

USE OF NET ZERO ENERGY SOLUTION SETS FOR THE REDESIGN OF THE REUNION ISLAND ENERPOS BUILDING IN CHRISTCHURCH

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ABSTRACT

The aim of this study is to establish the suitability of using existing net zero energy building (Net ZEB) solution sets to redesign Net ZEBs being moved into different climates. A case study was performed using the ENERPOS Building, located in Saint-Pierre, Reunion Island (cooling dominated climate), and moved to Christchurch, New Zealand (mixed heating and cooling climate).

The study concluded that with the addition of a heating challenge solution set established from existing Net ZEBs in a similar climate to Christchurch, the ENERPOS Building was once again able to be a Net ZEB in the Christchurch climate. Also concluded is that the use of existing building solution sets is a good starting point for redesigning buildings to reach net zero energy, and that they can be used to design new Net ZEBs.

INTRODUCTION – STUDY AIM AND SIGNIFICANCE

Energy efficiency has become an important topic in the building sector and groups such as the IEA SHC Task 40 / ECBCS Annex 52 has been mandated to study net zero energy buildings (Net ZEBs) as a solution to this need. Its task encompasses Net ZEB definitions, methods of calculation and verification, design tools and new technologies, and the development and documentation of whole building Net ZEB solution sets (IEA SHC Task 40 / ECBCS Annex 52, 2008).

The aim of this study is to assess the viability of using these Net ZEB solution sets to redesign buildings being moved into different climates. A case study approach was used to test whether solution sets can be used to redesign a building to be net zero energy again. The Net ZEB chosen for this study is the ENERPOS Building (French acronym for POSitive ENERgy), a 681 m² (net) educational building in Saint-Pierre, Reunion Island, a cooling dominated climate, near Madagascar. The building was relocated to Christchurch, New Zealand, a mixed heating and cooling climate, with the challenge to

redesign it to be Net ZEB again. There are two types of solution sets. The first Net ZEB solution set is the whole building solution set: a set of passive energy design, energy efficient technologies, and renewable energy technologies used in a specific climate, site context, and building type to reach the goal of annual net zero energy consumption. The second is the building challenge solution set: a set of solutions used to lower the energy needed by a particular building challenge (e.g. heating, cooling, lighting, plug loads etc.).

The literature shows many definitions of Net ZEB (Sartori et al., 2012; Marszal et al., 2011). In this study, a Net ZEB is defined as a building that achieves an annual net zero energy balance between energy use and renewable energy generation. The type of energy use includes building and user energy, but excludes embodied energy. The renewable energy supply options include on-building and on-site generation.

This study was carried out under the auspices of an IEA SHC Task 40 / ECBCS Annex 52 PhD Summer School program, the goal of which was to study the impact of climate on Net ZEB solution sets by relocating an existing Net ZEB to a different climate and redesigning it to be Net ZEB again. This exercise is meant to increase understanding of the various Net ZEB solution sets, the factors that affect their performance and provide an opportunity in designing Net ZEBs in a collaborative team with a diverse background in architecture and engineering.

METHODOLOGY FOR TESTING AND REDESIGNING THE ENERPOS BUILDING FOR CHRISTCHURCH

The study was performed using EnergyPlus models built to match the ENERPOS Building's size, shape, construction, and internal loads and patterns of use (US Department of Energy, 2013). Modelling simplifications were made to the sun shading, electric lighting, cooling, internal equipment, and fan energy and air movement. The simplifications are as follows:

- **Shading:** the actual building has louvers as solar shading. The model uses shading to the same area with a percentage of visible transmittance to replicate the multiple slats.
- **Lighting and internal equipment:** the model is based on the design loads for lighting and plug loads instead of what is actually installed in the real building. The design loads are distributed evenly per square metre of floor area and are likely to be highly over estimated in comparison to what is actually installed and used in the building.
- **Cooling:** scheduling of the cooling is based on a 9-5 weekday (on) operation and a constant set point. This may not be correct in reality as the data to confirm how often the cooling is used and what temperatures the cooling is set to was not available.
- **Fan energy and air movement:** ceiling fans are replicated by plug loads being operated when the internal air temperature reaches a set value. Simple ventilation modelling with a constant achievable Air Change per Hour (ACH) is used to mimic natural ventilation under ideal conditions.

The PhD summer school analysis methodology used in the study of the ENERPOS Building was split into three stages:

1. **Establish what is important in the current Net ZEB's circumstances by systematic removal of individual building challenge 'solutions.'** A model was used to simulate ENERPOS in its current climate to assess the existing energy circumstances and what the main energy drivers are.
2. **Change the climate to see to what extent the original solution set is climate dependent.** The ENERPOS Building was then simulated in the Christchurch, New Zealand climate and compared to the current building circumstances to assess how the climate interacts with the existing ENERPOS solution set.
3. **Use existing solution sets from other Net ZEBs in similar climates, site contexts and building types to make the building Net ZEB again in this new climate.** Net ZEB solution sets from existing non-residential Net ZEBs in mixed heating and cooling climates were used to redesign ENERPOS to reach Net ZEB again.

RESULTS AND DISCUSSION

Understanding the ENERPOS Building in Saint-Pierre's climate

An EnergyPlus model was used to simulate the ENERPOS Building in its current climate, Saint-Pierre, Reunion Island.

Figure 1 shows the simulated annual energy consumption and production of this base case. The simulated energy consumption is 65 kWh/(m²·yr) and the photovoltaic (PV) energy production is 72 kWh/(m²·yr), making a final energy balance of 7 kWh/(m²·yr). Thus, simulations show ENERPOS is a net energy positive building. By comparison, ENERPOS was designed for an energy use intensity (EUI) of 50 kWh/(m²·yr) and monitored results show a real EUI of 14.4 kWh/(m²·yr) (Franco et al., 2011).

Figure 2 shows the simulated thermal comfort results. The building design satisfies thermal comfort 60% of the time, considering a comfort range of 18 to 30° C during the regular operating hours of the building from 8 AM to 6 PM. However, when considering adaptive comfort, using the Givoni adaptive thermal comfort model (Givoni, 1992), with an interior air speed of 1 m/s, thermal comfort is satisfied 80% of the time, as depicted in figure 3.

The main energy drivers are identified along the three broad components of Net ZEB solution sets. The passive design features are: natural (cross) ventilation, fixed solar shading and large windows for daylighting, and thermal insulation on the roof. The energy efficiency features are: fluorescent T5 lighting, efficient office equipment, and ceiling fans. Finally, the renewable energy features consist of: roof-mounted PV panels, as illustrated in figure 4.

Systematically, the design features were removed, individually, to see the relative importance of each on the final comfort and energy profile of the building. The results in figure 5 show that eliminating solar shading, natural ventilation, efficient lighting, and efficient office equipment had the greatest detrimental impact on thermal comfort. Surprisingly, eliminating the thermal insulation (located only in the roof structure) had a positive effect on thermal comfort. This, however, can be explained by the PV array being situated over the roof that acts like an umbrella and shades the roof extensively from excess solar heat gains. Due to this, the existing insulation in the roof prevents the heat present in the building from escaping. Removing the insulation allows the heat inside the building to escape more easily, thereby reducing the number of 'too hot' hours.

In terms of energy performance, figure 6 shows that eliminating efficient office equipment and efficient lighting produced the greatest increases in energy consumption.

From the above, we can conclude that out of all the features in its Net ZEB solution set, ENERPOS in its actual climate is very dependent on solar shading, natural ventilation, efficient lighting and efficient office equipment. This corresponds with the design intentions of the building, which made use of the Givoni adaptive comfort model. In fact, the performance of the passive and energy efficient

solutions is great enough to obviate the need for auxiliary cooling.

Understanding the existing ENERPOS Building in the new Christchurch climate

The next step is to change the climatic conditions of the building. Ideally, the building should be relocated to a new climate that is as different as possible from the original climate and in the opposite hemisphere to examine how climate sensitive the Net ZEB solution sets are. In our case, we change from the cooling dominated climate of Saint-Pierre, Reunion Island to the mixed heating and cooling climate of Christchurch, New Zealand.

*Table 1
Comparison of climatic conditions*

PROPERTY	ORIGINAL CLIMATE (SAINT-PIERRE)	NEW CLIMATE (CHRISTCHURCH)
Location	21.3° S, 55.5° E	43.5° S, 172.5° E
Outdoor temperature range	21° C to 27° C	-4° C to 32° C
Outdoor relative humidity	68 to 72%	60 to 80%
Global horizontal irradiation	427 to 672 Wh/m ² (Average hourly)	190 to 482 Wh/m ² (Average hourly)
Daily horizontal illumination	27 klux to 42 klux	18 klux to 52 klux
Wind speed range	2 to 3 m/sec	3 to 5 m/sec

Table 1 shows a comparison of the climates of Saint-Pierre and Christchurch. The most significant differences are the outdoor temperatures that stay within a narrow tropical range of 21 to 27° C in Saint-Pierre to a dynamic -4 to 32° C range in Christchurch. The wind velocity is about 50% greater in Christchurch. There is less solar radiation in Christchurch: the global horizontal irradiation is 28% to 55% less than in Saint-Pierre. Daily horizontal illumination ranges are greater in Christchurch than in Saint-Pierre. Christchurch can be characterized as having a greater dynamic range of climate conditions than Saint-Pierre.

After changing the climatic conditions of the ENERPOS Building, a simulation was run to see how its Net ZEB solution set fared in the new climate. As can be expected (especially considering temperatures get as cold as -4° C in Christchurch), ENERPOS performs poorly in the Christchurch climate, achieving satisfactory thermal comfort for only 30% of the time. This is taking into consideration the 1 m/s indoor air speed included as part of the Givoni

adaptive thermal comfort model. The indoor air speed that was beneficial to thermal comfort in the Saint-Pierre climate turns out to be a detriment in the Christchurch climate, as can be seen in figure 3.

The energy performance is also very poor. Not only is the energy consumption of the building increased from 65 to 138 kWh/(m²·yr), the energy generation from the PV array is reduced by 34% from 72 to 47 kWh/(m²·yr). The most significant energy-consuming factor is heating. On the other hand, the baseline building in the new climate uses negligible energy for ceiling fans, and fans and auxiliary cooling, as shown in figure 7.

Net ZEB redesign solution set for Christchurch based on precedents

After the results have been analysed for the original building in Christchurch, and assessing the impact on the building's thermal and energy performance, a search begins for solution set precedents to help redesign the building to reach net zero energy again. Since Christchurch is a mixed heating and cooling climate, whereas Saint-Pierre is only cooling dominated, solution sets that dealt with heating challenges were primarily sought after, as the cooling performance was already good. A survey of the existing Net ZEBs — using published sources (Voss and Musall, 2011) and documentation provided at the PhD Summer School — with similar climates, site contexts and building type, yielded two office buildings, and three schools.

Five common features across the five buildings formed a suitable heating challenge solution set as a starting point for the redesign of ENERPOS. This solution set is comprised of: increased passive solar access; insulation of the whole envelope and exposed thermal mass; glazing allowing for solar gains; electric light dimming; and PV as the building's source of renewable energy generation. Each solution is discussed below.

Passive solutions

To increase passive solar heat gains and daylight access, building floor plans are typically elongated in the East-West axis. The original ENERPOS floor plan is already elongated along the East-West axis so the building shape was not altered. However, the building consists of two halves, and they were moved further apart, from 9 m to 21 m, creating a larger courtyard space between the two. This was to readjust the positioning of the two halves vis-à-vis the sun to prevent self-shading at the new latitude of Christchurch.

The existing building has insulation only in the roof. Therefore a high level of insulation was installed in the walls and floor, and the roof insulation was increased. ENERPOS already has double-glazed windows installed and this was altered for the new

climate in Christchurch by increasing their thermal resistance. The Solar Heat Gain Coefficient (SHGC) of the glazing was increased to standard clear glazing to allow for more solar heat gains in the building.

Exposed thermal mass is already present inside the building. The insulation was installed on the exterior of the existing thermal mass to not hinder its function of moderating the internal conditions.

As Christchurch is situated at much lower latitude than Saint-Pierre, the southern façade's solar shading was not needed and was therefore removed from the building. This aided in increasing daylight access and passive solar gains.

Energy efficient solutions

ENERPOS already uses daylighting as a passive design feature and the current electric lighting in the building is on a 2-hour timer to prevent the lights from being on when they are not needed. To increase efficiency further, a dimming system is installed to the already efficient fluorescent T5 lighting, making the combination of daylighting with electric light dimming controls an even more efficient system to lower the electric light energy use.

Renewables

As PV is always used either alone or in combination with other renewables in the other existing Net ZEB precedents, the existing PV arrays will remain on the building although redesigned to increase performance. The roof-mounted PV panels were adjusted for the latitude of Christchurch. The total surface area of the panels remains the same, but the panels had to be rearranged and repositioned to avoid shading each other, and the tilt angle was increased from the original 10° to a new angle of 33.5°.

One of the significant challenges of the redesign involved reconciling the competing requirements of the enumerated solutions. Sun exposure for the building interior was a priority for achieving the passive design solutions of daylighting and solar heat gain. This meant that both the building and the rooftop-mounted PV panels could not obstruct sunlight from reaching the interior, especially during the winter season when the sun is lower in the sky and solar gain is more beneficial to heat the building's thermal mass.

The near optimal tilt angle of the PV panels in the new climate of Christchurch is equal to the location's latitude, 43.5° (Duffie and Beckman, 2006). However, the height of a pitch meant the PV panels would obscure sunlight from reaching the southernmost building for an unacceptably large portion of the time. One remedy for this problem is to further distance the south wing from the shadow of the PV panels on the roof of the north building. However, this would have put the two buildings at a distance of 26 m from each other. This idea was

rejected because the buildings would be too far apart to operate as a whole. Instead, a compromise was made to lower the tilt of the PV panels to 33.5° and limit the distance between the two buildings to 21 m.

The redesigned ENERPOS Building for Christchurch's climate to be Net ZEB

Once the new Net ZEB solution set was optimised, the ENERPOS Building in the new climate of Christchurch simulates again as a Net ZEB. Figures 8 and 9 show a building cross section featuring the new Net ZEB solution set. Using the same thermal comfort parameters as before (18 to 30 °C, between 8 AM and 6 PM), figure 10 shows that the building is comfortable almost 100% of the time.

With respect to the baseline building in the Christchurch climate, figure 11 shows that the redesigned ENERPOS' energy consumption decreased significantly from 138 to 48 kWh/(m²·yr). The most significant savings was in heating energy, which decreased from 78.38 kWh/(m²·yr) to practically zero. This illustrates well the benefits of the passive design solutions of increasing the amount of exposed thermal mass in the building, and increasing the thermal resistance of the windows and envelope compositions.

The second notable savings was in interior electric lighting, which decreased by 50% from 16.24 kWh/(m²·yr) to 8.11 kWh/(m²·yr). This savings can be attributed to the energy efficiency solution of enhanced dimming controls on the electric lighting. In the baseline case, electric lights remained on at reduced power when stepped down to their minimum level due to increased daylight illuminance, whereas in the redesign case, the electric lights were turned off when stepped down to their minimum level.

Finally, in terms of renewables, the redesigned ENERPOS' energy production increased 27% from 47.36 to 60.32 kWh/(m²·yr). This is due to the improvement of the PV array arrangement, orientation, and tilt angle in the new climate. Table 2 summarises the energy results.

Table 2

Energy Use Intensity summary of ENERPOS in Christchurch. All values in kWh/(m²·yr)

	Base building	Redesigned building
Ceiling fans	0.07	0.15
Cooling	0.09	0.01
Heating	78.38	0.01
Interior lights	16.24	8.11
Interior equipment	43.63	39.86
Energy production	-47.36	-60.32
Energy Use Intensity	91.05	-12.18

CONCLUSION

The study concluded that the use of existing building solution sets is a good starting point for redesigning buildings to be net zero energy, and that they can be used to design new Net ZEBs. As well, with the addition of a heating challenge solution set established from existing Net ZEBs in a similar climate to Christchurch, the ENERPOS Building was once again able to be a Net ZEB in the Christchurch climate.

As seen from the initial simulation of the ENERPOS Building in its actual climate, the simulation results overestimate the energy use of the building when compared with monitored data. Some possible explanations for this stem from the modelling simplifications made to the sun shading, electric lighting, cooling, internal equipment, and fan energy and air movement. Thus, the results are only as accurate as the model that is being used in the assessment. Nevertheless, within the limits of our modelling assumptions, which were applied systematically across all simulations, the simulations have provided useful insight into the design of Net ZEBs. The most evident conclusion is that understanding climate is extremely important for designing Net ZEBs. Explicitly re-examining the effects of climate on building performance by changing it illustrates this well.

The Net ZEB redesign exercise shows that following precedents from existing solution sets for the climate and building type being considered provides a clear starting point for building redesign to net zero energy. Without the precedents, there could potentially be an unlimited number of design and technological options that could be used to redesign a building. Thus, existing measures that work in a similar context provided the best starting point. Also, the result of the ENERPOS Building being redesigned to be net zero energy using precedents proves this.

Finally, there was no definitive conclusion on whether the passive design, energy efficient technologies, or the renewable energy technologies had the most impact on energy performance. In the ENERPOS simulation in Saint-Pierre, the energy efficient equipment and internal lighting had the greatest impact on energy consumption. In the ENERPOS simulation in Christchurch, however, the greatest energy consumption impact came from the passive design solutions.

ACKNOWLEDGEMENT

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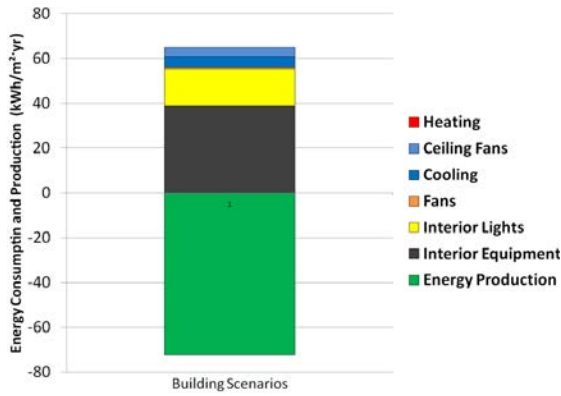


Figure 1 ENERPOS in Saint-Pierre: Annual energy end-use breakdown

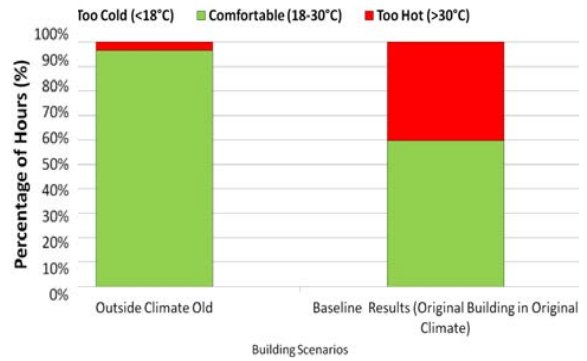


Figure 2 ENERPOS in Saint-Pierre: Percentage of hours that are 'too cold,' 'comfortable,' and 'too hot'

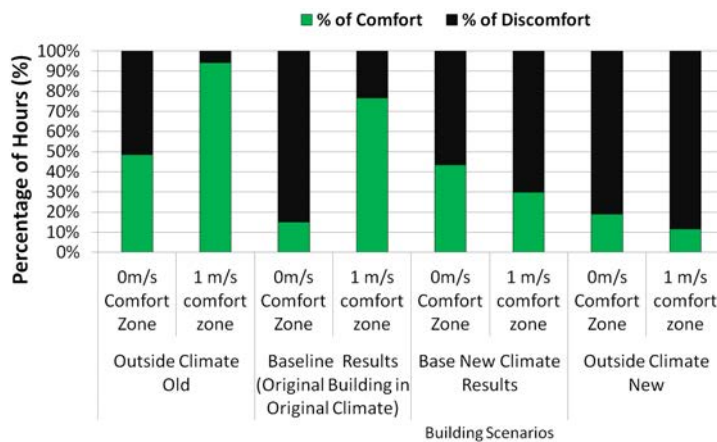


Figure 3 Givoni adaptive comfort: Percentage of hours of 'comfort' and 'discomfort' in old, original climate of Saint-Pierre and new climate of Christchurch

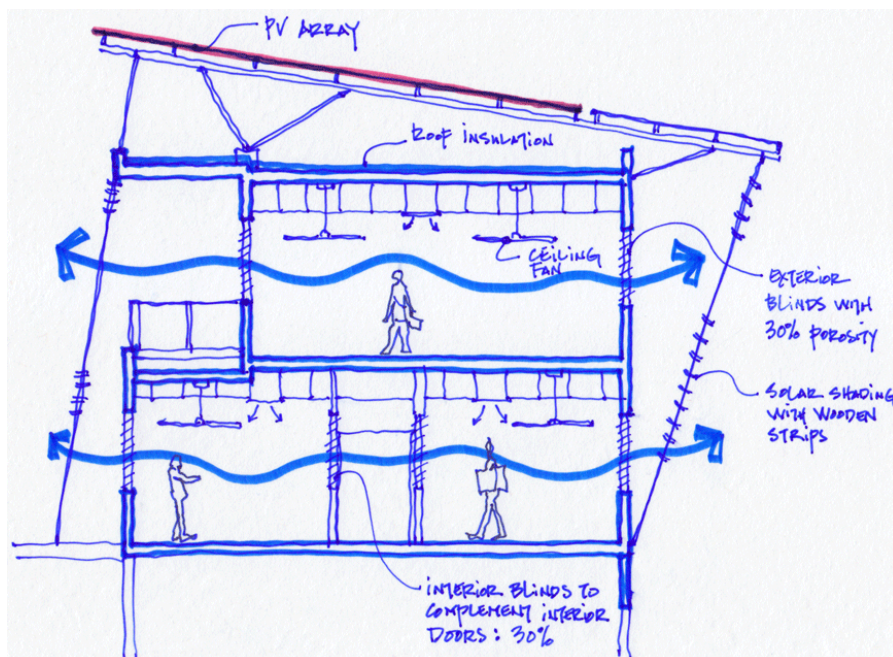


Figure 4 ENERPOS in Saint-Pierre: Building section illustrating Net ZEB solution set

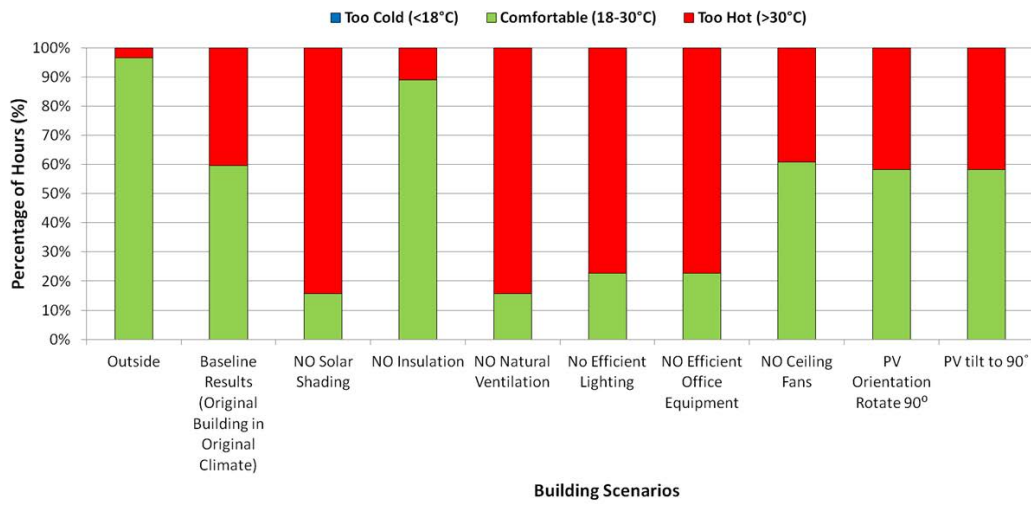


Figure 5 ENERPOS in Saint-Pierre: Percentage of hours that are 'too cold,' 'comfortable,' and 'too hot' for different building scenarios

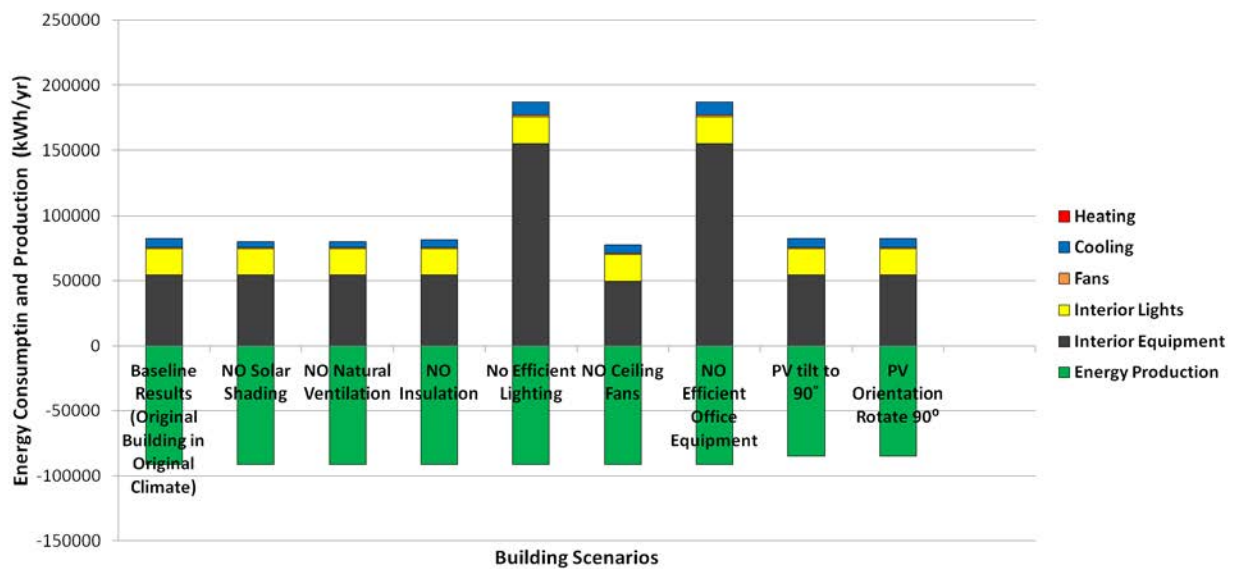


Figure 6 ENERPOS in Saint-Pierre: Annual energy end-use consumption and production breakdown for different building scenarios

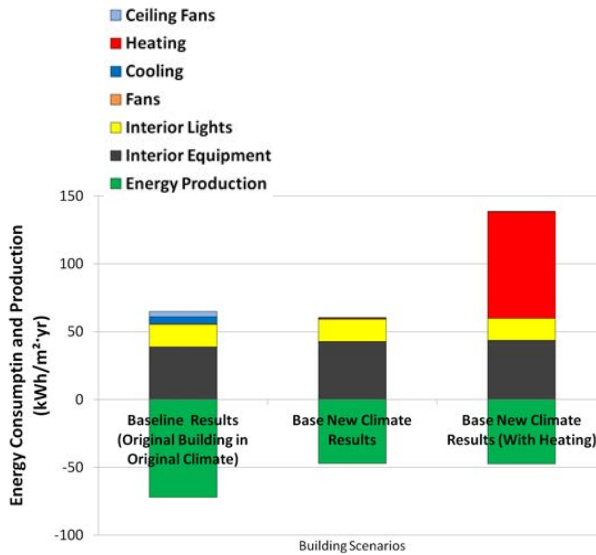


Figure 7 Annual energy end-use consumption and production breakdown: ENERPOS in original and new climates

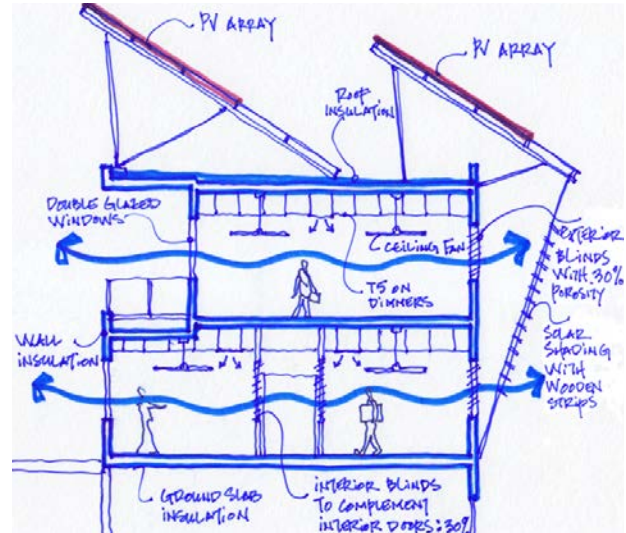


Figure 8 ENERPOS in Christchurch: Building section illustrating new Net ZEB solution set

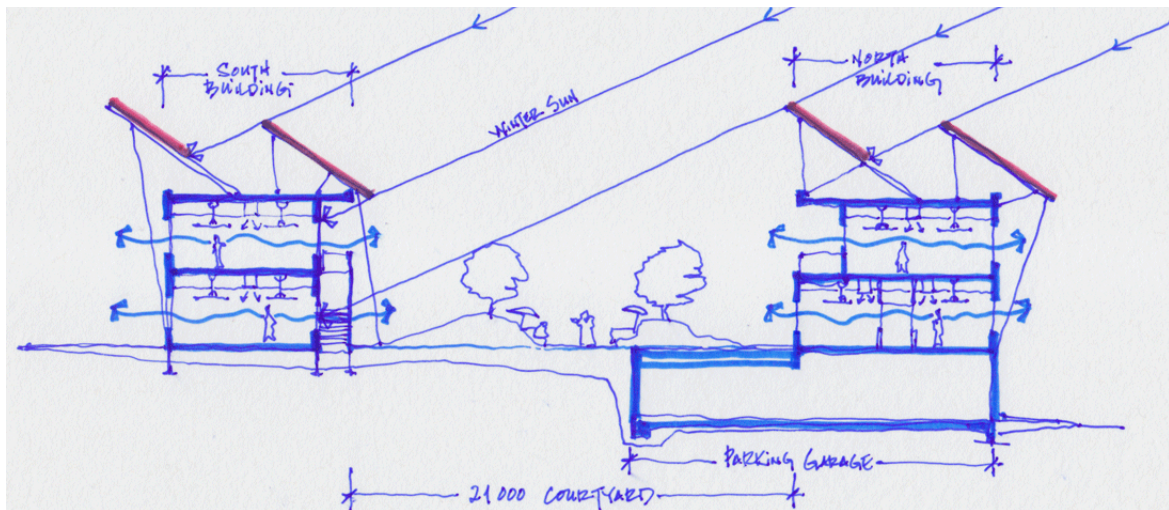


Figure 9 ENERPOS in Christchurch: Building section illustrating new Net ZEB solution set

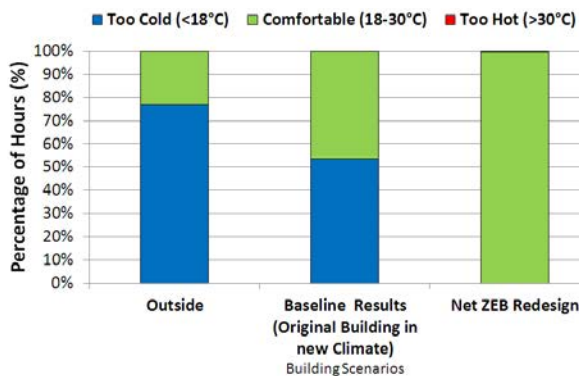


Figure 10 ENERPOS redesign: Percentage of hours of 'too cold,' 'comfortable,' and 'too hot' in new climate of Christchurch

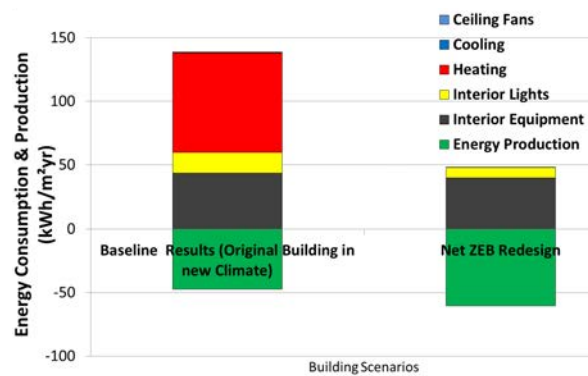


Figure 11 ENERPOS redesign: Annual energy end-use consumption and production breakdown