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USE OF NET ZERO ENERGY SOLUTION SETS FOR THE REDESIGN OF THE NEW ZEALAND MERIDIAN NET ZEB BUILDING

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ABSTRACT

Designing Net Zero Energy Buildings (Net ZEB) requires extensive work to identify a suitable combination of energy efficiency measures and energy generation technologies that will enable a building to satisfy its annual energy needs. Establishing design guidelines that can be followed to reach net zero energy consumption could ease the design of new Net ZEB. Would a Net ZEB still be net zero when moved to another climate? If not, could this building be modified to be net zero again by following design guidelines? The aim of this study is to assess the viability of using existing solution sets for redesigning an existing Net ZEB when subjected to another climate through a case study. The authors believe that existing solution sets can be helpful and serve as a basis for designing Net ZEB.

INTRODUCTION

Net Zero Energy Buildings (Net ZEB) are becoming an objective sought by many states and jurisdictions. For instance, by 2018, all new publicly owned European buildings shall be near zero energy while all buildings shall reach this target by 2020 (EU, 2010). Each state member can determine a minimum energy performance that would correspond to the definition of "nearly zero energy building" (Lenoir, Garde, Ottenwelter, Bornarel, & Wurtz, 2010).

Despite a rising interest towards Net ZEB, an internationally agreed definition and methodology are still under development (Marszal et al., 2011). A common definition of a Net ZEB is a building that produces, over the course of a year, all the primary energy required for the annual operation of the building. A Net ZEB has a very low energy demand compared to conventional buildings. This low amount of energy required should be preferably met by on-site renewable sources.

A Net ZEB is not a self-sufficient building but rather a building that operates in connection with an energy infrastructure. Such a building must first reduce significantly its energy needs with energy efficiency measures and then produce renewable energy that can be supplied to the grid to offset it own energy consumption (Voss et al., 2010).

Designing Net Zero Energy Buildings is often a tedious task which requires considering a multitude of options to identify cost effective energy conservation and generation measures that will enable a building to reach net zero energy consumption.

Despite challenges, Net ZEB are starting to being built all around the world (Voss & Musall, 2011). From Reunion Island to London, all climatic conditions offer some challenges and opportunities. Nevertheless, reaching net zero energy consumption seems achievable for all climates.

One way to facilitate the design of Net ZEB would be to identify design guidelines that are effective for reducing the energy consumption and generating renewable energy in buildings. Typical solutions for energy conservation measures and heat/electricity generation in Net ZEB can be found in Musall et al., 2010.

The methodology based on solution sets has been developed through the IEA SHC Task 28/38 program. A solution set is defined as a descriptive model which combines passive and active systems that can be used to improve energy efficiency. These green technologies should be aesthetically acceptable, easily integrated into the building, reliable, durable and socially and economically acceptable (Hyde et al., 2009).

Net zero energy solution sets can be grouped under three categories: passive design techniques, energy efficient technologies, and renewable energy technologies. Table 1 shows an example of possible solution sets that can be implemented in a Net ZEB. These solution sets are classified into two categories: whole building solution set and building challenge solution set. One particular solution set is always part of the whole building solution set, which includes a set of solutions used to lower the energy consumption of the whole building. This particular solution can also be classified into the building challenge solution set, which encompass a set of solutions used to lower the energy needed by a particular building challenge. For example, the solution *high insulation/thermal mass* is useful for reducing the energy needed for heating and cooling, as indicated in Table 1.

The aim of this study is to assess the viability of using existing Net ZEB solution sets to redesign a new building. The design process could start from an existing building design that needs to be modified to meet net zero energy consumption or from an existing Net ZEB being moved into a different climate.

The latter option is followed for this study. A case study was investigated using the existing Meridian building, located in Wellington, New Zealand, which was moved to Rome, in Italy. Both Wellington and Rome have a mixed heating and cooling climate. Interestingly, they have the same latitude but reverse: the latitude of Wellington is 41° South while the latitude of Rome is 41° North.

The work presented in this paper has been developed through the IEA SHC Task40/ECBCS Annex52: Towards Net Zero Energy Solar Buildings and the 2nd PhD Summer School on Net Zero Energy Buildings, held in Corsica in September 2012**.**

METHODOLOGY

Reference building

The Meridian Building was completed in 2007 on the harbour of Wellington, in New Zealand. It is a high performance, near net zero energy building using 60% less energy than a typical similar building. Because of its privileged location at the waterfront, it is generously glazed to allow connexion with the surroundings and judiciously shaded to avoid overheating.

The Meridian is a four storey office building with a conditioned floor area of 4795 m^2 and a net floor area of 5246 m^2. Three levels of offices are situated above the ground floor. The upper floor is set back from the edges on all sides. The building has a rectangular shape and a curved annex, as depicted in Figures 1 and 2. The top floor of the annex is also set back from the edges. The top picture of Figure 1 shows the North/West facing façades while the bottom picture show the South/East façades.

The building is taking advantage of passive solar gains by having a higher proportion of glazing on the north façade. The north façade (left façade in Figure 1, top) is facing 22° East of North. This façade has 77% of glazing and automated exterior louvers. The West façade (right façade in Figure 1, top) has a glazed proportion of 72% and consists of a double skin façade with motorized venetian blind inside the cavity. Likewise, the East façade (right façade in Figure 1, bottom) also consists of a double skin façade with motorized blinds and has a glazing proportion of 68%. The South façade (left façade in Figure 1, bottom) is made of concrete panels with punched windows with a lower glazed proportion of 54%. The curved annex is practically entirely glazed and is protected with deep fixed wooden external

Figure 1: The Meridian Building –
Top: North-West façade - Bottom: South-East façade

louvers. The U values of the roof, walls, floor and windows are approximately equal to 0.2, 0.4, 0.4 and 2 W/(m^{2}K).

The building is equipped with motorized windows for natural ventilation. The suspended ceiling panels allow hot air to be absorbed behind the panels by the concrete slab and night ventilation is practiced for releasing heat. There is a large central staircase which favours stack effect. The openings for ventilation are predominantly oriented East/West. The floor plan of levels one and two is presented in Figure 2.

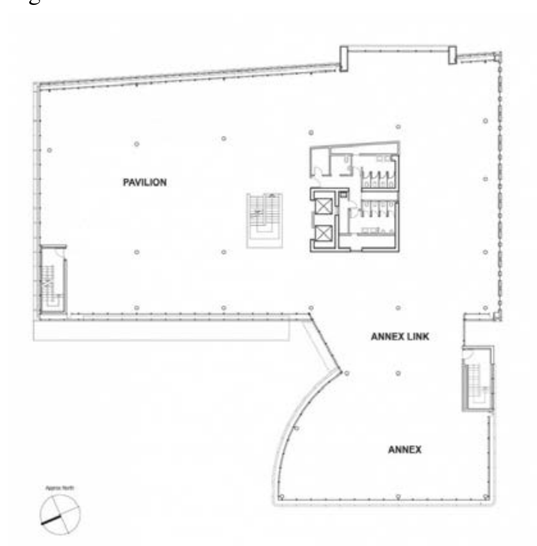

Figure 2: Floor plan of levels 1 and 2

The HVAC system uses an energy recovery wheel with 75% efficiency. Rainwater is collected on the roof and is used to supply 75% of the toilet water. The occupant density is 0.05 person/m^2.

***Whole Building Solution Set** - The set of solutions used to lower the energy consumption of the whole building.*		***Building Challenge Solution Set** - The set of solutions used to lower the energy needed by a particular building challenge.*						
Design Strategy	**Solution**	**Heating**	**Cooling**	**Ventilation**	**Lighting**	**Plug Loads**	**Water heating**	**Energy Export**
Passive Design Techniques	Optimized Floor plan > Optimized orientation/length-width > Volume to surface ratio > Building form follows sun path	✓	✓	✓	✓			
	Improved/Advanced Envelope > High insulation / thermal mass > Green roof and/or façade > Triple glazed, gas filled windows	✓	✓					
	Maximization of Passive Solar Heat Gain > Building orientation and form	✓						
	Solar Shading > External shades fixed/moveable > Interior shades/blinds		✓					
	Site Vegetation > Solar shading, moderation of winds		✓					
	Natural Ventilation > Cross ventilation, night cooling		✓	✓				
	Advanced Daylighting Measures > Large amounts of glazing > Solar tubes/ skylights				✓			
Energy Efficient Technologies	Energy Efficient Lighting > High efficiency fluorescents/LED > Low lighting power density, task lamps				✓			
	Advanced Lighting Controls > Electric light daylight dimming > Occupancy sensors				✓			
	Efficient Office Equipment > Low electric equipment power density > High efficiency computers/laptops/printers					✓		
	Efficient HVAC Equipment > Ground source heat pump > Ceiling fans (adaptive comfort)	✓	✓					
	Heat Recovery Ventilation	✓						
	Water Conservation and efficiency Measures > Low flow taps and showers > Hot water recovery						✓	
Renewable Energy Technologies	Photovoltaics > Building-integrated photovoltaics > Fixed/tracking photovoltaics > Photovoltaic/Thermal (PV/T) System							✓
	Solar Thermal Systems > Space heating system > Domestic hot water	✓					✓	
	Renewable Energy Boiler > Wood pellets	✓						

Table 1
Possible solution sets for reaching net zero energy consumption

There are eight solar thermal panels supplying 70% of hot water needs. The north facing saw-tooth shape of the roof was designed to facilitate an eventual integration of photovoltaic panels.

Simulation model of the reference building

A simplified EnergyPlus (DOE, 2012) model was created to simulate the reference building. No detailed HVAC systems were simulated: an ideal load air system is implemented in the model. The building has been divided into 28 zones, 7 per floor. For a typical floor, the annex and the annex link are both modelled as individual zones and the main building floor is divided into five zones: four perimeter zones and a central zone.

The louvers were modelled using a constant shading coefficient. The shading coefficient was set to 0.9 for the north façade of the building and to 0.5 for the north façade of the annex. The louvers on the west and south façade of the annex were modelled with a constant shading coefficient of 0.5 and 0.3 respectively. The U and the solar heat gain coefficient of glazings for specific orientations are indicated in Table 2. Window 6.3 (LBNL, 2011) was used to create glazings with similar properties than the actual building and then imported in EnergyPlus. South and North windows of the main building and all façades of the annex are equipped with double tinted low emissivity windows. The east and west double skin façades are made of an outside sealed double glass with an air gap of 17 mm and an inside clear glass with an air gap of 600 mm. The double skin façade is not ventilated in the simulation model and is therefore considered as triple glazing. There is an exterior blind on the outside controlled to block beam solar radiation.

		SHGC
Roof U-value	0.2 (W/m^{2}K)	-
Walls U-value	0.4 (W/m^{2}K)	-
Floor U-value	0.4 (W/m^{2}K)	-
South and North windows	2.03 (W/m^{2}K)	0.54
Double Skin windows	1.81 (W/m^{2}K)	0.68
Glazed proportion - South	54%	-
Glazed proportion - East	68%	-
Glazed proportion - West	72%	-
Glazed proportion - North	77%	-
Efficiency of energy recovery wheel	75%	-
Occupant density	0.05 p/m^2	-

Table 2: Characteristics of the Meridian Building

The heating and cooling set points are constants throughout the year and equal to 20°-24°. The building is equipped with a lighting capacity of 9.5 W/m^2 which is controlled based on a schedule. The lights are controlled to supplement the available daylight, if necessary, by continuous dimming. The U value of the floor and walls is 0.4 W/(m^{2}K) while

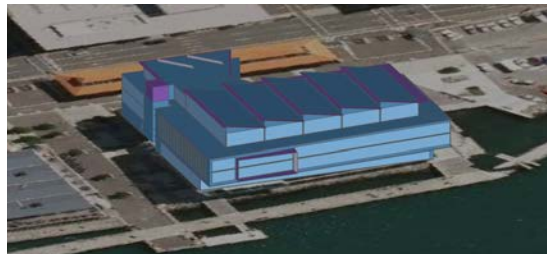

Figure 3: The Meridian Building model

the roof has a U value of 0.2 W/(m^{2}K), like the existing building.

Each zone has 0.1 air changes per hour (ACH) due to infiltration and is provided with 4 ACH with mechanical ventilation with 75% efficiency. Infiltration and ventilation are treated together as an effective 1.1 ACH for energy calculations. During the warm season (Dec 1 to March 1), night cooling occurs in the build at 1 ACH from midnight to 6am.

No photovoltaic panels are installed on the reference building. Hot water use and solar thermal panels have not been included in the model.

Original climate: Wellington, New Zealand

Wellington benefits from a fairly moderate temperate climate with a minimum temperature of 2°C and a maximum temperature of 25°C. Wellington is a sunny city with an annual average daily total direct normal radiation of 4066 Wh/(m^{2}day). The lowest average daily direct normal solar radiation is 2127 Wh/m^2 in June and reaches a maximum of

City	Wellington	Rome
Lowest temperature	2°C	-4°C
Highest temperature	25°C	32°C
Annual average temperature	13°C	16°C
Lowest monthly mean relative humidity	61%	73%
Highest monthly mean relative humidity	80%	81%
Lowest monthly mean daily total direct normal radiation	2127 Wh/(m^{2}day)	1729 Wh/(m^{2}day)
Highest monthly mean daily total direct normal radiation	6358 Wh/(m^{2}day)	5784 Wh/(m^{2}day)
Annual average daily total direct normal radiation	4066 Wh/(m^{2}day)	3295 Wh/(m^{2}day)
Annual average wind velocity	7 m/s	3.9 m/s
Heating degree day (18°C)	1718	1475

Table 3: Climate characteristics of Wellington and Rome

6358 Wh/m^2 in January. Predominant winds blow from the North in the warmer season with an annual average wind speed of 7 m/s. Despite the fact that Wellington is at the same latitude than Rome, it is cooler due to the moderating effects of the Pacific Ocean.

New climate: Rome, Italy

Even though Rome is located at the same latitude but in the opposite hemisphere, Rome is subjected to more pronounced weather variations. The minimum temperature in Rome is -4° while the maximum can reach 32°C. Rome receives less solar radiation than Wellington: the lowest monthly direct normal solar radiation is 1729 Wh/m^2 per day in December and reaches 5784 Wh/m^2 per in July. The annual average wind speed in Rome is 3.9 m/s. The relative humidity is higher in winter than in summer: the lowest monthly mean relative humidity is 73% in August and the maximum reaches 81% in March.

Redesign process

A simplified EnergyPlus model was used to simulate the Meridian building in its current climate. In order to assess the practicality of using solution sets for redesigning Net ZEB, the Meridian building was then moved from Wellington to Rome. The simulation of the Meridian building in Rome was compared with the actual building location.

Solution sets from existing Net ZEB offices in mixed heating and cooling climates were used to identify design changes for redesigning the building to reach net zero energy. Different solutions were simulated iteratively until the energy consumption of the building was significantly reduced.

RESULTS

The energy consumption for heating, cooling, lighting and office equipment is depicted in Figure 4 for various designs of the Meridian building. The first design is the reference building in Wellington and the second design is the same building but subjected to Rome's weather.

The following solutions were simulated iteratively:

- Adjustment of the night cooling schedule (from May 15 to October 1st) and rotating the building 158° (the North façade becomes perfectly aligned with South).
- Reduction of the SHGC of the East and West double skin façade and reduction of the equivalent transmittance of the louvers from the north and west façades of the annex to 0.3.
- Changing the insulation of the walls and ceiling from the inside to the outside and removing tiles on the ground floor to expose thermal mass (concrete).
- Increasing the night ventilation to 3 ACH and readjusting the night cooling schedule until October 8.
- Increasing the cooling set point from 24 to 27 and adding ceiling fans to meet thermal comfort requirements.
- Increasing the efficiency of the HVAC system to 85%.
- Reducing the equivalent shading transmittance to 0.7 for the South façade and reducing the SHGC of the South and North windows and the double skin façade.
- Improving the efficiency of the lighting system to 8 W/m^2.

All these changes have been inspired from the solution set presented in Table 1. It can be seen that the performance of the Meridian building is not as good when this building is moved into the Rome climate. The annual heating load increases from 22 kWh/m^2 to 32 kWh/m^2 and the annual cooling load increases drastically from 32 kWh/m^2 to 76 kWh/m^2. However, after implementing the design changes described above, the performance of the building can be significantly improved and better suited to the new climate.

Increasing the cooling set point from 24°C to 27°C reduced significantly the cooling energy consumption. The warm season in Rome is relatively hot and dry. The addition of ceiling fans would ensure that thermal comfort conditions are met according to the Givoni comfort zone (Givoni, 1992). The energy consumption of ceiling fans has not been added in the model, but their electricity consumption would be small compared to the saved cooling energy.

The cooling load remains a significant portion of the total heating consumption. Adding photovoltaic on the slanted part of the saw-tooth roof would generate 40,3 MWh annually. This would cover about 20% of the building energy needs.

The existing solution sets of the original Meridian building and the modified building design for Rome are presented in Table 4. Since the two climates were relatively similar, most existing solution were kept but only adapted to values more appropriate for the new climate. Only two new solutions were adopted: the addition of ceiling with an increased cooling set point and the addition of building-integrated photovoltaics.

Additional work on the building design would be needed to make this building reaching net zero energy consumption. Nevertheless, the total energy consumption of the building has been significantly reduced following this methodology, from 145 kWh/m^2 per year down to 70 kWh/m^2 per year, a 52% reduction.

CONCLUSION

This paper presented a case study that was conducted to assess the viability of using solutions sets to help redesigning buildings to reach net zero energy consumption. The authors found that using existing guidelines can be useful and ease the design of Net ZEB. Following such a process could be particularly useful to building professionals unacquainted with high performance buildings or working in a different climate.

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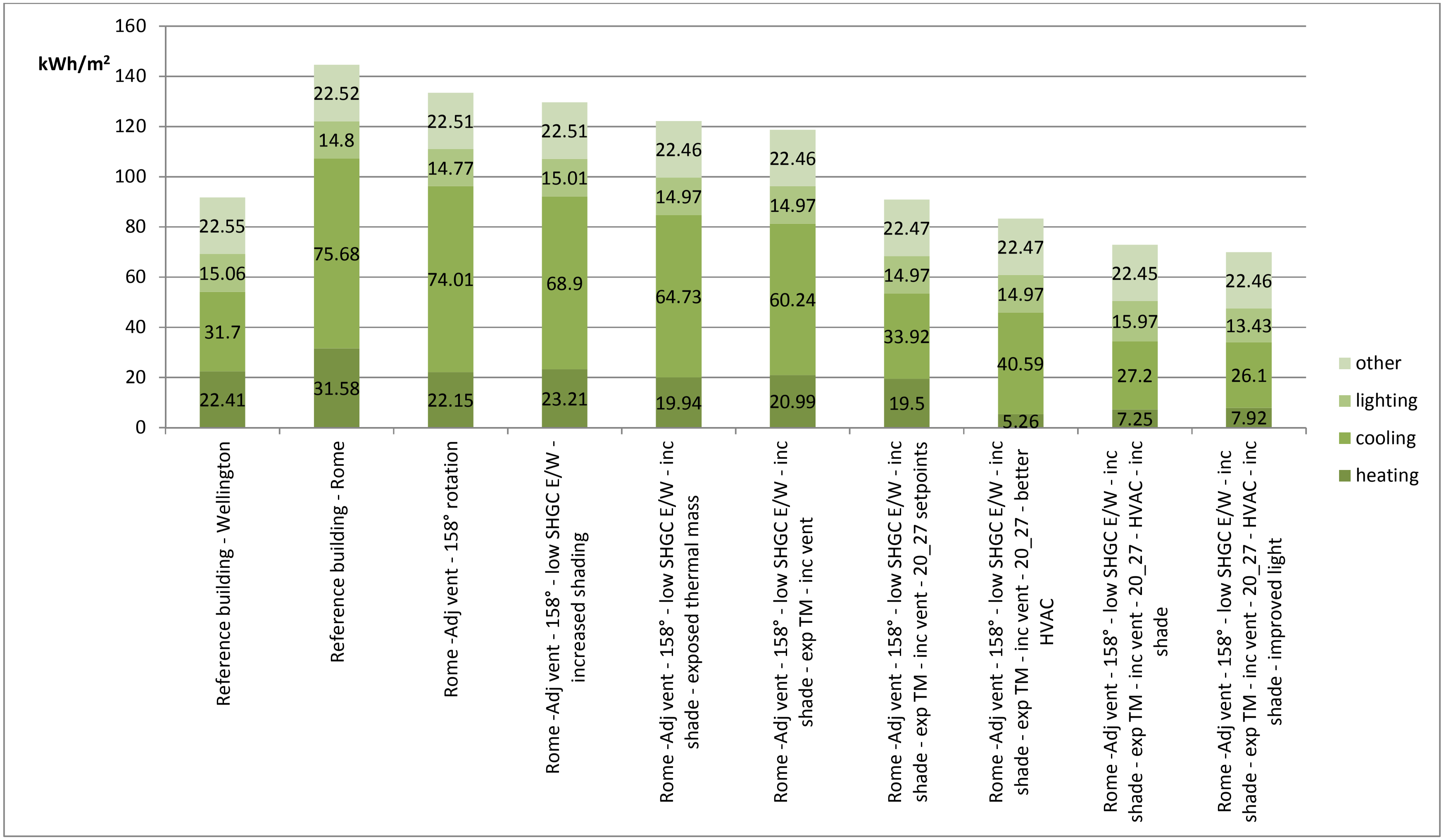

Figure 4
Annual specific energy consumption of various designs of the Meridian building.

Design Strategy	**Original Solution Set– Meridian, Wellington, New Zealand**	**Modified Solution set- Meridian, Rome, Italy**
Passive Design Techniques	Improved/Advanced Envelope > High thermal mass	Improved/Advanced Envelope > Increased thermal mass
	Maximization of Passive Solar Heat Gain > Building orientation and form	Maximization of Passive Solar Heat Gain > Building orientation adjusted for new climate
	Solar Shading > Fixed and motorized external shades > Double skin façade with motorized venetian blinds in the cavity	Solar Shading > Fixed and motorized external shades > Double skin façade with motorized venetian blinds in the cavity > Readjustment of shades to further reduce cooling loads
	Natural Ventilation > Double skin façade, cross ventilation, night cooling	Natural Ventilation > Double skin façade, cross ventilation, increased night cooling with schedule adapted to new location
	Advanced Daylighting Measures > Large amounts of glazing	Advanced Daylighting Measures > Large amounts of glazing, but with reduced SHGC
Energy Efficient Technologies	Energy Efficient Lighting > High efficiency fluorescents	Energy Efficient Lighting > High efficiency fluorescents > Reduced installed power density
	Advanced Lighting Controls > Electric light daylight dimming > Occupancy sensors	Advanced Lighting Controls > Electric light daylight dimming > Occupancy sensors
	Efficient Office Equipment > LED screens > Predominantly laptops	Efficient Office Equipment > LED screens > Predominantly laptops
	Integrated Monitoring > Energy/load management	Integrated Monitoring > Energy/load management
	Heat Recovery Ventilation > Energy recovery wheel with 75% efficiency	Heat Recovery Ventilation > Upgraded energy recovery wheel with 85% efficiency
	Efficient HVAC Equipment > Reverse-cycle heat pump > Chilled beams	Efficient HVAC Equipment > Reverse-cycle heat pump > Chilled beams > Ceiling fans (adaptive comfort) and increased cooling set point
	Water Conservation and efficiency Measures > Low flow taps > Rainwater collection	Water Conservation and efficiency Measures > Low flow taps > Rainwater collection
Renewable Energy Technologies	Photovoltaics > “Solar ready” roof (appropriate shape for future integration of PV)	Photovoltaics > Building-integrated photovoltaics
	Solar Thermal Systems > Domestic hot water	Solar Thermal Systems > Domestic hot water

Table 4
Solution sets of the original Meridian building, in New Zealand, and the modified building design, in Rome.