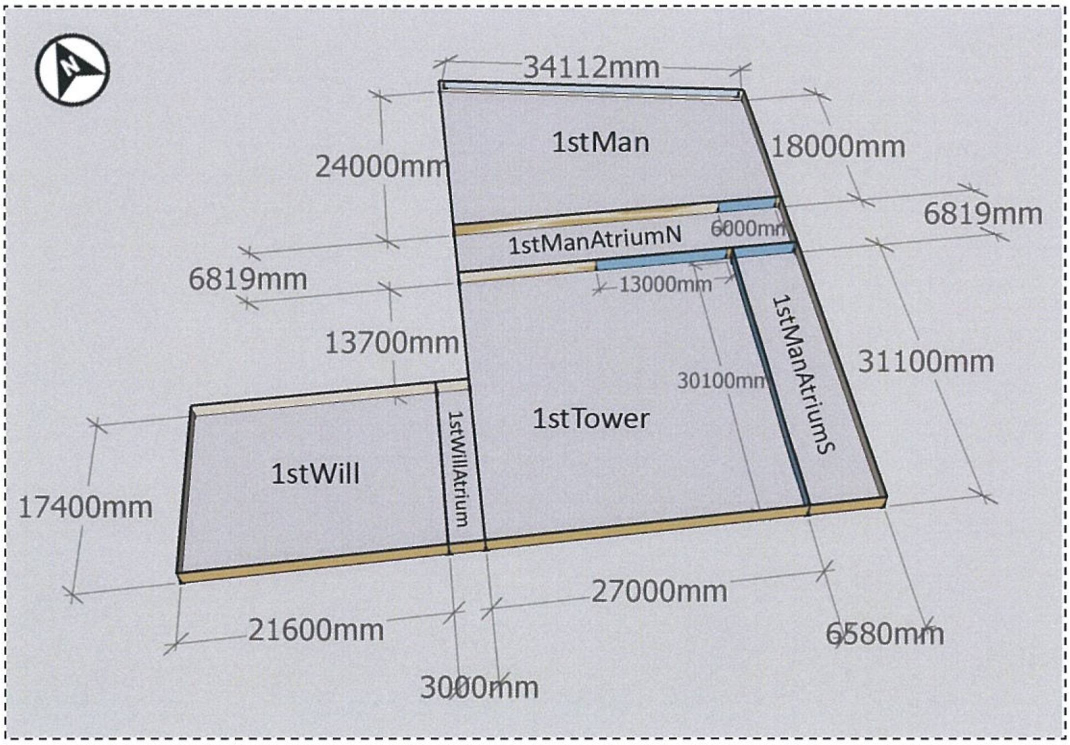
Modelled Zones

The ground floor zones modelled are as follows. They are drastically simplified when compared to the plans, but achieved the same result as if every room were modelled (Refer to section 11.15 for Conservation House building Plans).

Ground Floor Zones

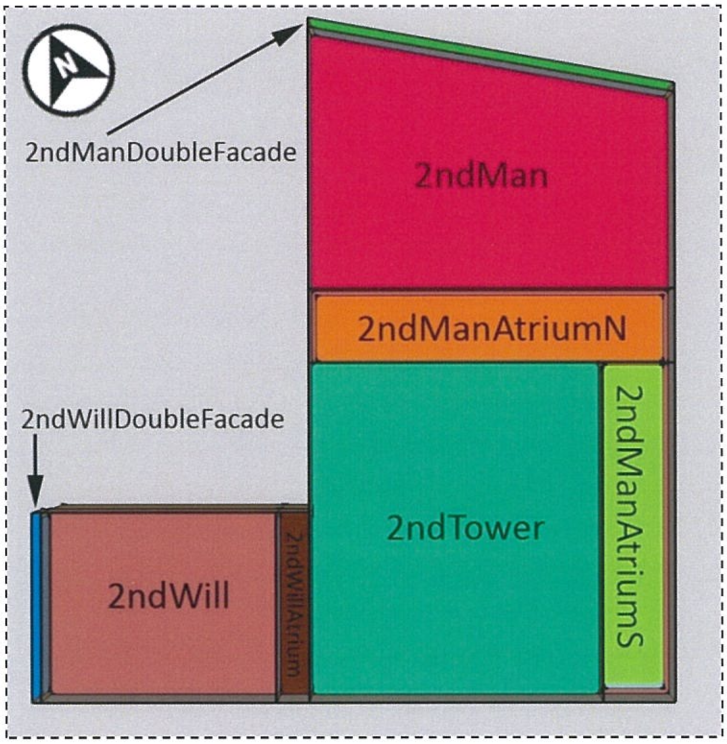


Ground Floor Dimensions

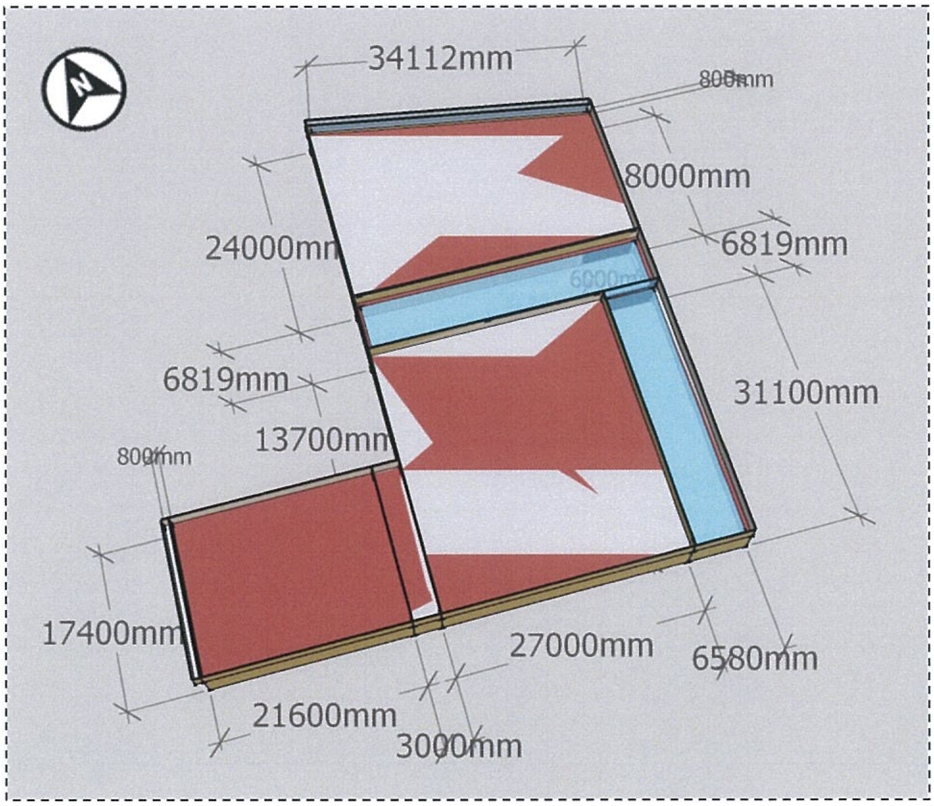


The 1st through to 3rd floor zones modelled are as follows. The other two floors have 3rd and 4th instead of 2nd in-front of the building sections. *Note: the 4th floor café's equipment is included in the fourth floors count in zone 4thMan.*

1st – 3rd Floor Zones

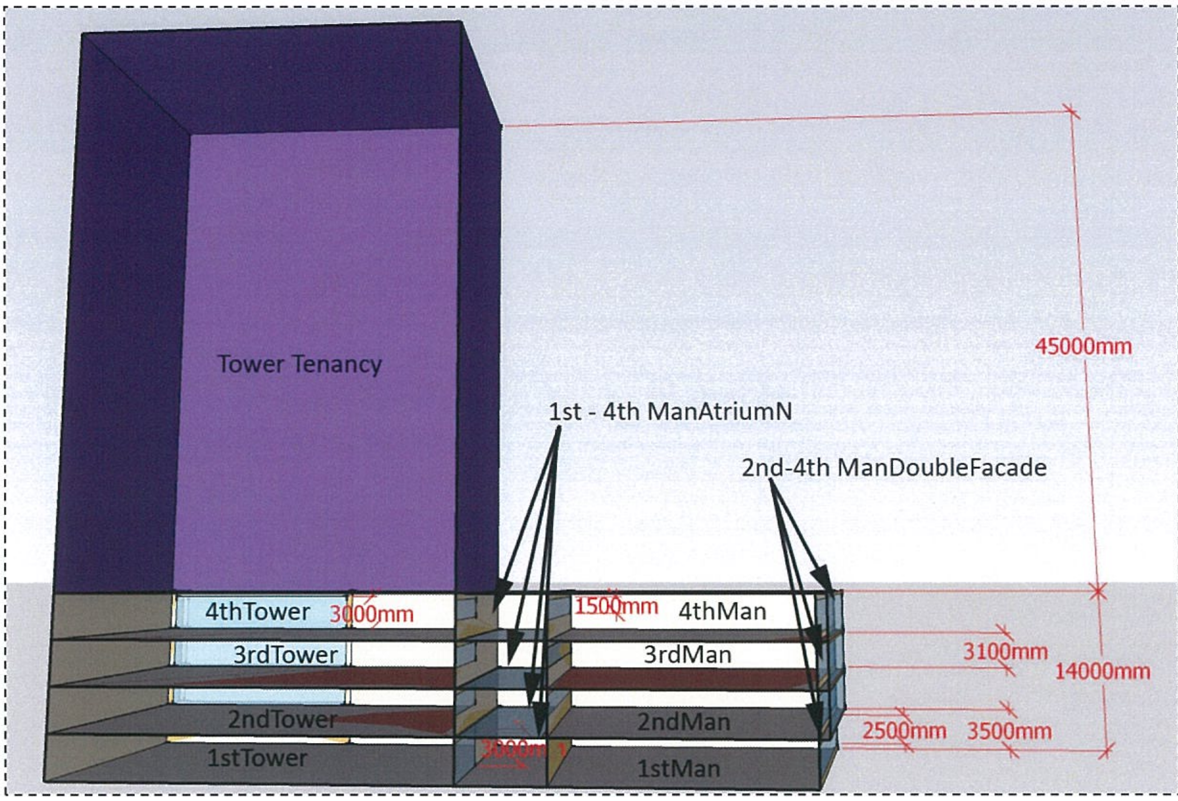


1st – 3rd Floor Dimensions

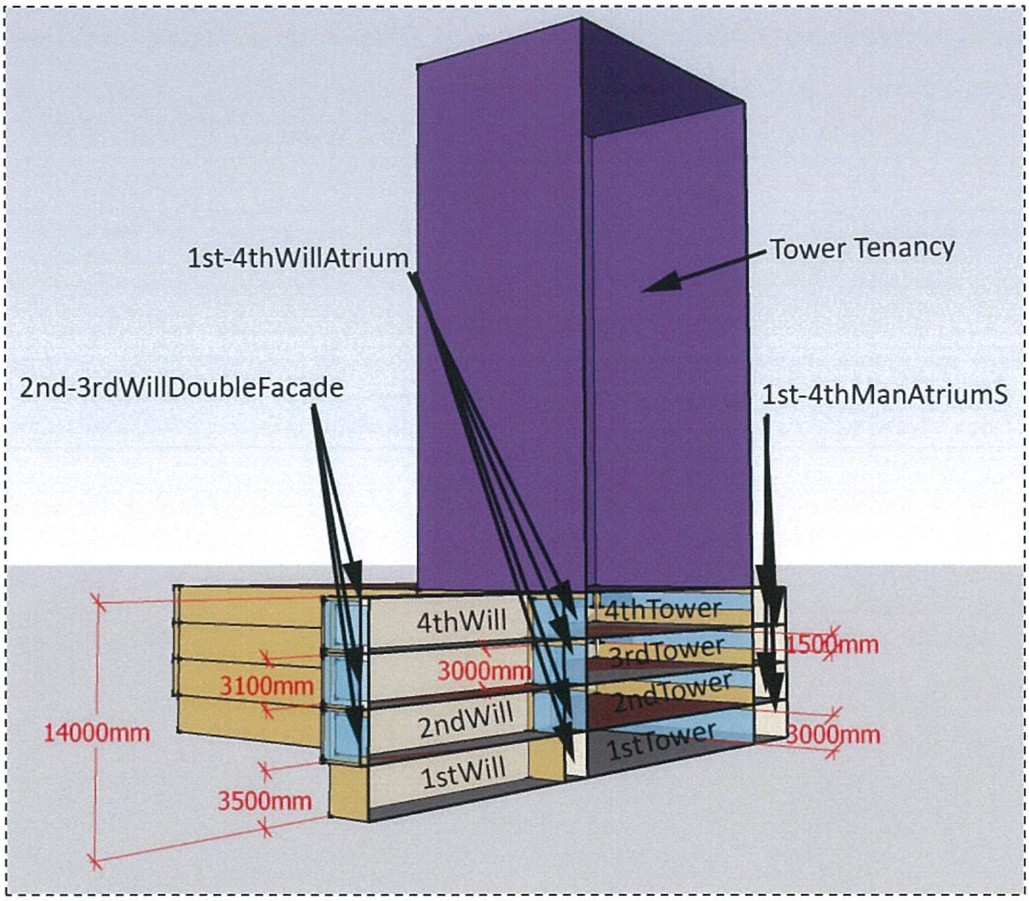


The following pictures are sections through the model, the first along the north-south axis and the second along the east to west axis.

North to South Axis



East to West Axis



HVAC – Cooled Beam Heating and Cooling Factors

The HVAC system was simulated by comparing the district heating and cooling of the Energy Plus example file for a Cooled Beam HVAC system to the actual space conditioning energy consumption that was produced by the building with the system installed. Two factors were established, one for heating and one for cooling. These factors were applied to the district heating and cooling of the Conservation House simulations to account for the current cooled beam HVAC system loadings and efficiency. The factors are:

Cooling = 0.537641561

Heating = 0.637577985

The Heat Pump and Chiller efficiencies were established by the product specifications (SKM and Plus 2005) and are:

Chiller = 3.2

Heat Pump = 3.4

Weather Files

The 2008 weather file used was generated using the Energy Plus Weather Statistics and Conversion tool that is installed with the Energy Plus version 3.1 download. (DOE 2009) The 2008 Wellington Weather data that was gathered from NIWA ((NIWA), The National Climate Database 2009) and was used to overwrite the existing weather data from the Energy Plus Weather File. This created the weather file for the Wellington weather during the 2008 year.

All the simulations, for the refurbishment of Conservation House, were simulated using a Typical Meteorological Years weather data. (U. D. (DOE), Energy Plus Energy Simulation Software - Weather Data 2009)

11.3 Solar Hot Water Calculation

Equation Used

Lowered Energy Use = Annual Energy Consumption x 75 percent

Solar Hot Water

Lowered Energy Use = 3kWh/m^2.yr *x 0.75*

Energy Use Index = 2.25kWh/m^2.yr

Assumption

The designed Solar Hot Water consumed 3kWh/m^2.yr and the current model incorporated the design schedules and was inside the design annual energy consumption. So it was assumed that the solar hot water usage was 3kWh/m^2.yr.

11.4 Replacement LED Lamps

The following lamps were used to replace the existing lamp types, see table below. Example lamps of the same wattage are referenced. It was assumed that an efficacy of close to 120lm/W can be produced. (CREE 2009)

Change	LED	Watts	Correlated Colour Temperature (CCT)	Colour Rendering Index (CRI)	Replaced Current Lamp Number	Example LED at:
a	T5 1200MM LED Tubes	14.5	3000K	84	1, 3, 6 & 10.	http://www.ledlightsorient.com/t5-1200mm-145w-led-tubes-ltt5145w1200-p-188.html (Last accessed on: 20th of October 2009)
b	T5 600MM LED Tubes	6.7	3000K	84	4 & 9	http://www.ledlightsorient.com/t5-600mm-67w-led-tubes-ltt5607w600-p-186.html (Last accessed on: 20th of October 2009)
c	LED Bulb	5	3000K	-	5 & 7	http://www.ledlightsorient.com/5w-led-bulbs-llb16e271w5-p-138.html (Last accessed on: 20th of October 2009)
d	230V LED Downlight	12	2700K	95	2	http://www.creeledlighting.com/downloads/LR6-230V%20Sales%20Sheet.pdf (Last accessed on: 20th of October 2009)
e	LED PAR 38 Lamp	12	2700K	92	11	http://www.creeledlighting.com/downloads/LRP-38.pdf (Last accessed on: 20th of October 2009)
f	LED Downlight	50	2700	80	80	http://www.ledlightsorient.com/50100w-led-industrial-lighting-lil1706-460mm-diameter-p-133.html (Last accessed on: 20th of October 2009)

11.5 Energy Efficient Equipment

The following equipment was used to replace the existing office and miscellaneous equipment, see table below. The products of the same wattage are referenced.

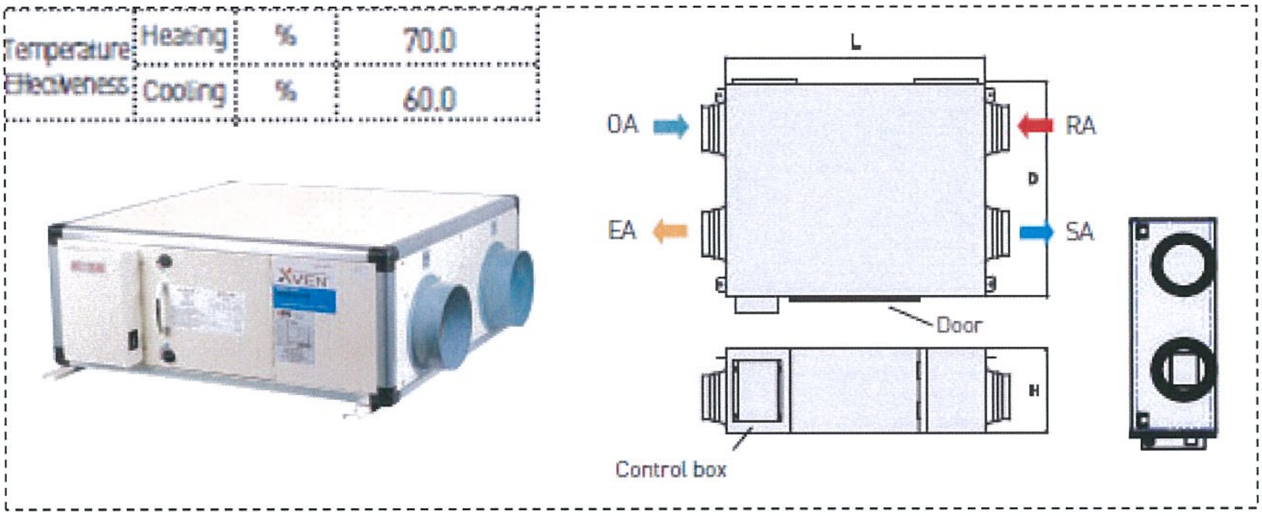
Change	Equipment Type	Watts	Example at:
a	Apple Mac Mini	28	http://www.apple.com/macmini/specs.html (Last accessed on: 20th of October 2009)
b	Dell G2410 LED Monitor	18	http://www.dell.com/content/topics/topic.aspx/global/products/landing/en/monitor-energy?c=us&l=en&cs=04 (Last accessed on: 20th of October 2009)
c	Lexmark X560n Multi-function Printer	650	http://www.lexmark.com/publications/pdfs/techref_1Q09.pdf (Last accessed on: 20th of October 2009)
d	Cannon laser printer - LBP-5050	210	http://www.canon.com.au/laserprinters/Data/Document/LBP-5050n%20Tech%20Sheet_AK_AB.pdf (Last accessed on: 20th of October 2009)
e	Canon FAX-JX210P Fax Machine	39	http://www.faxmachines.org.uk/category/canon/ (Last accessed on: 20th of October 2009)
f	Canon L295 Fax Machine	500	http://www.faxmachines.org.uk/category/canon/ (Last accessed on: 20th of October 2009)
g	Lamitek PhotoPro 13 Pouch Laminator	400	http://www.mybinding.com/.sc/ms/dd/ee/1234/Lamitek-PhotoSmart-13-Pouch-Laminator (Last accessed on: 20th of October 2009)
h	EC 22A / Datex Shredder	70	http://www.asktechnologies.co.in/officeshredder.asp (Last accessed on: 20th of October 2009)
i	Frigidaire Professional Series Oven	1000	http://www.brandsconnection.com/proddetail.php?prod=PLEF489GC (Last accessed on: 20th of October 2009)
j	Amana AMV1154BA Microwave	1000	http://www.homeeverything.com/web/sitefiles/product.asp?sku=1270&ref=cPGrab (Last accessed on: 20th of October 2009)
k	SAMSUNG Flat Screen LED Televsion	127	http://www.comet.co.uk/shopcomet/product/539139/SAMSUNG-UE55B7020WWXXU/tab/specification (Last accessed on: 20th of October 2009)
l	Bosch Coffee Machine 800 Watt	800	http://www.kalahari.net/appliances/Bosch-Coffee-Machine-800-Watt/42749/34064958.aspx (Last accessed on: 20th of October 2009)

11.6 Thermochromic Window Model Assumptions

The spectral data details of the Pleotint Thermochromic windows could not be obtain through contact with the company. Due to this, the Energy Plus Thermochromic example file spectral data was used to simulate the redesigning of Conservation House. The example file is downloaded with Energy Plus version 3.1. (DOE 2009)

11.7 Energy Recovery Ventilation

The energy recovery ventilation system calculated was an XVEN SPE Series energy recovery Ventilation system. It has a heating efficiency of 70 percent and a cooling efficiency of 60 percent. (Air2Energy 2009)



11.8 Solar Shading Study

The annual solar shading factors used in the PV energy generation calculations were determined by assessing the shading by surrounding buildings on the Manners, Willis and Tower rooftops. The shaded area was estimated as a percentage and was completed for the summer and winter solstices. The two percentages were averaged to get the resulting overall annual solar shading factor. The pictures that follow show the results of the study.

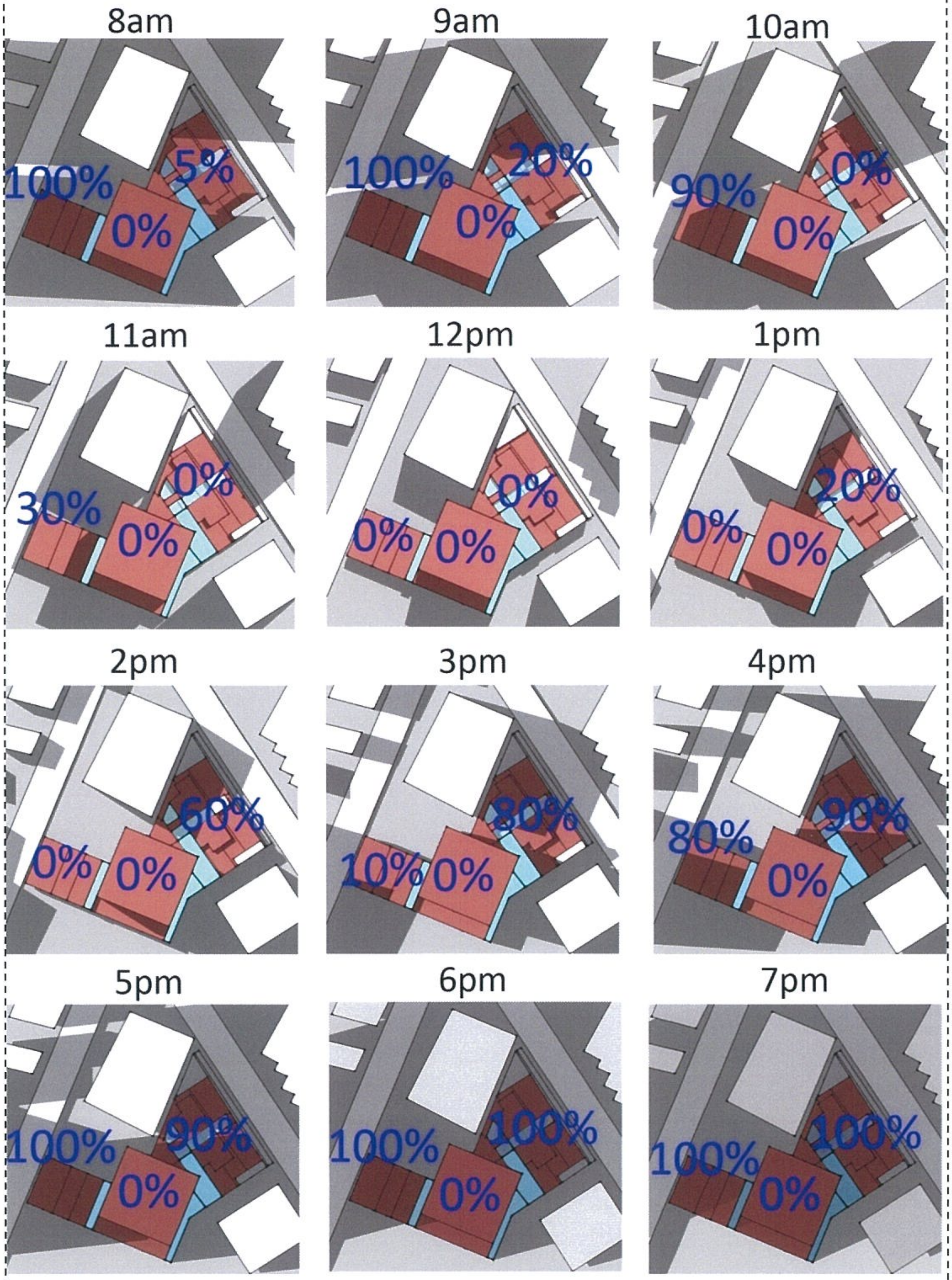
The overall annual shading factors are:

Manners = 57%

Tower = 0%

Willis = 54%

Summer Solstice

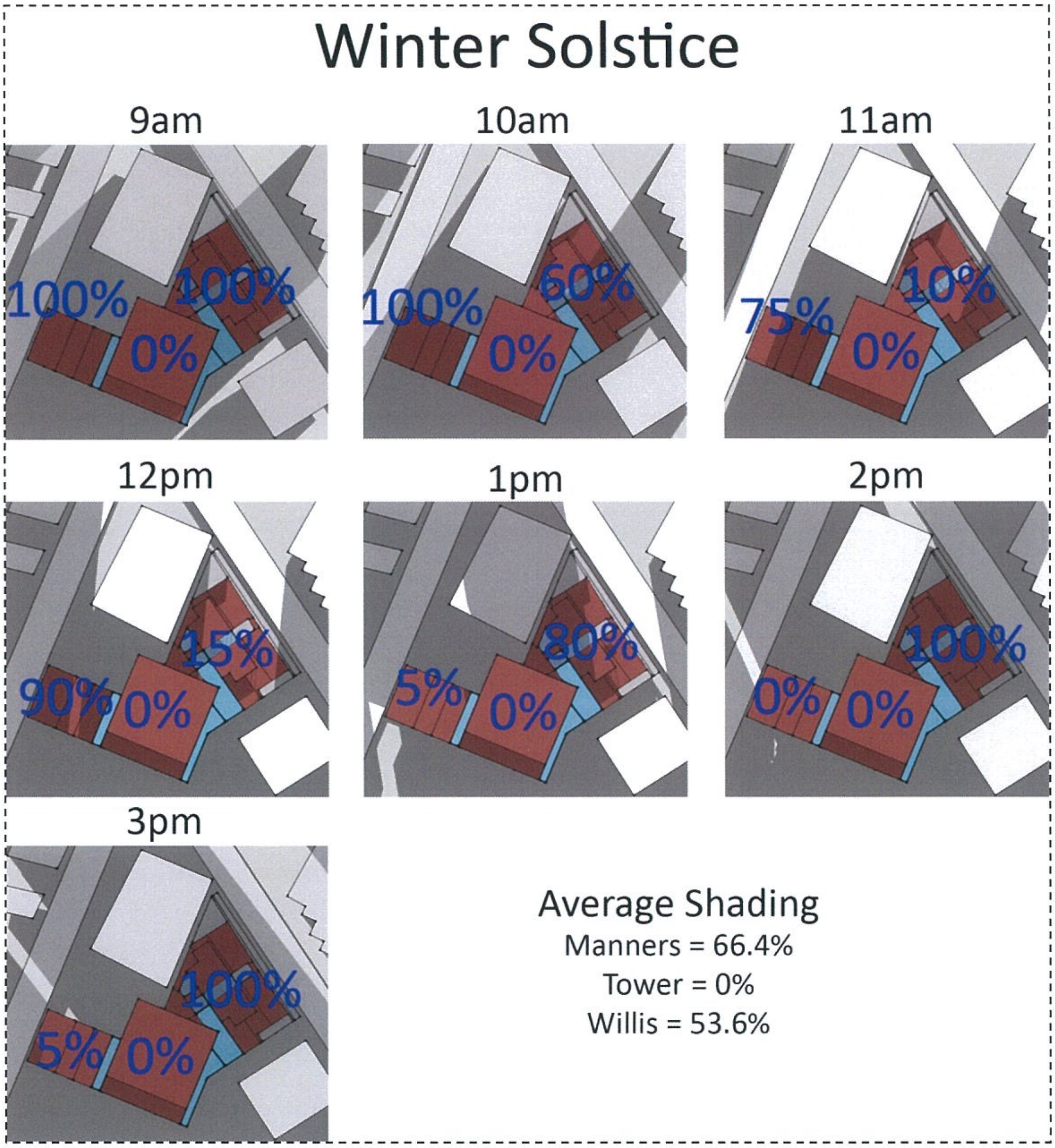


Average Shading

Manners = 47.1%

Tower = 0%

Willis = 54.6%


Winter Solstice
9am
100%
100%
0%
10am
100%
60%
0%
11am
75%
10%
0%
12pm
90%
15%
0%
1pm
5%
80%
0%
2pm
0%
100%
0%
3pm
5%
100%
0%
Average Shading
Manners = 66.4%
Tower = 0%
Willis = 53.6%

11.9 Podium Wind turbine Generation versus Tower Wind Turbine Generation

First the hourly wind speeds are gathered for Wellington. (Liley 2007) The hourly wind speeds are multiplied by the tower and podium rooftop boundary layer factors and are: Tower = 0.72 (72% of the wind speed gathered at the wellington weather station, at the Wellington Airport); Podium = 0.47.

As can be seen below, the podium wind turbine generates far less than the tower turbine. It generates 73 percent less energy than if it was placed on the Tower. This is due to the effect on the wind speeds by the boundary layer and wind direction sheltering from the surrounding buildings.

Tower Placement of one 10kW VAWT

Wind Speed Generation Intervals	Wind Hours	Multiply	kWh Generation rating from 10kW turbine	Muliply	Equals	Energy Generated 1 x 10kW
4-5m/s	1254	x	1	x 0.8 x 0.9	=	903
5-6m/s	1299	x	2	x 0.8 x 0.9	=	1,871
6-7m/s	820	x	3	x 0.8 x 0.9	=	1,771
7-8m/s	964	x	5	x 0.8 x 0.9	=	3,470
8-9m/s	632	x	7	x 0.8 x 0.9	=	3,185
9-10m/s	262	x	9	x 0.8 x 0.9	=	1,698
10-11m/s	219	x	10	x 0.8 x 0.9	=	1,577
11-12m/s	120	x	10.5	x 0.8 x 0.9	=	907
12-13m/s	60	x	10.75	x 0.8 x 0.9	=	464
13-14m/s	40	x	11	x 0.8 x 0.9	=	317
Total	5670					16,163.28kWh

Podium Placement of one 10kW VAWT

Wind Speed Generation Intervals	Wind Hours	Multiply	kWh Generation rating from 10kW turbine	Muliply	Equals	Energy Generated 1 x 10kW
4-5m/s	1,489	x	1	x 0.8 x 0.9	=	1,072
5-6m/s	927	x	2	x 0.8 x 0.9	=	1,335
6-7m/s	429	x	3	x 0.8 x 0.9	=	927
7-8m/s	202	x	5	x 0.8 x 0.9	=	727
8-9m/s	48	x	7	x 0.8 x 0.9	=	242
9-10m/s	21	x	9	x 0.8 x 0.9	=	136
10-11m/s	1	x	10	x 0.8 x 0.9	=	7
11-12m/s	0	x	10.5	x 0.8 x 0.9	=	-
12-13m/s	0	x	10.75	x 0.8 x 0.9	=	-
13-14m/s	0	x	11	x 0.8 x 0.9	=	-
Total	3117					4446.0kWh

<u>Podium Turbines: Overall Energy Generated</u>

Equation Used

Overall Energy Generation = PV Generation + Wind Turbine Generation

Split: Common Scenario

Overall Energy Generation = 114.6 (Appendix 11.10 – Split: Common Scenario PV generation) + 44.46

= 159.1MWh/yr

<u>Podium Turbines: Overall Energy Balance</u>

Conservation House's refurbished annual energy consumption is 274.4MWh (Refer to Appendix 11.13).

Equation Used

Net Energy Consumption = Annual Energy Consumption – Annual Energy Generation

Split: Common Scenario

Net Energy Consumption = 274.4 – 159.06 (Appendix 11.10 – Split: Common Scenario PV generation)

= 115.3MWh/yr (Net Energy Consumer)

Percentage of demand remaining = 115.3 / 274.4

= 42% of demand remains

= 100 – 42

= 58% of demand is offset

11.10 PV Generation Calculations

First the hourly solar radiation values are gathered for Wellington. (Liley 2007) The hourly solar radiation is summed and multiplied by the three rooftop shading factors. It is then split into the direct and diffuse components.

Equation Used

Energy Generation = PV area x Solar Radiation x Cell Efficiency x Orientation Factor x Sky Factor x Correction Factor x Loss Factor

Split: Common Scenario

Manners Direct: Energy Generation = 175.5 x 637.13702 x 0.24 x 0.95 x 1 x 0.9 x 0.8

= 18,356.0kWh/yr

Willis Direct: Energy Generation = 248.5 x 681.58844 x 0.24 x 0.95 x 1 x 0.9 x 0.8

= 27,804.5kWh/yr

Manners Diffuse: Energy Generation = 175.5 x 1430.27598 x 0.24 x 0.95 x 0.7 x 0.9 x 0.8

= 28,844.4kWh/yr

Willis Diffuse: Energy Generation = 248.5 x 1385.82456 x 0.24 x 0.95 x 0.7 x 0.9 x 0.8

= 39,573.1kWh/yr

Total Energy Generation = 18,356.0+ 27,804.5 + 28,844.4 + 39,573.1

= 114,578.1kWh/yr

= 114.6MWh/yr

Split: Evolution Scenario

Manners Direct: Energy Generation = 175.5 x 637.13702 x 0.4 x 0.95 x 1 x 0.9 x 0.8

= 30,593.3kWh/yr

Willis Direct: Energy Generation = 248.5 x 681.58844 x 0.4 x 0.95 x 1 x 0.9 x 0.8

= 46,340.9kWh/yr

Manners Diffuse: Energy Generation = 175.5 x 1430.27598 x 0.4 x 0.95 x 0.7 x 0.9 x 0.8

= 48,074.1kWh/yr

Willis Diffuse: Energy Generation = 248.5 x 1385.82456 x 0.4 x 0.95 x 0.7 x 0.9 x 0.8

= 65,955.2kWh/yr

Total Energy Generation = 30,593.3+ 46,340.9+ 48,074.1+ 65,955.2

= 190,963.4kWh/yr

= 191.0MWh/yr

Mixed: Common Scenario

Manners Direct: Energy Generation = 175.5 x 637.13702 x 0.24 x 0.95 x 1 x 0.9 x 0.8

= 18,356.0kWh/yr

Willis Direct: Energy Generation = 248.5 x 681.58844 x 0.24 x 0.95 x 1 x 0.9 x 0.8

= 27,804.5kWh/yr

Tower Direct: Energy Generation = 219.75 x 1481.714 x 0.24 x 0.95 x 1 x 0.9 x 0.8

= 53,451.6kWh/yr

Manners Diffuse: Energy Generation = 175.5 x 1430.27598 x 0.24 x 0.95 x 0.7 x 0.9 x 0.8

= 28,844.4kWh/yr

Willis Diffuse: Energy Generation = 248.5 x 1385.82456 x 0.24 x 0.95 x 0.7 x 0.9 x 0.8

= 39,573.1kWh/yr

Tower Diffuse: Energy Generation = 248.5 x 585.699 x 0.4 x 0.95 x 0.7 x 0.9 x 0.8

= 14,790.0kWh/yr

Total Energy Generation = 18,356.0+ 27,804.5 + 53,451.6 + 28,844.4 + 39,573.1 + 14,790.0

= 182,819.7kWh/yr

= 182.8MWh/yr

Mixed: Evolution Scenario

Manners Direct: Energy Generation = 175.5 x 637.13702 x 0.4 x 0.95 x 1 x 0.9 x 0.8

= 30,593.3kWh/yr

Willis Direct: Energy Generation = 248.5 x 681.58844 x 0.4 x 0.95 x 1 x 0.9 x 0.8

= 89,086.0kWh/yr

Tower Direct: Energy Generation = 219.75 x 1481.714 x 0.4 x 0.95 x 1 x 0.9 x 0.8

= 46,340.9kWh/yr

Manners Diffuse: Energy Generation = 175.5 x 1430.27598 x 0.4 x 0.95 x 0.7 x 0.9 x 0.8

= 48,074.1kWh/yr

Willis Diffuse: Energy Generation = 248.5 x 1385.82456 x 0.4 x 0.95 x 0.7 x 0.9 x 0.8

= 65,955.2kWh/yr

Tower Diffuse: Energy Generation = 248.5 x 585.699 x 0.4 x 0.95 x 0.7 x 0.9 x 0.8

= 24,650.0kWh/yr

Total Energy Generation = 30,593.3 + 46,340.9 + 46,340.9 + 48,074.1+ 65,955.2 + 24,650.0

= 304,699.5kWh/yr

= 304.7MWh/yr

11.11 Wind Generation Calculations

First the hourly wind speeds are gathered for Wellington. (Liley 2007) The hourly wind speeds are multiplied by the Tower rooftop boundary layer factor and is: 0.72 (72% of the wind speed gathered at the wellington weather station, at the Wellington Airport).

Equation Used

Energy Generated = *(4-5m/s hours of occurrence x generation rating) + (5-6m/s hours of occurrence x generation rating) + ... (≥14m/s hours of occurrence x generation rating) x Correction Factor x Loss Factor*

Split Scenario

Equations are fulfilled by moving across the table below to the right.

Wind Speed Generation Intervals	Wind Hours	Multiply	kWh Generation rating from 10kW turbine	Muliply	Equals	Energy Generated 1 x 10kW	Energy Generated 10 x 10kW turbines
4-5m/s	1254	x	1	x 0.8 x 0.9	=	903	9,029
5-6m/s	1299	x	2	x 0.8 x 0.9	=	1,871	18,706
6-7m/s	820	x	3	x 0.8 x 0.9	=	1,771	17,712
7-8m/s	964	x	5	x 0.8 x 0.9	=	3,470	34,704
8-9m/s	632	x	7	x 0.8 x 0.9	=	3,185	31,853
9-10m/s	262	x	9	x 0.8 x 0.9	=	1,698	16,978
10-11m/s	219	x	10	x 0.8 x 0.9	=	1,577	15,768
11-12m/s	120	x	10.5	x 0.8 x 0.9	=	907	9,072
12-13m/s	60	x	10.75	x 0.8 x 0.9	=	464	4,644
13-14m/s	40	x	11	x 0.8 x 0.9	=	317	3,168
Total	**5670**					**16,163.28kWh**	**161,632.8kWh**
							161.6MWh

Mixed Scenario

Equations are fulfilled by moving across the table below to the right.

Wind Speed Generation Intervals	Wind Hours	Multiply	kWh Generation rating from 10kW turbine	Muliply	Equals	Energy Generated 1 x 10kW	Energy Generated 10 x 10kW turbines
4-5m/s	1254	x	1	x 0.8 x 0.9	=	903	4,514
5-6m/s	1299	x	2	x 0.8 x 0.9	=	1,871	9,353
6-7m/s	820	x	3	x 0.8 x 0.9	=	1,771	8,856
7-8m/s	964	x	5	x 0.8 x 0.9	=	3,470	17,352
8-9m/s	632	x	7	x 0.8 x 0.9	=	3,185	15,926
9-10m/s	262	x	9	x 0.8 x 0.9	=	1,698	8,489
10-11m/s	219	x	10	x 0.8 x 0.9	=	1,577	7,884
11-12m/s	120	x	10.5	x 0.8 x 0.9	=	907	4,536
12-13m/s	60	x	10.75	x 0.8 x 0.9	=	464	2,322
13-14m/s	40	x	11	x 0.8 x 0.9	=	317	1,584
Total	**5,670**					**16,163.28kWh**	**80,816.4kWh**
							80.8MWh

11.12 Overall Energy Generation

Equation Used

Overall Energy Generation = PV Generation + Wind Turbine Generation

Split: Common Scenario

Overall Energy Generation = 114.6 + 161.6

= 276.2MWh/yr

Split: Evolution Scenario

Overall Energy Generation = 191.0 + 161.6

= 352.6MWh/yr

Mixed: Common Scenario

Overall Energy Generation = 182.8 + 80.8

= 263.6MWh/yr

Mixed: Evolution Scenario

Overall Energy Generation = 304.7 + 80.8

= 385.5MWh/yr

11.13 Energy Balance Equations

The balance is between the energy consumed and the energy generated. Conservation House's refurbished annual energy consumption is 274.4MWh.

Equation Used

Net Energy Consumption = Annual Energy Consumption – Annual Energy Generation

Split: Common Scenario

Net Energy Consumption = 274.4 – 276.2

= -1.8MWh/yr (Net Zero Energy Building)

Split: Evolution Scenario

Net Energy Consumption = 274.4 – 352.6

= -78.2MWh/yr (Net Energy Producer)

Mixed: Common Scenario

Net Energy Consumption = 274.4 – 263.6

= 10.8MWh/yr (Net Energy Consumer)

Mixed: Evolution Scenario

Net Energy Consumption = 274.4 – 385.5

= -111.1MWh/yr (Net Energy Producer)

11.14 Open Site - Energy Calculation and Balance Equations

PV Generation Calculations

First the hourly solar radiation values are gathered for Wellington from NIWA. ((NIWA), The National Climate Database 2009) It is then split into the direct and diffuse components.

Equation Used

Energy Generation = PV area x Solar Radiation x Cell Efficiency x Orientation Factor x Sky Factor x Correction Factor x Loss Factor

Split: Common Scenario

Manners and Willis Direct: Energy Generation = 424 x 1481.714 x 0.24 x 0.95 x 1 x 0.9 x 0.8

= 103,133kWh/yr

Manners and Willis Diffuse: Energy Generation = 424 x 585.699 x 0.24 x 0.95 x 0.7 x 0.9 x 0.8

= 28,536.8kWh/yr

Total Energy Generation = 103,133 + 28,536.8

= 131,669.8kWh/yr

= 131.7MWh/yr

Split: Evolution Scenario

Manners and Willis Direct: Energy Generation = 424 x 1481.714 x 0.4 x 0.95 x 1 x 0.9 x 0.8

= 171,888.3kWh/yr

Manners and Willis Diffuse: Energy Generation = 424 x 585.699 x 0.4 x 0.95 x 0.7 x 0.9 x 0.8

= 47,561.4kWh/yr

Total Energy Generation = 171,888.3+ 47,561.4

= 219,449.7kWh/yr

= 219.4MWh/yr

Mixed: Common Scenario

Manners, Willis and Tower Direct: Energy Generation = 643.75 x 1481.714 x 0.24 x 0.95 x 1 x 0.9 x 0.8

= 156,584.6kWh/yr

Manners, Willis and Tower Diffuse: Energy Generation = 643.75 x 585.699 x 0.24 x 0.95 x 0.7 x 0.9 x 0.8

= 43,326.8kWh/yr

Total Energy Generation = 156,584.6+ 43,326.8

= 199,911.4kWh/yr

= 199.9MWh/yr

Mixed: Evolution Scenario

Manners, Willis and Tower Direct: Energy Generation = 643.75 x 1481.714 x 0.4 x 0.95 x 1 x 0.9 x 0.8

= 260,974.3kWh/yr

Manners, Willis and Tower Diffuse: Energy Generation = 643.75 x 585.699 x 0.4 x 0.95 x 0.7 x 0.9 x 0.8

= 72,211.4kWh/yr

Total Energy Generation = 260,974.3 + 72,211.4

= 333,185.7kWh/yr

= 333.2MWh/yr

Wind Generation Calculations

Equation Used

Energy Generated = *(4-5m/s hours of occurrence x generation rating) + (5-6m/s hours of occurrence x generation rating) + ... (≥14m/s hours of occurrence x generation rating) x Correction Factor x Loss Factor*

Split Scenario

Equations are fulfilled by moving across the table below to the right.

Wind Speed Generation Intervals	Wind Hours	Multiply	kWh Generation rating from 10kW turbine	Muliply	Equals	Energy Generated 1 x 10kW	Energy Generated 10 x 10kW turbines
4-5m/s	746	x	1	x 0.8 x 0.9	=	537	5,371
5-6m/s	864	x	2	x 0.8 x 0.9	=	1,244	12,442
6-7m/s	827	x	3	x 0.8 x 0.9	=	1,786	17,863
7-8m/s	899	x	5	x 0.8 x 0.9	=	3,236	32,364
8-9m/s	864	x	7	x 0.8 x 0.9	=	4,355	43,546
9-10m/s	676	x	9	x 0.8 x 0.9	=	4,380	43,805
10-11m/s	644	x	10	x 0.8 x 0.9	=	4,637	46,368
11-12m/s	478	x	10.5	x 0.8 x 0.9	=	3,614	36,137
12-13m/s	275	x	10.75	x 0.8 x 0.9	=	2,129	21,285
13-14m/s	580	x	11	x 0.8 x 0.9	=	4,594	45,936
Total	6853					30,512	**305,116.2kWh**
							305.1MWh

Mixed Scenario

Equations are fulfilled by moving across the table below to the right.

Wind Speed Generation Intervals	Wind Hours	Multiply	kWh Generation rating from 10kW turbine	Muliply	Equals	Energy Generated 1 x 10kW	Energy Generated 10 x 10kW turbines
4-5m/s	746	x	1	x 0.8 x 0.9	=	537	2,686
5-6m/s	864	x	2	x 0.8 x 0.9	=	1,244	6,221
6-7m/s	827	x	3	x 0.8 x 0.9	=	1,786	8,932
7-8m/s	899	x	5	x 0.8 x 0.9	=	3,236	16,182
8-9m/s	864	x	7	x 0.8 x 0.9	=	4,355	21,773
9-10m/s	676	x	9	x 0.8 x 0.9	=	4,380	21,902
10-11m/s	644	x	10	x 0.8 x 0.9	=	4,637	23,184
11-12m/s	478	x	10.5	x 0.8 x 0.9	=	3,614	18,068
12-13m/s	275	x	10.75	x 0.8 x 0.9	=	2,129	10,643
13-14m/s	580	x	11	x 0.8 x 0.9	=	4,594	22,968
Total	6853					30,512	**152,558.1kWh**
							152.5MWh

Overall Energy Generation

Equation Used

Overall Energy Generation = PV Generation + Wind Turbine Generation

Split: Common Scenario

Overall Energy Generation = 131.7+ 305.1

= 436.8MWh/yr

Split: Evolution Scenario

Overall Energy Generation = 219.4 + 305.1

= 525.1MWh/yr

Mixed: Common Scenario

Overall Energy Generation = 182.8 + 152.5

= 335.3MWh/yr

Mixed: Evolution Scenario

Overall Energy Generation = 304.7 + 152.5

= 457.2MWh/yr

Energy Balance Equations

The balance is between the energy consumed and the energy generated. Conservation House's refurbished annual energy consumption when placed in an open site is 291.1MWh (1.d.p).

Equation Used

Net Energy Consumption = Annual Energy Consumption – Annual Energy Generation

Split: Common Scenario

Net Energy Consumption = 291.1– 436.8

= -145.7MWh/yr (Net Energy Producer)

Split: Evolution Scenario

Net Energy Consumption = 291.1– 525.1

= -234MWh/yr (Net Energy Producer)

Mixed: Common Scenario

Net Energy Consumption = 291.1– 335.3

= -44.2MWh/yr (Net Energy Producer)

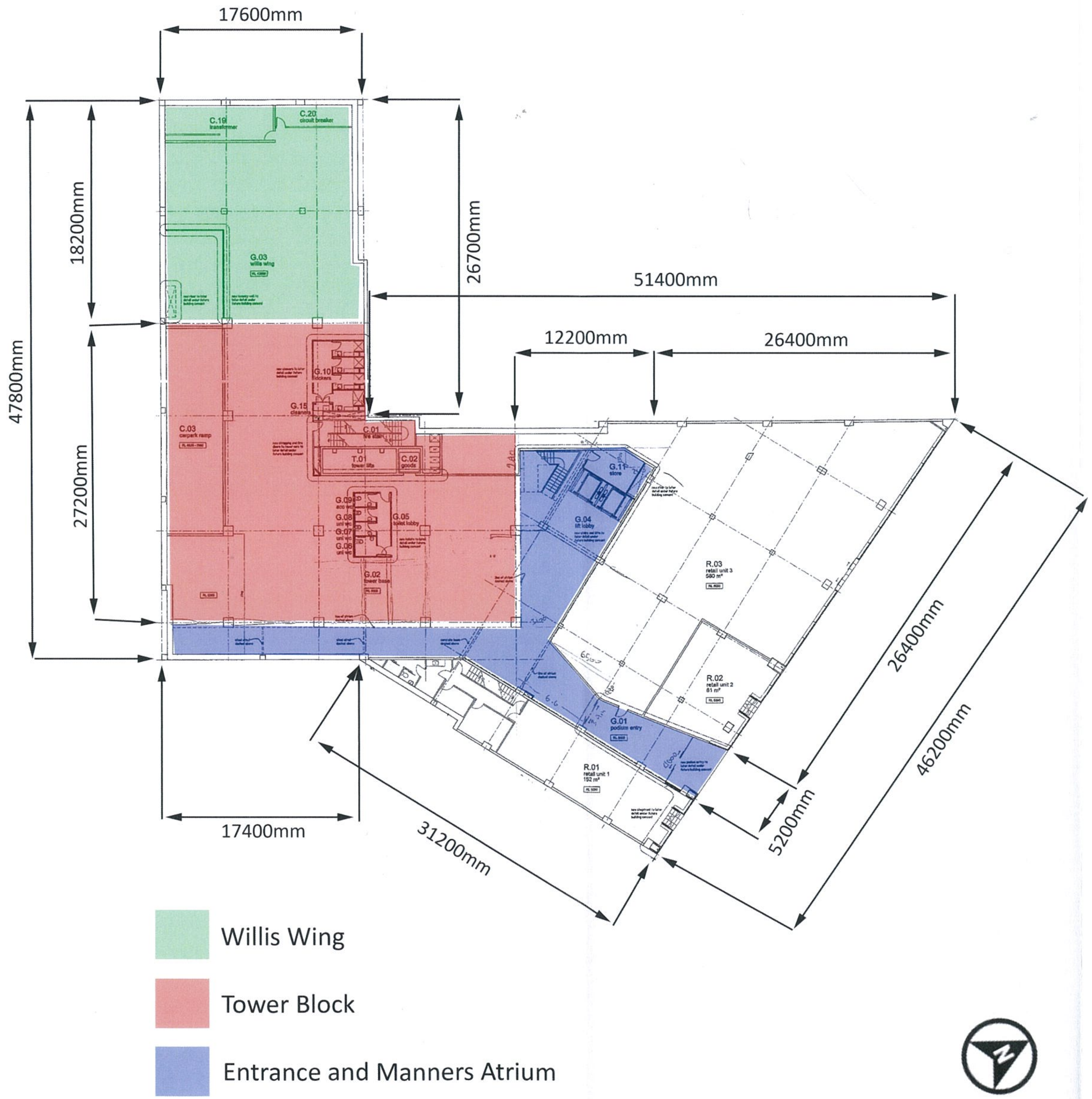
Mixed: Evolution Scenario

Net Energy Consumption = 291.1 – 457.2

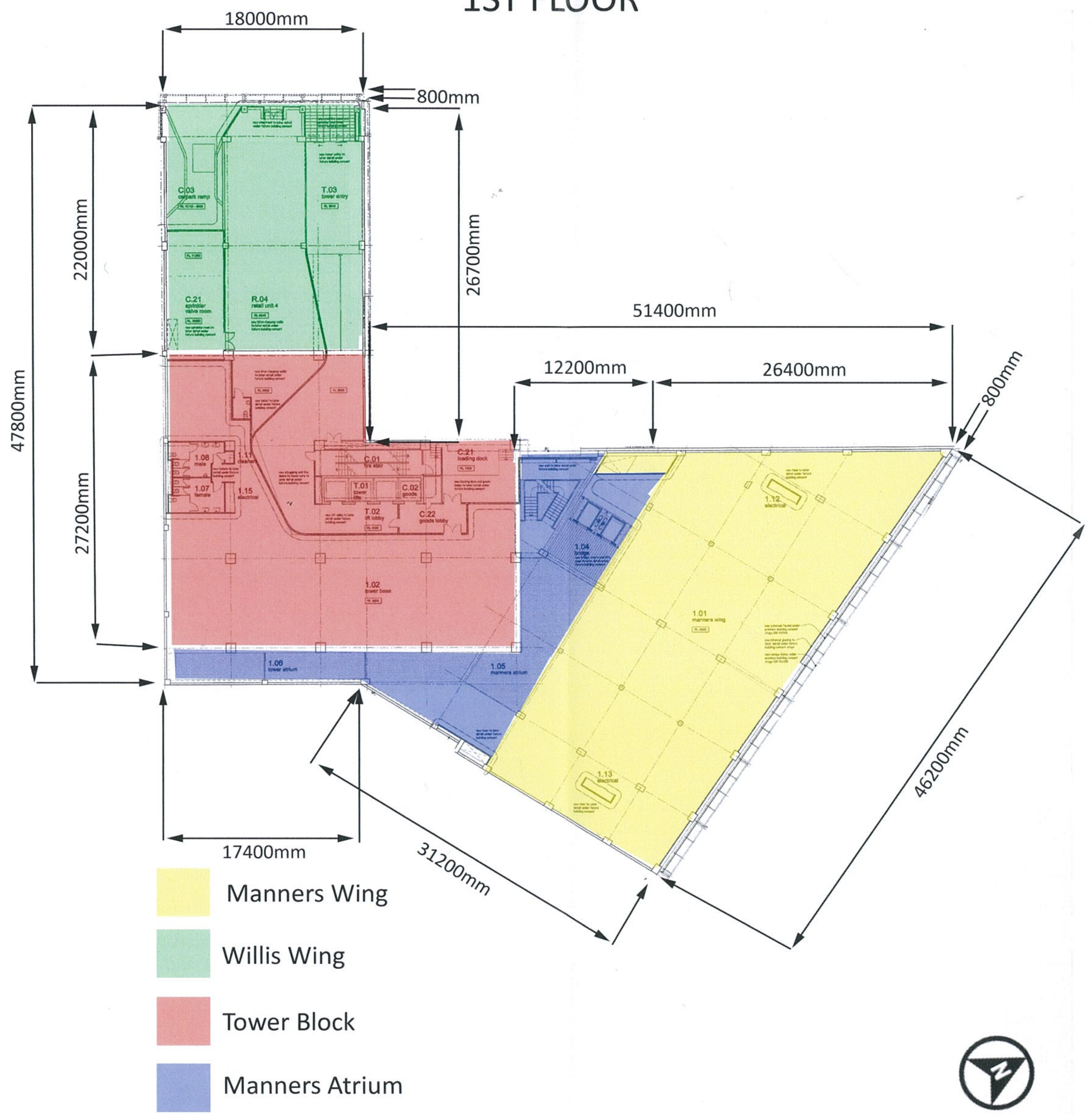
= -166.1MWh/yr (Net Energy Producer)

11.15 Conservation House Building Plans

GROUND FLOOR



1ST FLOOR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47800mm
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800mm
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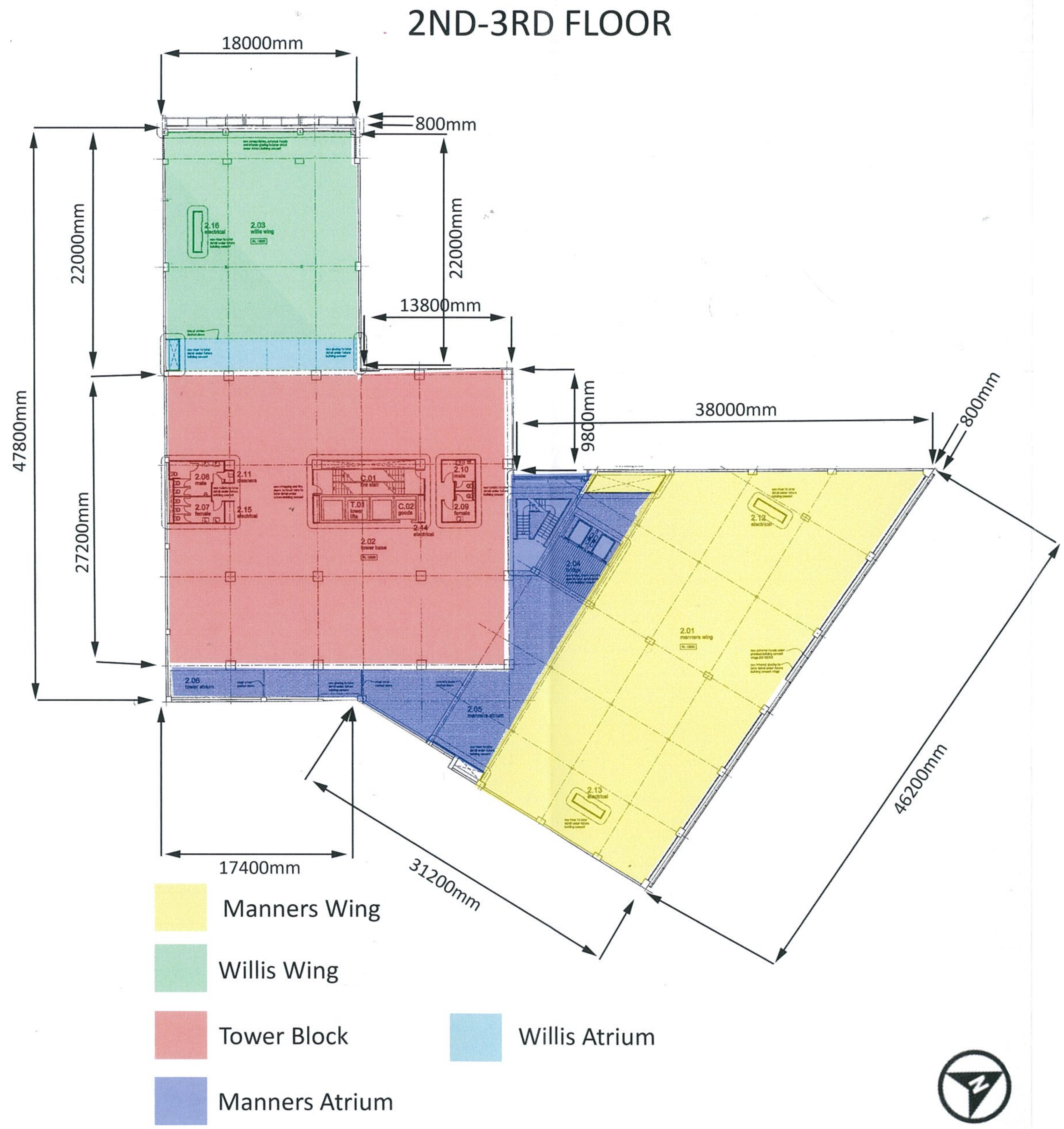
31200mm
Manners Wing
Willis Wing
Tower Block
Manners Atrium


2ND-3RD FLOOR
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800mm
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13800mm
47800mm
9800mm
38000mm
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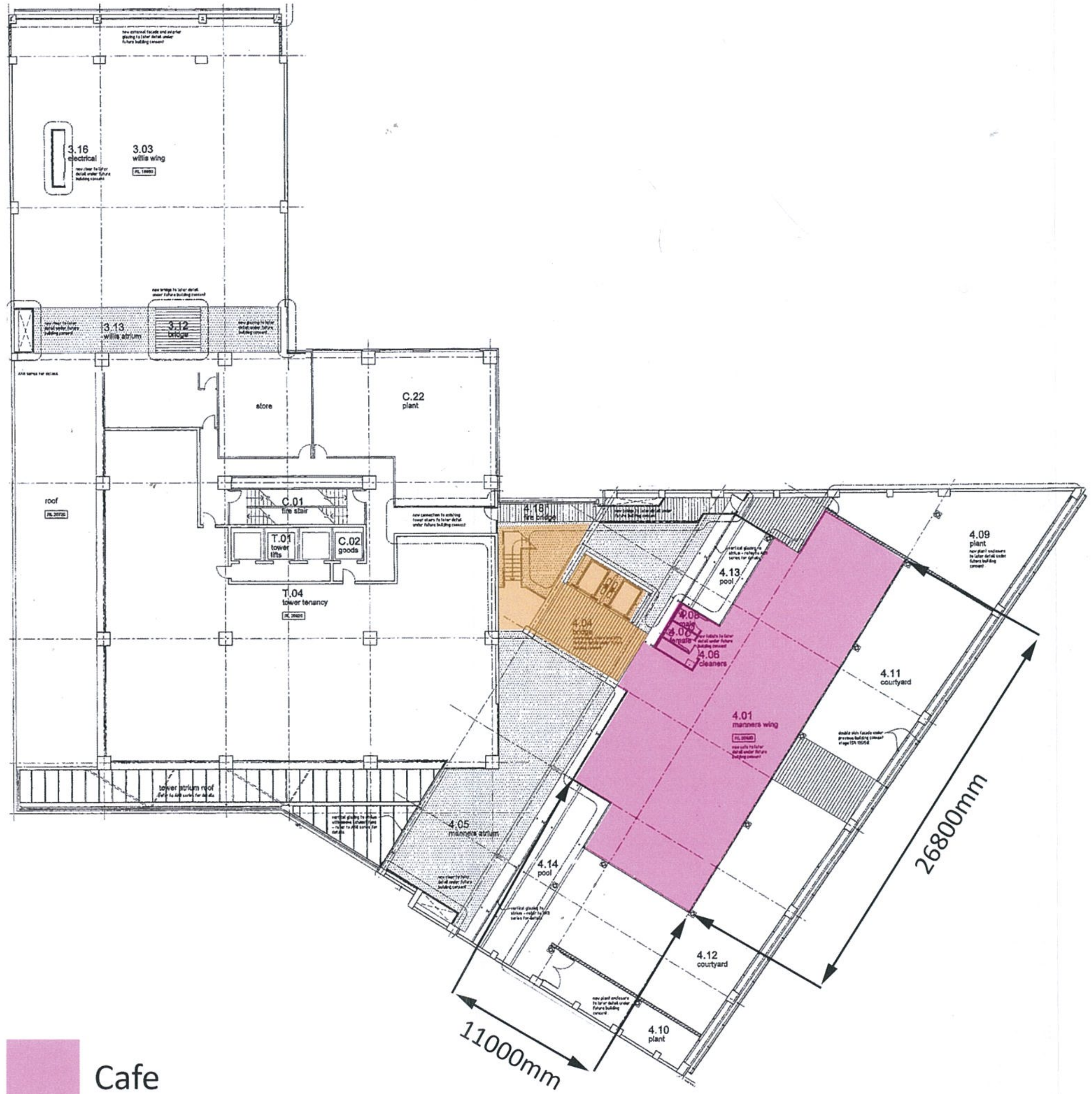
Manners Wing
Willis Wing
Tower Block
Willis Atrium
Manners Atrium

4TH FLOOR



Cafe

Manners Atrium Stairs/Lifts