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Renewable Energy and Sustainable Buildings

Selected Papers from the World Renewable Energy Congress WREC 2018

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Chapter 55
Performance Gap and nZEB Compliance of Monitored Passivhaus in Northern Ireland, the Republic of Ireland and Italy

S. Colclough, V. Costanzo, K. Fabbri, S. Piraccini, P. Griffiths, and Neil J. Hewitt

55.1 Introduction

The legislative framework existing in the EU is driving the development of low-energy building standards including the recast Energy Performance of Buildings Directive (EPBD) [1]. Near Zero Energy Buildings (nZEB) are required for public buildings from the end of 2018 and for all buildings from 2020. The Passive House has been shown to potentially be a key enabler for the nZEB standard, and as such it offers potential, as it represents a well-proven methodology for compliance [2].

Analysis of case studies across a number of regions in the EU, where the deployment of the Passive House standard has successfully taken place, has demonstrated that considerable benefits are seen to have accrued [3]. These include the development of local markets, the creation of jobs and the consequential increase in innovation, enterprise, research and resources at a regional level. A key enabler for the adoption of the Passive House standard was the involvement of forward-thinking municipalities.

Given the adoption in 2016 of the Passive House standard in Dun Laoghaire-Rathdown County Council and the requirement to build ca 30,000 dwellings per annum to the nZEB standard in the Republic of Ireland, considerable potential exists for the architects, builders and equipment suppliers for the Passive House.

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This is particularly the case given that the nZEB standard has been demonstrated to be achievable via the passive house route at no extra cost compared to the current building regulations [4, 5].

This monitoring and analysis exercise has quantified and highlighted some advantages offered by the Passive House standard in achieving nZEB. The Passive House has been demonstrated as providing a superior indoor climate while consuming approximately a third of the energy required for heating compared with contemporaneous dwellings built complying with the prevailing minimum building regulations.

Further, at a societal level, the data already gathered has the potential to facilitate an evidence-based discussion on the future of the housing stock. In particular, this study has shown that the Passive House requires only 38% of the energy required by houses built to the current building regulations. Further, the potential with respect to fuel poverty is self-evident given that space heating costs for a 1000 ft^2 passive house can be approximately £200 per annum.

The implications of Brexit are yet to be fully understood within Northern Ireland and the UK [6]. One key aspect that needs to be considered is the possibility that the EU's Directive will not apply to the building stock in Northern Ireland. On the other hand, Italy will firmly be part of the EU in the years to come, and as highlighted by some authors, the techno-economic feasibility of nZEB can be achieved by energy-efficient solutions at both the building [7, 8] and urban scales [9].

This chapter examines if existing passive houses built in the island of Ireland and in Italy perform as expected in the operational phase and thus provide a "toolkit" for designers not only to achieve the nZEB energy requirements but also to achieve good Indoor Environmental Quality (IEQ) conditions in different climates. A special focus is given to bedroom conditions because the very strict requirements set by low-energy standards in terms of air infiltration and ventilation rates could be detrimental in terms of overheating and high CO_2 concentrations.

55.2 Methodology

55.2.1 Characteristics of the Monitored Houses

Ulster University has carried out monitoring of four passive houses in NI, hereafter called PH 1–4, and a number of passive houses in the Republic of Ireland, with PH 6 reported on in this chapter. An evidence-based analysis has been employed to quantify the performances of the houses, carried out for a 12-month period including both the summer (2016) and the winter (2016/17) seasons.

In order to appreciate climate-induced differences on the performances of a passive house, a house located in the Mediterranean climate of Cesena in Italy (PH 5) has been monitored as well for an entire year (from April 2016 to April 2017) (Table 55.1).

Table 55.1 Characteristics of monitored passive houses

House	Building type	Location	Size (m^2)
PH 1	2 storey, detached,	NI	158
PH 2	Bungalow, detached	NI	220
PH 3	Bungalow, detached	NI	145
PH 4	2 storey, detached	NI	247
PH 5	4 storey, detached	Italy	317
PH 6	Bungalow, detached	RoI	182

All these buildings have been designed using the Passive House Planning Package (PHPP) software to comply with the Passivhaus standard prescriptions [10], namely:

- Space heating demand lower than 15 kWh $m^{-2}y^{-1}$ or space heating load lower than 10 W/m^2
- Total primary energy needs, including space heating, domestic hot water production and electrical appliances, lower than 120 kWh $m^{-2}y^{-1}$
- Air infiltrations lower than 0.6 h^{-1} at 50 Pa pressure difference
- Mechanical Ventilation with Heat Recovery (MVHR) system with efficiency higher than 75%
- Opaque envelope components with U-values lower than 0.18 $Wm^{-2}K^{-1}$ and glazing components with U-values lower than 0.8 $Wm^{-2}K^{-1}$
- High-efficiency lighting and equipment

Over the 26-year period since the passive house standard was first espoused, many examples have been built throughout Europe and the world. After the implementation in the EU of the aforementioned EPBD Directive that prescribes the construction of nZEB from 2020, the opportunity afforded by utilising a well-established standard became apparent, and some authors started exploring its feasibility mainly by means of dynamic building performance simulations [11–13].

The Passive-On project [14] guidelines, as adopted by the Passivhaus Institut, introduced further prescriptions for houses located in warm climates:

- Energy demand for space heating/cooling lower than 15 kWh $m^{-2}y^{-1}$
- Air infiltration lower than 1 h^{-1} at 50 Pa pressure difference, if outdoor air temperature does not fall below 0 °C

Total primary energy needs should now account also for space cooling yet still have to remain below the 120 kWh $m^{-2}y^{-1}$ threshold. The indoor maximum temperature requirements remain unaltered (no more than 10% of the hours in a year with temperatures exceeding 25 °C in living areas).

Table 55.2 Characteristics of the monitoring instruments

Physical variable	Measurement range	Accuracy range
Indoor temperature	0–50 °C	±0.3 °C
Relative humidity	0–100%	±3%
CO_2 meter	0–5000 ppm	±50 ppm

55.2.2 Monitored Parameters

The Indoor Environmental Quality (IEQ) parameters monitored in all the houses are:

- Indoor temperature (°C)
- Relative humidity (%)
- CO_2 concentrations (PPM)

The metrics have been gathered at 5-min intervals, and then averaged over a 1-h time step. The relevant measurement and accuracy ranges for every instrument are summarised in Table 55.2. Threshold values have been set for each metric according to Passivhaus design requirements and national building regulations, and the percentage of time when these thresholds are exceeded is considered as well. The heating energy data has been gathered via real-time monitoring for the houses located in the island of Ireland, whereas these figures were not available for the case study in Italy at the time of writing this chapter.

55.3 Results and Discussion

55.3.1 Indoor Temperatures

Figures 55.1, 55.2 and 55.3 report on the proportion of time-specific temperature ranges that are experienced in the monitored bedrooms together with the relative average temperatures for the summer and winter, respectively. Consideration of the summer temperatures allows investigation into the extent of overheating, while consideration of the winter temperatures allows the "strength" of the good thermal performance of passive house to be examined.

Considering the summer temperatures, PH 1–4 (Northern Ireland) and PH 6 (Republic of Ireland) experience more moderate temperatures than those exhibited by PH 5 (Italy). However, it is evident that—as can be seen in PH 2—overheating can occur, albeit significantly below the PH threshold of 10% of occurrences of temperatures greater than 25 °C in the year.

As for the Italian case (PH 5), temperatures are within the range of 20–24 °C for almost 60% of time, with no occurrences of too cold temperatures (lower than 18 °C). On the other hand, temperatures higher than 25 °C are recorded for 19% of the time, thus exceeding the PH prescriptions about comfort conditions (even though this

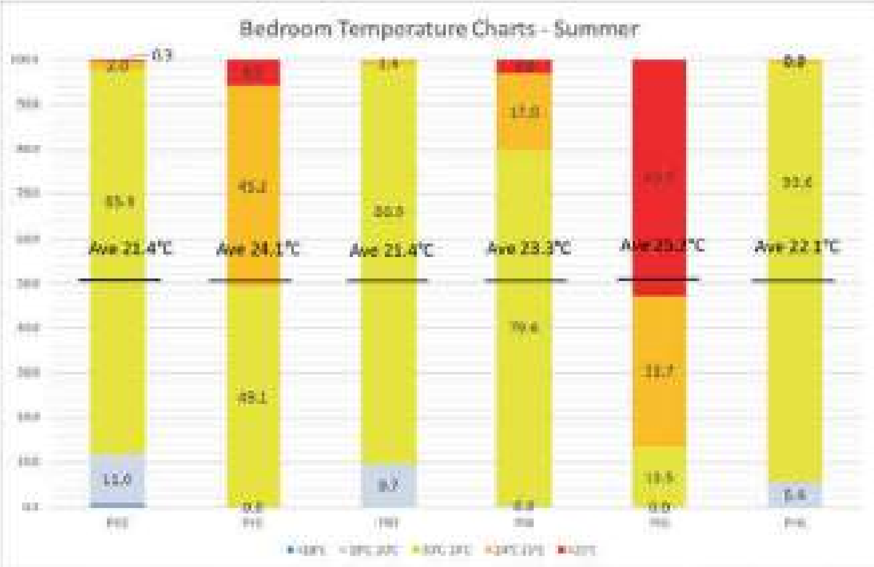

Fig. 55.1 Summer bedroom temperatures for PH 1–6

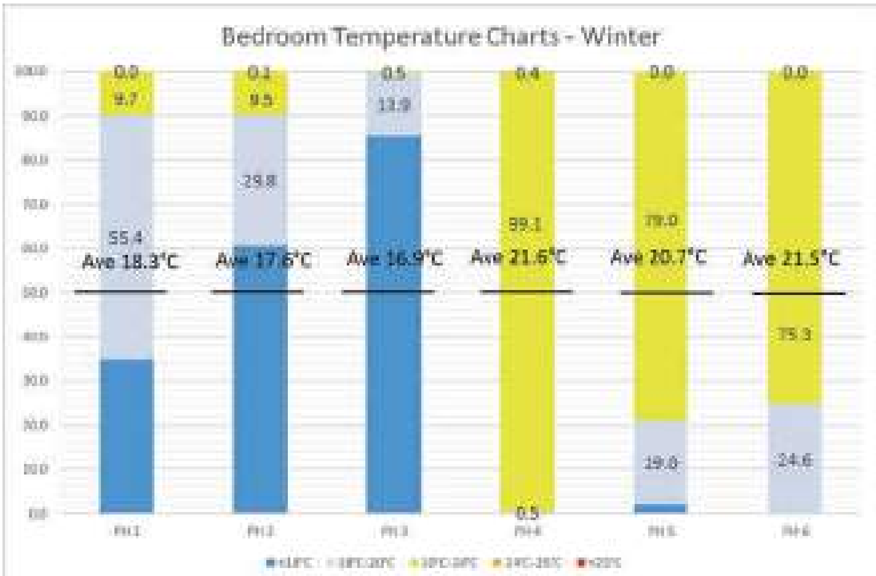

Fig. 55.2 Winter bedroom temperatures for PH 1–6

RH {%}	PH 1	PH 2	PH 3	PH 4	PH 5	PH 6
Average	54.1	48.6	54.1	53.0	47.84	57.0
Max	71.0	59.0	66.0	66.0	76.64	69.0
Min	38.0	36.0	40.0	40.0	19.78	46.0
30-60 {%}	76%	100%	88%	87%	80%	75%

Fig. 55.3 Annual, max, min and frequency of occurrence of between 30% and 60% for bedroom relative humidity

Table 55.3 Annual average values of the IEQ metrics

House	Indoor temperature (°C)	Relative humidity (%)	CO_2 concentrations (ppm)
PH 1	18.4	50.7	721.2
PH 2	17.6	48	596.8
PH 3	16.9	50.9	493.7
PH 4	21.6	48.2	946.9
PH 5	22.6	47.8	660.7

requirement strictly applies to living rooms only) and representing a potential overheating issue. The peak temperature recorded was of 27.8 °C.

Significant variations in temperature are also exhibited in the PH bedrooms during winter. The average temperatures range from 16.9 °C to 21.6 °C. It is noted that the warmest bedroom (PH 4) is located in Northern Ireland and that the bedroom located in Italy experiences a broader range of temperatures than PH 4.

55.3.2 *Relative Humidities*

While no specific requirements are put in place from the Passivhaus Institute about relative humidity ranges, it is well known that this physical quantity determines thermal comfort in conjunction with temperature. Considering the ASHRAE 55-2013 standard [15] as a reference, comfort conditions (i.e. relative humidity values within the boundaries of 30–60%) are experienced for at least 75% of the time in all the monitored passive houses (see Table 55.3).

Overall, it is found that relative humidity is not an issue for the passive houses under examination due to the MVHR system operation, ensuring a sufficient number of air changes per day.

55.3.3 *CO_2 Concentrations*

The indoor air quality (IAQ) in bedrooms is of particular interest when considering the overall indoor environment. This is because bedrooms are typically inhabited for an uninterrupted 7 or 8 hours per day during which time there is little adaptation

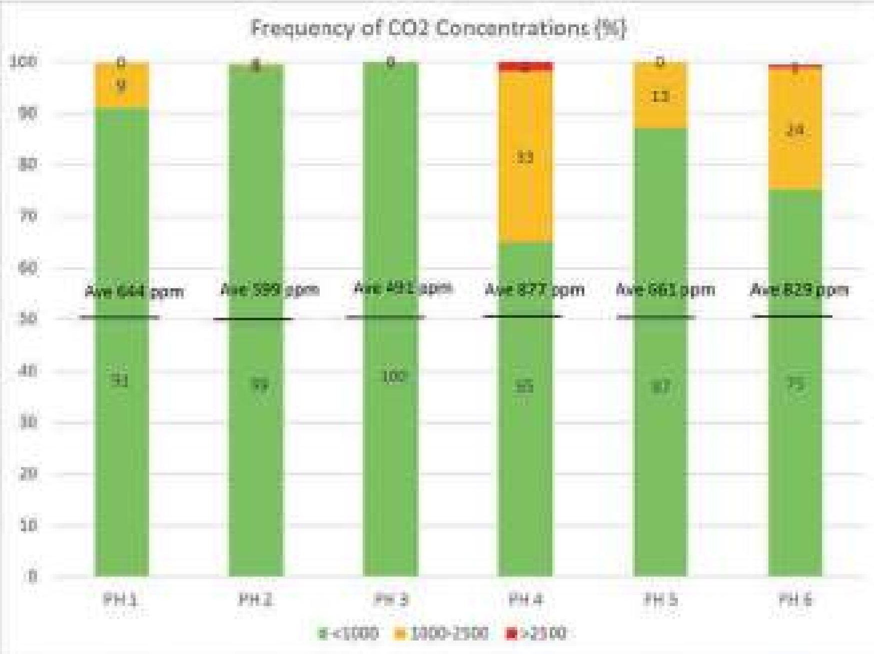

Fig. 55.4 Bedroom CO_2 concentrations for 12-month period

of the indoor environment (e.g. by opening windows or doors). Recent publications have highlighted the link between sleep quality and indoor air quality [16]. In addition, given the reduced air infiltration of nZEB dwellings, there is potentially less ventilation in the buildings of the future especially when compared with the building standards of the past.

The Passivhaus Institute does not specify acceptable levels of CO_2 concentrations. However, carbon dioxide concentrations are the subject of increasing focus, with acceptable levels recognised as typically below 1000 PPM, with levels over 2500 ppm considered as undesirable.

As can be seen from Fig. 55.4, the average carbon dioxide concentrations vary significantly, from the lowest in PH 2 (599 ppm) to the highest in PH 4 (877 ppm). Of particular note is the frequency of occurrence of relatively high carbon dioxide concentrations in PH 4 and PH 6. Given that the bedroom is occupied for only one-third of the 24-h period, the bedrooms clearly exhibit carbon dioxide concentrations in excess of 1000 PPM for the vast majority of the occupied period, with levels exceeding the undesirable 2500 PPM threshold in both PH 4 and PH 6.

Further investigation is needed to determine the root cause, as the Mechanical Ventilation with Heat Recovery systems should be calibrated to provide sufficient ventilation (as is clearly the case in the remaining monitored dwellings).

55.3.4 Energy Demand and nZEB Compliance

While there is uncertainty caused by Brexit, the nZEB standard has been proposed for Great Britain and NI as requiring primary energy for regulated loads of less than or equal to 43.6 kWh $m^{-2}y^{-1}$ (or 44 kWh $m^{-2}y^{-1}$ to the nearest integer). Of the four Northern Ireland passive houses monitored, Energy Performance Certificates (EPCs) are available for the three and indicate the "approximate Energy Use" primary energy unregulated loads as 40 kWh $m^{-2}y^{-1}$ (PH 2), 39 kWh $m^{-2}y^{-1}$ (PH 3) and 44 kWh $m^{-2}y^{-1}$ (PH 4). While further more detailed analysis will be required once the nZEB standard for the UK is finalised, based on the primary energy use metric, the three passive houses are seen to comply with nZEB requirements.

For the Republic of Ireland, there is an indicative regulated load primary energy consumption of below 45 kWh $m^{-2}y^{-1}$ for nZEB purposes (with the nZEB standard to be finalised in 2018). Monitoring of PH 6 has taken place over a 12-month period, and the total purchased electricity was recorded at 4063 kWh. When this is multiplied by the primary energy conversion factor of 2.08 (to give 9575 kWh primary energy demand), the specific primary energy demand is seen to be 52.6 kWh $m^{-2}y^{-1}$ (based on a floor area of 182 m^2). This is below the 61.61 kWh $m^{-2}y^{-1}$ predicted by the National Energy Rating software for regulated loads alone (which comprises heating, ventilation and fixed lighting). The overall consumed energy is approaching the requirements to comply with the forthcoming nZEB specifications with respect to regulated loads.

55.4 Conclusion

Monitoring campaigns carried out during a whole year period (2016/2017) in five passive houses located on the island of Ireland (temperate maritime climate) and one passive house located in Italy (Mediterranean climate) showed that, overall, they perform as per design and represent a viable manner in which to achieve the nZEB target. It has been demonstrated that three of the dwellings already comply with the nZEB primary energy consumption targets, despite not having been designed with the target in mind.

Some potential issues have been recorded in bedrooms, especially for the Italian case, where temperatures are higher than the 25 °C threshold for 19% of year (and 53% of the summer period), but also in the temperate maritime climate of Northern Ireland, where PH 2 recorded temperatures of greater than 25 °C for 6% of the time during the summer. In addition, the CO_2 concentrations can reach values as high as 2371 ppm, with PH 4 and PH 6 recording average CO_2 concentrations of greater than 800 ppm and exceeding 1000 ppm for 35% of the time and 25% of the time, respectively.

While the high summer temperatures in PH 2 are due to a lack of shading (deviating from the plan), the elevated carbon dioxide concentrations may be correlated with a higher than expected occupancy density or the operation of the MVHR system coupled with the intrinsic airtightness of the envelope prescribed by the Passivhaus standard. Future work should thus explore the use of different ventilation techniques, namely, natural and hybrid ventilation, for passive cooling and IEQ purposes.

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