Scottish Passive Houses as wind-energy buffers

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Introduction

Moving towards a zero-carbon energy system as quickly as possible, in order to avert dangerous climate change, requires electricity to be decarbonised while fossil fuel is simultaneously replaced with electricity for both heating and transport [Roberts 2017]. As fossil-fuelled electricity generation is replaced with less flexible, variable renewables, the ability to choose when to operate loads will become increasingly valuable.

Passive House standard buildings can be an important part of this transition; reducing energy demand will make supplying that demand with renewables easier. Furthermore, because Passive Houses lose heat very slowly, they could be heated intermittently, primarily when there is an over-supply of renewable energy. In this way they could act as a simple battery - absorbing excess renewable generation and storing it as heat in the building so that at times when there is insufficient generation the heating may be switched off without adversely affecting occupant comfort.

Scotland has an abundance of wind, and it is likely that in a future zero-carbon energy system the dominant energy source during the winter months will be wind power. This study examines strategies to shift heating loads to times of wind-energy abundance for a hypothetical residential Passive House in Oban, on the west coast of Scotland. Their efficacy in shifting heating demand to periods of wind-energy abundance is assessed along with the additional heat demand required for these strategies.

Method

A simple 100m^2 TFA Passive House building was first designed using PHPP to only just meet the Passive House heating demand target of 15 kWh/(m^{2}a), and then modelled in DesignBuilder, a dynamic simulation tool. The weather file for Oban was analysed and a heating schedule derived that aimed for a higher temperature outside peak demand hours (deemed to be 1500-2000) when the wind speed was above 4.4 m/s (henceforth referred to as ‘windy hours’). One third of total hours for the reference year in Oban have wind speeds above this value, and in Scotland wind power generates close to optimal output approximately 1/3 of the time [Symonds 2016]. Two different Passive House types were modelled; lightweight (timberframe) and heavyweight (dense blockwork inside the insulated envelope, dense concrete floors and partitions). A base-case scenario for both types was simulated in which the building was heated to a constant 20°C.

Heating demand, rather than delivered heating, was simulated. This demand could theoretically be met by either electric resistance heating or a heat pump.

Results and discussion

First the lightweight building was tested for the strategy described by [Höfer 2016], heating the building to 22°C during windy hours and otherwise to 19°C. In this strategy 97% of the heating demand occurred during windy hours (compared to 34% for the base-case scenario). There was a 7% increase in total heating demand compared to the base case because of substantial time spent above 20°C, hence a greater ΔT between internal and external temperatures. A similar study [Höfer 2016] used a thermally-massive building, but in this scenario the same temperature range worked well in a thermally-lightweight building.

This scenario may be problematic in terms of thermal comfort. Firstly because considerable time is spent below the standard Passive House comfort threshold of 20°C and secondly because even more time is spent substantially above it (up to 22°C). Whether occupants will find 19°C acceptable a few days after adapting to 22°C is not clear.

Because of these concerns three other scenarios were tested, all staying above the standard threshold of 20°C but with different maximum temperatures (Table 1).

Building type	Scenario	% of heating demand met during wind-abundance	Additional heat demand compared to base case
Lightweight	20-21°C	71%	6%
Lightweight	20-22°C	88%	13%
Lightweight	20-23°C	93%	20%

Table 1: A summary of scenarios tested on the lightweight building model. Raising the maximum temperature increases the percentage of heating demand met at times of wind-abundance but also increases the total heat demand.

The heavyweight building was tested to see how much it could improve the 20-21°C strategy. More of the heating demand was met during windy hours (79% compared to 71% for the lightweight building), but this came at an additional energy cost (10% extra on base case compared to 6% extra for the lightweight building). This is because the additional thermal mass keeps the building at a higher ΔT for longer than the lightweight building.

Conclusions

A narrow temperature range of 20-21°C is enough to produce a significant shift in heating demand to windy times for the scenarios studied. Wider ranges are more effective but increase total heat demand unless a lower base temperature is implemented. More research is needed to establish how occupants are likely to respond to these strategies.

Thermally massive construction increased the proportion of heating that could be shifted to windy times slightly but also increased total heating demand. This suggests that adopting thermally-massive construction in order to enhance the building's capacity to act as a thermal battery, in the absence of other reasons to build this way, would be inadvisable.

References

[Höfer 2016] Höfer, R and Bretzke, A.: Regenerative heat supply with storage from PH building in the Smart Grid. iPHA conference 2016, Vienna.

[Roberts 2017] Roberts, D.: *The key to tackling climate change: electrify everything.* Website: https://www.vox.com/2016/9/19/12938086/electrify-everything last accessed 4/12/2017.

[Symonds 2016] Symonds, A.: "Typically wind farms in Scotland operate at full max power about 30% of the time." Personal communication by e mail with wind-energy engineer, 22nd April 2016.

Summary

Using dynamic simulation, strategies to shift heating demand to periods of excess wind energy are investigated for a Passive House on the west coast of Scotland. Up to 97% of heating demand can be shifted to periods of over-supply of wind energy for a small increase in total heating demand.