PLEA 2017 EDINBURGH
Design to Thrive

The near Zero Energy Building standard and the Passivhaus standard – a case study

Shane Colclough[1#], Tomas O'Leary[2], Neil Hewitt[1], Philip Griffiths[1]

[1] Centre For Sustainable Technologies, Ulster University, Newtownabbey, Co Antrim, BT370QB, UK. [#] Correspondence email address - s.colclough@ulster.ac.uk
[2] MosArt, Wicklow County Campus, Clermont House, Rathnew, Co. Wicklow, A67 X566, Ireland.

Abstract: The EU has mandated that all buildings are built to the near Zero Energy Buildings (nZEB) standard from 2020. The Passivhaus standard has been in existence for over 25 years and potentially offers a tried and tested method of achieving nZEB.

This paper explores if there is a performance gap between the PH standard and the nZEB standard. Further, analysis is carried out based on monitoring results from a real building: a 103m^2 three bedroom dwelling located in Ireland. The comparison of the two standards is carried out with particular focus on the assumed and recorded indoor temperature assumptions and heating periods for both standards.

The analysis looks at the actual indoor climate experienced, based on the following recorded metrics which are being gathered at five-minute intervals:

a. occupancy profile
b. indoor air temperature
c. indoor relative humidity
d. indoor carbon dioxide concentrations
e. outdoor temperature
f. outdoor relative humidity
g. wind speed
h. barometric pressure
i. energy consumption

Based on the above metrics a discussion takes place on the energy and IEQ performance in the context of the performance mandated by the respective standards in the quest to deliver Passive and Low Energy Architecture.

Keywords: Passivhaus, nZEB, Monitoring, IAQ

Typical performance standards for NZEB for dwellings

	Low Energy[6] Dwelling with Solar Thermal DWH
Primary Energy (kWh/m^2yr)	45
CO_2 Emissions (Kg/m^2yr)	10
EPC	.302
CPC	.305

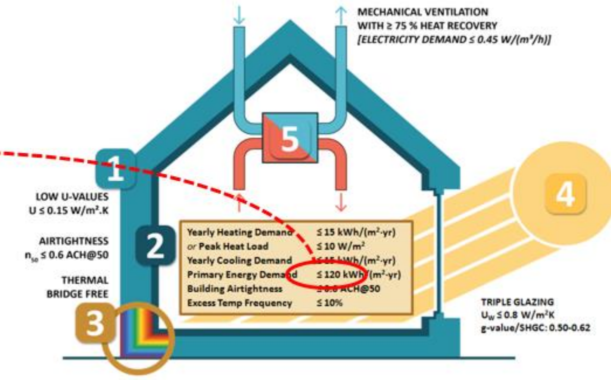

Figure 1. Comparison of nZEB and PHPP primary

Introduction

Given the planned 2020 implementation of the near Zero Energy Building (nZEB) standard in the Republic of Ireland, a comparison with the well-established Passive House (PH) standard is timely. While a number of publications have been written to investigate the potential for the Passive House standard in the Irish climate (e.g. Colclough, 2011; Clarke et al, 2012) and a number have considered net zero energy buildings, (Hernandez and Kenny, 2010, Goggins et al, 2016), none have compared the PH with the newly defined nZEB standard for the Republic of Ireland.

To comply with the Passive House standard, dwellings must consume less than 120 $kWh/m^2/a$ of primary energy, as determined by the Passive House planning package (PHPP). The nZEB standard in Ireland (to be finalised in 2019) requires that dwellings must consume less than 45 $kWh/m^2/a$ (anon, 2012), see figure 1. It therefore appears that the nZEB standard is more stringent than the Passive House standard. However, this is not a like-for-like comparison. This paper answers the question of whether a performance gap exists by comparing the derived figures for a case study of a building which has been built to the Passive House standard. In addition, initial monitoring results are presented to determine if the dwelling is complying with the assumptions inherent in the Passive House standard and Irish building regulations.

Comparison of standards

To compare both standards correctly consideration needs to be given to the basis of the comparison, in particular with respect to the energy consumption calculations. Recognising that the calculations will vary depending on the dwelling specifics, this case study examines a house which has been designed to comply with the Passive House standard, and has been constructed by building firm Bennetts in Enniscorthy, Co Wexford, Ireland.

The house is a certified Passive House of 103 m² and is occupied by one person. It utilises an integrated HRV system which addresses the space heating and domestic hot water requirements of the dwelling, with electricity as the fuel. In addition to heating the air via a heat pump, the unit also controls two 400W electric heating elements located in the sitting room and hall.

The DEAP (Dwelling Energy Assessment Procedure) is the software used to calculate the Building Energy Rating (BER) for dwellings in Ireland and ensure compliance with the nZEB standard. The DEAP calculations were carried out on the case study dwelling, and are presented in figure 2, in addition to the calculations carried out in the Passive House Planning Package (PHPP), the software used to ensure compliance with the Passive House standard. Two figures are presented for the PHPP - "Normal PHPP", and with the PHPP modified to perform calculations on the same basis as the DEAP software ("DEAP PHPP"). Details are provided in the next section on the calculation methodology.

As can be seen, the building is compliant with the nZEB performance standards as calculated by the DEAP software, with respect to primary energy consumption, carbon dioxide emissions, Energy Performance Coefficient (EPC) and Carbon Performance Coefficient (CPC) requirements and is therefore an nZEB standard compliant dwelling.

In addition, the PHPP calculations show that the dwelling is in compliance with the Passive House standard with respect to primary energy consumption, as it consumes 91 kWh/m^2/a, within the Passive House standard limit of 120 kWh/m^2/a.

The case study shows that the house designed to comply with the Passive House standard, meets the nZEB requirements. However, a clear discrepancy exists between the primary energy consumption and carbon dioxide emission figures using the two methodologies. In the analysis below a comparison is made based on the specifics of the dwelling under consideration. The analysis highlights the inherent differences in the two apparently similar primary energy consumption figures.

Table 1: Typical performance standards for NZEB for dwellings

	Low Energy[6] Dwelling with Solar Thermal DWH	DEAP	Normal PHPP	'DEAP' PHPP
Primary Energy (kWh/m^{2}yr)	45	24.37 ✓	91.1 ✗	31.2 ✓
CO_2 Emissions (Kg/m^{2}yr)	10	5.26 ✓	18.6 ✗	6.31 ✓
EPC	.302	0.159 ✓	N/R	N/R
CPC	.305	0.165 ✓	N/R	N/R

- **'DEAP' PHPP adjusted to omit plug loads, include PV production and reduce Primary Energy factor for electricity from 2.6 to 2.19**
- **Bennett Passive House Already NZEB**

Figure 2. Comparison of nZEB calculations using DEAP, PHPP and PHPP adjusted for DEAP requirements.

Comparison of PHPP and DEAP derived specific energy consumption

The Passive House standard calculates the primary energy required to meet all the energy needs of the dwelling (PHI, 2016) whereas the DEAP methodology bases its calculation on the building services energy load for space heating, water heating, fixed lighting and ventilation (Anon, 2012). Therefore electricity required for cooking, washing machines, clothes dryers, lighting, TV and entertainment equipment, Home Office equipment and all other plug loads are not considered. In addition, given the focus on reducing DHW and heating energy consumption in low energy dwellings to be implemented via the nZEB standard, and the significant growth in consumer electronics and electrical devices, while current building services loads in Ireland are estimated to be 50% (Anon 2015), the proportion of energy spent on building services is forecast to reduce further.

Both PHPP and the DEAP software use a primary energy conversion factor to convert the calculated energy consumed in the dwelling to the energy content of the fuel used to produce electricity in the generation stations. The PHPP calculation assumes a primary energy conversion factor of 2.6, whereas the DEAP software assumes 2.19.

When the services not included in the DEAP methodology are removed from the PHPP, and the primary enrgy conversion factor set to the DEAP version of 2.19, the PHPP primary energy demand reduces by almost 50% i.e. from 91 to 49 kWh/m^2/a and when the PV contribution is subtracted, this figure drops to 31.2 kWh/m^2/a.

Table 1 shows other differences in the DEAP and PHPP methodologies used. Of particular note is the floor area calculation. The PHPP works on the basis of the Treated Floor Area, TFA (PHI, 2014), which excludes areas included in the assumed DEAP calculation methodology such as the floor area associated with stairs, internal walls etc. The difference between the TFA and the DEAP floor area varies based on the geometry of the individual dwelling. In the case of the house under consideration the PHPP underestimates the house size by 10%, therefore over estimating the specific energy consumption.

	DEAP Model	**PHPP Model**
Basis for model	Benchmark house	Bespoke model for each design
Validation of performance	Unpublished	Scientifically validated
Floor area calculation	Gross	Net ("Treated Floor Area") (excludes internal walls and stairs)
Heating duration	8 hours per day	24 hours per day
Winter Interior Temperature	~ 18.5^{O}C Average based on typical Irish dwelling layouts for 8 hrs per day	20^{O}C throughout
Summer Interior Temperature	Overheating not predicted	25^{O}C Max for 10% of year
Radiant Temperature Asymmetry	Not considered	Avoided
Unintended air infiltration	< 7 m^3/m^2/hr @ 50Pa	< 0.6 ach^{-1} @ 50Pa
Ventilation rate	Not required	15m^3 fresh air per person per hour

Table 1. Basis of calculation methodologies for DEAP and PHPP.

If the average temperature is reduced from the PHPP normal temperature of 20°C to the DEAP equivalent temperature for the reference dwelling of 18.5°C, the PHPP figure drops to 24 kWh/m^2/a and when the floor area is adjusted to the DEAP assumed figure, the PHPP derived specific primary energy consumption figure drops to 19 kWh/m^2/a.

Therefore without taking into consideration that the heating period in a Passive House is 24 hour compared with the DEAP assumption of 8 hours per day, the PHPP adjusted consumption figure is 19 kWh/m^2/a where the DEAP software assumes 24.4 kWh/m^2/a.

Recorded Performance
The house has been monitored since August 2016.

Temperature and carbon dioxide
Figure 3 gives the temperature charts for the three month period October, November, December 2016 for the kitchen, living room and bedroom. In addition to providing an insight into the thermal comfort of the dwelling, the analysis allows a comparison of monitored internal temperatures, against those predicted by the Passive House Planning Package software and the DEAP software.

It is noted that the monitoring units deployed in the dwellings are commercially available units which are not of laboratory grade. While the units have been found to be calibrated correctly with respect to temperature, some units have been found to be outside the specified limits for relative humidity and carbon dioxide concentration. Thus, readings outside the threshold levels indicate that further investigation may be warranted.

Passive Houses are designed to have a uniform temperature of 20°C throughout. A temperature threshold has therefore been set at 20°C to aid analysis of the performance against the Passive House standard.

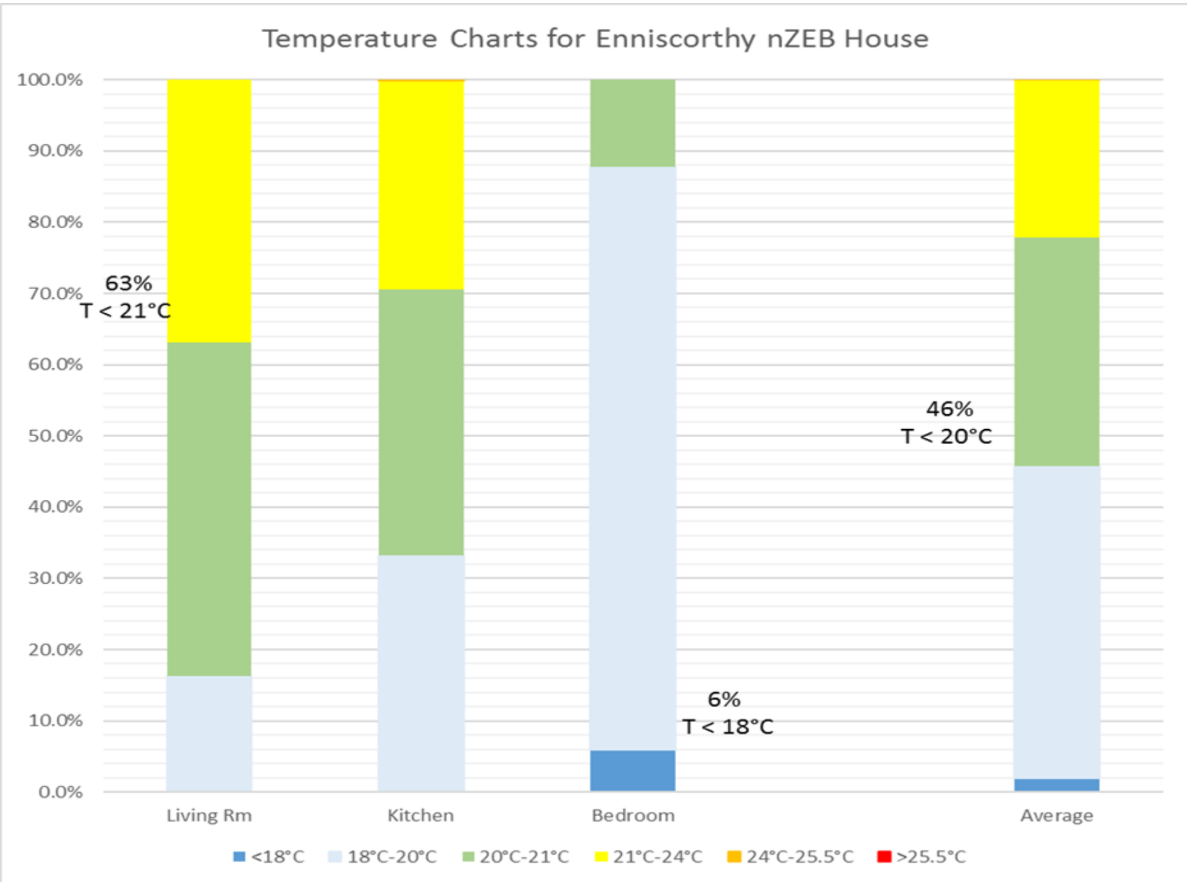

Figure 3. Temperature Chart for Enniscorthy nZEB House, October, November and December 2016.

The Republic of Ireland's Dwelling Energy Assessment Procedure (DEAP) assumes a two-hour heating period in the morning (7 AM to 9 PM), as well as six-hour heating period in the evening (5 PM to 11 PM), during which time the heating system is assumed to have a set temperature. The DEAP software assumes a set temperature of 21°C for the living room and 18°C for the "rest of dwelling" i.e. outside the living area. Thus 18°C and 21°C have been chosen as threshold temperatures in the temperature charts in Figure 3.

The temperature in the living room, kitchen and bedroom exceeds the Passive House set temperature of 20°C for 84%, 67% and 12.3% of the time respectively, leading to an overall figure of 54% of the time when the temperature is above the set temperature of 20°C. The relatively low temperatures in the bedroom are due to a personal preference by the occupant.

The temperature in the living room, kitchen and bedroom exceeds the building regulations set temperatures 37%, 100% and 94% of the time respectively. It is noted that further analysis could be carried out to determine the periods of time for which the temperatures exceed the set temperatures during the DEAP specified heating periods.

Figure 4 gives the carbon dioxide concentrations for the dwelling. Overall, the CO_2 concentrations are seen to be below 1000 ppm for 97% of the time, reflecting the relatively low occupancy profile.

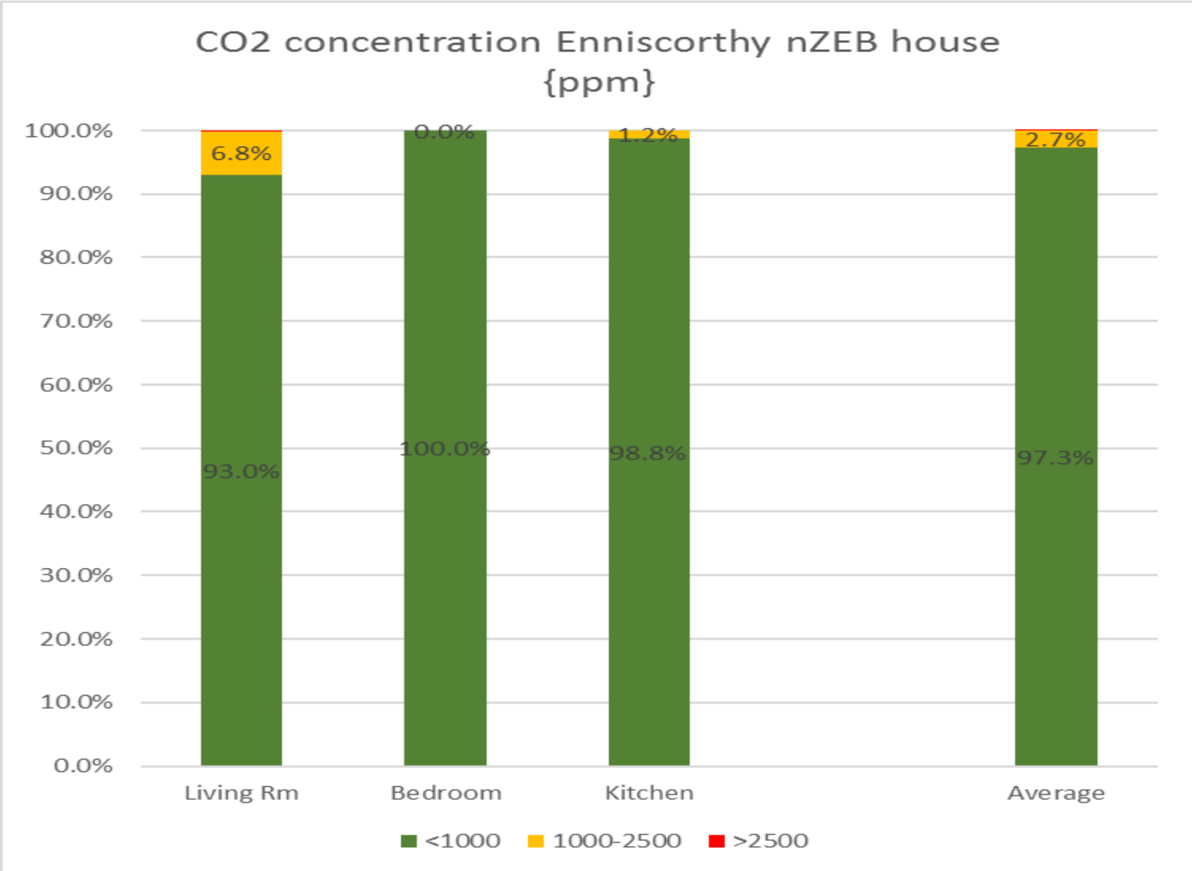

Figure 4. Carbon Dioxide Concentration Chart for Enniscorthy nZEB House.

Energy consumption

Figure 5 shows the heating and ventilation energy consumption of the dwelling for six months of September 2016 to March 2017 along with the overall energy consumption. The annual consumption is therefore not available, but will be reported on in a future publication.

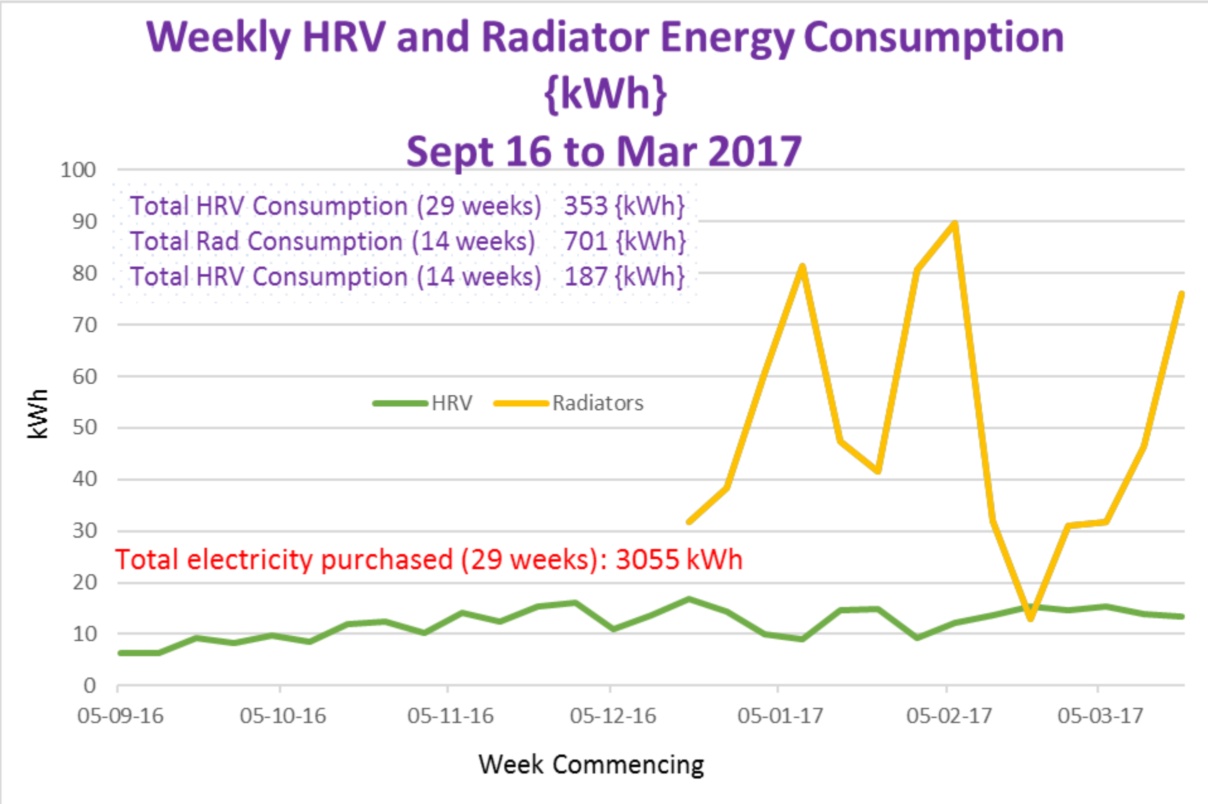

Figure 5. Energy Consumption for Enniscorthy nZEB House.

DHW and space heating energy consumption for the 14 week (w/c 19/12/2016) period was recorded at 888 kWh equivalent to 8.6kWh/m^2/a (based on 103 m²), or 9.5 kWh/m^2/a based on a treated floor area of 93 m². The Passive House standard requires less than 15 kWh/m^2/a for space heating alone, so even allowing for 6.6% lower than average heating degree days for the period, it appears that the certified Passive House is performing within expected parameters. The dwelling also appears to be performing within the DEAP maximum energy consumption of 45 kWh/m^2/a, as 888 kWh is equivalent to 18.9 kWh/m^2/a (based on 103 m² and a primary energy conversion factor of 2.19). It is noted that while this figure does not include lighting, it does include DHW, space heating and ventilation energy consumption, and covers the period which typically reflects the greatest heating demand.

Overall electricity energy purchase from the grid for the 29 week period is 353 kWh, equivalent to 65 kWh/m^2/a (based on 103 m²) of primary energy (at a conversion factor of 2.19).

Conclusion

This analysis has shown that a certified passive house designed using the Passive House Planning Package is compliant with the nZEB requirements. Using the DEAP building energy rating software, the dwelling is deemed to consume 24 kWh/m^2/a, significantly below the 45 kWh/m^2/a required for nZEB compliance.

The monitoring found that the house is performing within expected limits. The temperature in the living room, kitchen and bedroom exceeds the Passive House set temperature of 20°C for 84%, 67% and 12.3% of the time respectively, and exceeds the building regulations set temperatures 37%, 100% and 94% of the time respectively. The indoor air quality is also good with carbon dioxide concentrations in the living room, kitchen and bedroom staying below 1000 ppm for 93% 98% and 100% of the time respectively.

Overall DHW and space heating energy consumption for the 14 week period (w/c 19/12/2016) was recorded at 888 kWh, equivalent to 8.6kWh/m^2/a, of which 187 kWh was for operation of the heat recovery ventilation unit. Monitoring is continuing to determine the annual energy performance and IEQ of the dwelling.

References

ANON, 2015. *Energy Efficiency Trends and Policies in the Household and Tertiary Sectors.* EU Intelligent Energy Europe.

ANON, 2012. *Towards Nearly Zero Energy Buildings in Ireland, Planning for 2020 and Beyond* . Dublin: Department of Environment, Community and Local Government.

CLARKE, J., COLCLOUGH, S., GRIFFITHS, P. and MCLESKEY, J.T., 2014. A passive house with seasonal solar energy store: in situ data and numerical modelling. *International Journal of Ambient Energy,* (1), pp. 35-70.

COLCLOUGH, S.M., 2011. *Thermal energy storage applied to the Passivhaus standard in the Irish climate*, University of Ulster.

COLCLOUGH, S. and MCGRATH, T., 2015. Net energy analysis of a solar combi system with Seasonal Thermal Energy Store. *Applied Energy,* **147**, pp. 611-616.

GOGGINS, J., MORAN, P., ARMSTRONG, A. and HAJDUKIEWICZ, M., 2016. Lifecycle environmental and economic performance of nearly zero energy buildings (NZEB) in Ireland. *Energy and Buildings,* **116**, pp. 622-637.

HERNANDEZ, P. and KENNY, P., 2010. From net energy to zero energy buildings: Defining life cycle zero energy buildings (LC-ZEB). *Energy and Buildings,* **42**(6), pp. 815-821.

PHI, 2016-last update, Passive House Planning Package. Available: https://passipedia.org/planning/calculating_energy_efficiency/phpp_-_the_passive_house_planning_package.

PHI, 2014-last update, Energy balances. Available: https://passipedia.org/planning/calculating_energy_efficiency/energy_balances_-_background.

SEAI, 2012. *DEAP Manual, Version 3.2.1.*

Acknowledgements

The authors wish to acknowledge the support of the Interdisciplinary Centre for Storage, Transformation and Upgrading of Thermal Energy (i-STUTE) under EP/K011847/1 for this research.