Building passive houses in subtropical climates? A lesson learnt from New Zealand

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1. Introduction

The tourism image of New Zealand, in many ways, is far removed from the reality of the country's features, resources and living conditions of its people. It is known as a natural paradise, with inexhaustible sources of energy and a subtropical climate that undermines the efforts undertaken by the building industry in other countries to reduce the environmental impact of the built environment, making superfluous any commitment towards energy efficiency and GHG emission reductions. In this ideal (or idealized?) scenario, why talk about Passive House standard? With mean annual temperatures around 10°C in the South and 16°C in the North, and 2000 sunshine hours/year across the country, NZ seems to provide adequate climate and resources to support comfortable, energy efficient and sustainable dwellings. Unfortunately though, most of the country's current housing stock is made up of poorly performing homes with worrying consequences on energy consumption and occupant health. This paper traces the causes of this failure and proposes, through an overview of recent achievements and projects still in the pipeline, 'local' constructive solutions based on the Passive House (PH) standard as an effective solution. This also opens new perspectives on the potential of diffuse energy generation and integration of renewables in residential buildings.

2. NZ myths: energy, climate and low house performance

In 2011, a total of 77% of NZ electricity generation came from renewable resources due to record high geothermal generation, good hydro inflows and a 20% increase in generation from wind [MoED, 2012]. However, the country will soon face its 'peak hydro', which is the likely consequence of predicted droughts due to temperature increases [NIWA, 2010]. Furthermore, it remains a net importer of oil, while its expected growth in electricity demand imposes to build 'new power generation'. Thus, historical reliance on endless energy resources is no longer an option. Instead, alternative strategies are required, addressing the reduction of energy consumption and renewable energy sources, as well as the lack of national policies and incentives aiming to encourage their use. It is worth noticing, that over one third of grid electricity, regardless of its clean nature, is used, and often wasted, by the residential sector [Isaacs, 2006], as it is the largest energy source for space and water heating. Unfortunately, the problem is intensified when buildings perform inefficiently.

A consolidated myth concerning NZ is its ‘tropical’ climate and the consequent low performance required for residential buildings. Lying midway between Antarctica and the tropics (34°-47° latitude South), NZ‘s climate has a wide variation from the ‘winterless North’ to the deep South with chilled winters approaching those of European regions of similar latitude. NZ Building Code divides the country into only three different climate zones - zone one being the warmest and most populated, including the Auckland Region, where one third of the population lives. Regardless of climatic conditions, the same basic housing types - typically single detached houses - are used throughout NZ, still built following the original construction method introduced by the 1800‘s British settlers. Mainly timber framed houses with metal roofs and little insulation, they fail to provide comfortable and healthy indoor living environments. This anomaly is perpetuated by the limited legislative provisions for energy performance and comfort, with no minimum internal temperature for residential buildings, and allowed building envelopes’ R-values that are rather low, especially for the coldest areas of the country.

The 2010 NZ House Condition Survey reveals that a large portion of the existing stock, including the most recent buildings, offers substandard living conditions [Buckett et al, 2011], with insufficient insulation, ventilation and heating. The link between cold and damp NZ homes and asthma and other winter-related conditions has been proved by many scientific studies [Howden-Chapman, 2005], which aimed to understand why the country has one of the highest rates of asthma in the developed world. In this 'disenchanted’ context, talking about PH standard starts to make sense.

3. Passive House standard: a solution for New Zealand

As PH is synonymous with indoor comfort and energy efficiency, it appears the most effective solution to NZ’s housing problems, and its European success leads to the question of whether the standard is applicable to the country’s ‘unique’ climatic, social and market conditions. In 2010 the first report commissioned to the Passivhaus Institut by The University of Auckland demonstrated the potential of the standard to be applied in NZ [Grove-Smith & Schnieders 2010]. The study was to determine basic PH planning criteria in NZ climates. Reference PHs were projected with PHPP (proven to be valid for planning in NZ) and compared with Code compliant houses. Results highlighted potential energy savings and far superior indoor comfort conditions. Since then, PHs have slowly spread in NZ, also thanks to the efforts of the Passive House Institute New Zealand, founded in 2011, and currently there numerous projects under construction, which followed the first PH completed in Auckland in July 2012. Despite favourable evidence though, building 'passive' in NZ is still challenging. A recent article published by Building Research Association NZ [Jaques & McNeil, 2012], confirms local resistance to ‘suspicious’ forms of building innovation, particularly when imported from overseas, as they are seen as at risk to damaging sedimented (but not necessarily correct) local building traditions - survived thanks to NZ's geographical isolation. Comparing the existing NZ housing stock performance with the most enhanced European housing standards, the need for innovation in construction methods and technology becomes evident.

3.1 The eHaus prototype, Wanganui 2010

NZ's first certified PH followed the pragmatic experience of the eHaus prototype, built in Wanganui (climate zone two). This project was highly significant to test the PH design in relation to standard NZ construction solutions, and to verify material and component supply issues, local workforce skills and the economic feasibility of the proposed PH solution. The eHaus prototype design was added into the PHPP software and found to conform in all areas except the under floor insulation (50mm of polystyrene) and the thermally broken aluminum window joinery. Even with these obvious flaws, the PHPP software indicated a space heating demand of 22.5 kWh/(m^2a) and a heating load of 15 W/m^2. The wall construction chosen was an insulated concrete form, which proved to be cost effective, providing air-tightness, simple thermal bridge free detailing, sufficient insulation and it was readily available in NZ. It integrates well with the concrete raft foundations that are commonly used in the country. PH designs differ from standard construction in that a continuous layer of polystyrene, typically 150mm thick for locations in the North Island, is placed beneath the concrete floor slab. The MHRV system was imported from Germany and everything else was sourced locally. Using a vapour check membrane in the ceiling space gave the house an air-tightness (n50) of 0.6 h^-1. Double glazed locally sourced low-e argon filled window joinery (U_g=1.58W/m^2K) proved to be sufficient for the local temperate climate in Wanganui.

The four bedroom house (253m^2) had a construction cost of 1,800 NZD/m^2, including water harvesting and solar hot water systems, which is within an average range for NZ. The house has been monitored since its first occupation, and shown very positive results for reduced heating and hot water energy consumption. Despite the eHaus prototype being unable to meet the PH standard, the average daily temperatures recorded in winter 2012 are generally four degrees higher than a reference typical 3-year old brick clad house, with considerable reduced daily temperature swings. Beside the MHRV, additional heating is provided by a pellet fire unit, which ran for only about 40 hours for the measured month.

3.2 New Zealand's first certified Passive House, Auckland 2012

Positive results for the eHaus prototype attracted potential stakeholders and led to the rapid development of NZ's first certified Passive House, completed in Auckland and certified in October 2012. The project polarized energies and resources of a team of academics, practitioners and industry partners, which already had been committed for a couple of years to promoting the PH standard in the country. The detached house of 249m^2 in floor area presents a mixed construction. The insitu reinforced concrete floor is poured over 100mm thick EPS polystyrene insulation, which is laid on top of a continuous layer of polythene [floor U-value=0.36 W/(m²K)]. The exterior 187mm thick timber-framed walls (on top of basement walls in concrete-filled EcoBlocks), with two layers of glass wool insulation, are lined internally with plasterboard over an airtight vapour check layer, and outside with cedar weatherboard cladding over an underlay [wall U-value=0.368 W/(m²K)]. The roof construction combines steel and timber framing, with the interior plasterboard ceiling fixed over an air-tight vapour check layer. The roofing material is corrugated metal laid on top of an underlay and 200mm of glass wool [roof U-value=0.233 W/(m²K)]. Double glazed low-e argon-filled (U_g=1.66 W/m²K) windows, with insulated profiles (U_f=0.95 W/m²K), were locally assembled using components imported from Germany. Overall this envelope ensures air-tightness (n50) of 0.44 h^-1. The German MHRV system is integrated by heating coils and a wood stove for additional space heating. Hot water is supplied by a German heat pump (COP=3.94), which is strapped to the structure for stability, to meet NZ seismic requirements. Electric energy is partially generated by a 3KW photovoltaic system onsite, introduced for demonstration purposes together with the rainwater harvesting, as this first PH was planned as a show-case, displaying up-to-date sustainable technologies.

The University of Auckland has recently started a two year monitoring campaign, utilising a Wireless Sensor Network suite, which represents a complete solution for remote monitoring. However, winter energy consumptions already confirm a reduction of up to 90% on heating bills. Overall the implementation of the first PH was particularly challenging because the design was defined before the certification goal, and, for size and features, it does not represent what might be called a 'typical' house for an average NZ family.

ZONES 1 AND 2			
Roof	R 2.9	U 0.34	U 0.2
Walls	R 1.9	U 0.53	U 0.25
Floor	R 1.3	U 0.77	U 0.77
Heated floors	R 1.9	U 0.53	Not Req
Windows	R 0.26	U 3.85	U 1.6
Skylights	R 0.26	U 3.85	U 1.2
ZONE 3			
Roof	R 3.3	U 0.29	U 0.14
Walls	R 2.0	U 0.50	U 0.16
Floor	R 1.3	U 0.77	U 0.2
Heated floors	R 1.9	U 0.53	Not Req
Windows	R 0.26	U 3.85	U 0.95
Skylights	R 0.31	U 3.85	U 0.80

Figure 1, Timber framed house insulation requirements of NZ Building Code compared to PH values
Figure 2, NZ's first PH in Auckland, certified in October 2012 (courtesy of Carters)

4. The new PH generation towards net zero energy

The 2011 NZ Energy Data File [MoED 2012] indicates that renewable energy made up 39% of the country's Total Primary Energy Supply, surpassing the precedent year's record. Furthermore, NZ has one of the best markets suited to wind and solar power systems, due to increasing electricity prices, geographic isolation and its climate. The emerging solar energy market is still undermined, but has potential: the (unfortunately) unstoppable urban sprawl combined with the high percentage of people commuting from the rural city fringes result in many single dwellings still 'off-grid' (with conveniently orientated pitched roofs), which could easily benefit from solar energy usage for space and hot water heating, also addressing the lack of traditional central heating systems.

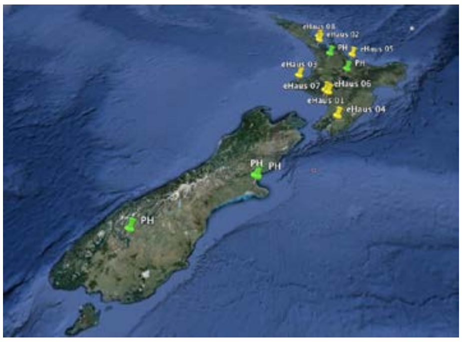
4.1 PH projects under construction: renewables and prefabrication

The goal of providing PH designs for mass and social housing has triggered a series of projects, each exploring new experimental solutions in terms of construction methods, materials and equipment. Currently there are at least ten PH projects in the pipeline, some already close to completion. Among the most relevant experiments are prefabricated solutions for the post-earthquake reconstruction of Christchurch (zone three) and the latest designs integrating renewables and other sustainable solutions, such as rainwater harvesting and grey-water recycling for flushing toilets and watering greenery.

At least seven new PHs situated in the North Island are either being constructed or at the design stage. Their construction cost (that includes windows imported from Germany) is typically around 2,200 NZD/m². For the most recent project local companies have supplied the window joinery, although they typically still import components from Germany for NZ assembly - as the national market is generally satisfied with non-thermally broken aluminum joinery with poor performing double glazing. Some of these houses are fitting solar PV grid tied systems (typically 4kW) that enable them achieving net zero energy over a 12 month period. This trend is encouraged by decreasing system costs, currently between 12,000 and 15,000 NZD. Already built PHs prove that extra costs compared to a standard Code compliant house stand in the range of 10%-15% per m^2, but increase in the South Island due to the harsher climate.

Table 1, eHaus Passive Houses completed or currently under construction in New Zealand

eHaus 01 [prototype]	Wanganui	2010	22.5 kWh/(m^2a)	
Haus 02 [first certified PH]	Auckland	2012	7 kWh/(m^2a)	3kW PV
eHaus 03	New Plymouth	April 2013	13 kWh/(m^2a)	
eHaus 04	Masterton	May 2013	12 kWh/(m^2a)	
eHaus 05	Tauranga	June 2013	12 kWh/(m^2a)	
eHaus 06 [net zero energy]	Wanganui	July 2013	9 kWh/(m^2a)	4kW PV
eHaus 07 [net zero energy]	Wanganui	Nov 2013	TBC	4kW PV
eHaus 08 [net zero energy]	Whangaparoa	Feb 2014	TBC	4kW PV



5. Discussion and conclusions

Low values for NZ residential energy use does not reflect efficiency but low levels of space heating – also suggesting a considerable percentage of total households in fuel poverty. For this reason, addressing low energy consumption through envelope super-insulation appears a very effective strategy. However, given the highly varied climate, establishing the correct climate data and then ensuring building designers understand the challenges of both under and overheating is essential.

Despite market constraints, the non-prescriptive nature of the PH standard allows adapting local construction methods and employing locally sourced material and components, except for highly performing window joinery and MHRV systems, whose additional costs cannot be offset by potential savings due to the traditional plant dismissal, as NZ houses generally do not have central heating and cooling systems. The barrier of lacking workers' skills still impacts on construction and time costs, but is slowly improving, with a number of local builders committed to this niche. Finally, the use of renewables to cover the low amount of energy required by PHs fits perfectly into the NZ scenario of urban sprawl (an issue that PH cannot address), and low population density with frequent off-grid buildings spread in the countryside, which make autonomous houses a necessity.

Recently built PHs prove to be economically viable in NZ, especially considering long term benefits due to energy and health costs' savings. Furthermore, at a national scale, the success of 'active' solutions, including renewables, could contribute to revitalize the green image of the country, committed to invest not only on clean energy but also on energy conservation strategies, starting with the building sector, one of its biggest energy sinks.

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