Optimising Life Cycle Energy Performance of Housing

The value of occupancy control

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ABSTRACT: There is a trend towards reducing heating and cooling requirements of buildings by using high levels of insulation, minimizing thermal bridging, and ensuring excellent air tightness, together with the operation of efficient mechanical ventilation heat recovery (MVHR) systems. In temperate climates, this approach has already raised questions about potential risks of over-specifying some construction elements and installations. This study argues that in maritime climates, appropriate building design with occupant controlled natural ventilation could provide an optimum life cycle energy performance. A heating demand analysis of a sample case study house with MVHR and of the same case study with naturally ventilation is presented, testing different levels of insulation for each case. Embodied energy data of the additional envelope insulation and the MVHR system is added to the operational energy , and the options are compared from a life cycle perspective.
Keywords: low energy houses, occupancy control, life cycle analysis

INTRODUCTION

Building regulations around the world are changing to include more strict limitations of heat transfer through envelope. Voluntary standards such as the PassiveHaus [1] or Canadian Super-E [2] introduced a more radical approach defining strict limits for the heating demand, generally by using high levels of insulation, minimizing thermal bridging, and ensuring excellent air tightness to efficiently operate mechanical ventilation heat recovery (MVHR) systems. There is a large potential for the application of these techniques, not only in colder countries but also in maritime climates such as in Ireland [3]. However, we also need to consider that as we improve the energy performance of a building, generally we are using a large quantity of additional materials. Additional insulation and systems such as MVHR have all gone through energy-demanding manufacturing process before their installation in a building and this reduces the net energy savings achieved thorough its life cycle. At the same time, this type of low energy standards, which were initially developed for very cold climates suggesting a 24/7 MVHR system as best solution, might not be necessary in maritime climates, where the mild temperatures could allow the occupants to provide adequate natural ventilation through the year while maintaining adequate comfort levels.

This paper describes a life cycle energy analysis including dynamic energy performance simulation and embodied energy calculations for four options of houses. Two options are houses with MVHR, and two options of occupant controlled naturally ventilated house. Embodied energy for the different systems and construction elements will be added to the 'operational' energy use of each option.

CASE STUDY

The Irish climate could be classified as a mild climate, which under classifications such as the Köppen-Geiger system would correspond to a maritime temperate climate without a dry season and with reasonably warm climates [4]. Temperatures are mild, as shown in figure 1, rarely registering daily means below 5 degrees in winter or above 20 degrees in summer, and solar radiation levels, as shown are similar to those in Central and Northern Europe [5].

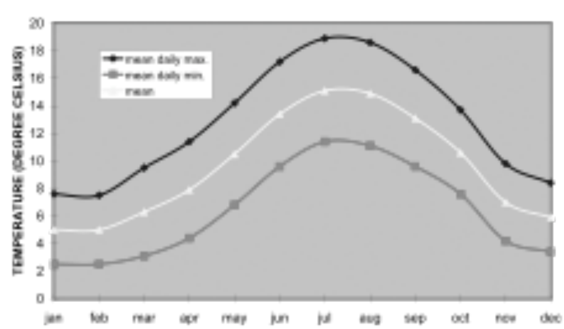

Figure 1: Monthly mean and extreme values [6]

The design analyzed is a semi-detached house, taken from a prototype developed as part of the 'Guidelines for the Design and Construction of Passive House Dwellings in Ireland' [7]. The prototype house considers the use of a MVHR system, which allows for enough fresh air to the house to achieve good air quality without the energy expense. The MVHR units defined for the calculations in this paper are 85% efficient and with a specific fan power of 0.8 W/(l/s). Figures 2 to 4 show plans of the proposed house with MVHR.

Figure 2: Prototype passive house ground floor plan. [7]

Figure 3: Prototype passive house first floor plan. [7]

Figure 4: Prototype passive house front elevation to the south. [7]

Naturally ventilated house To allow the most comprehensive comparison between design options, we will use the same building structure and layout as in the house with MVHR. In the naturally ventilated sample no MVHR is installed and instead we will allow for occupant control, which will result in some temperature differences between the different rooms, being the south oriented rooms (living space) generally at higher temperature than bedroom spaces. Without the mechanical ventilation in place the occupants will rely on their operation of window trickle vents and window openings to achieve sufficient indoor comfort and air quality. This would mean that the occupant is fully responsible of the air quality of the house and it should be ensured that an adequate degree of ventilation be provided. Providing sufficient ventilation is particularly important in building locations where invisible and imperceptible pollutants such as radon might be an issue. To simulate occupants behaviour, we define a background ventilation of 0.3 air changes per hour through the house (that could be provided by trickle vents), and an additional ventilation rate of 3.0 air changes per hour for 20 minutes during midday in all rooms, which could correspond to occupants fully opening windows.

Table 1 provides an overview of the main differences between these naturally ventilated options and the two options with MVHR. For this study, we assume that the building presents a high thermal mass, excellent air tightness, an attention to the detail avoiding practically all thermal bridging, and triple glazed windows with a whole window U value of 0.9 W/m^2K.

Table 1: Different options considered for the analysis

OPTION ID	Opaque Envelope Average U value	MVHR unit	Ventilation
MVHR	0.15 W/m2K	YES	0.5 ach whole house
MVHR Improved	0.10 W/m2K	YES	0.5 ach whole house
Naturally ventilated	0.15 W/m2K	NO	Occupant control, room dependant, intermittent.
Naturally ventilated Improved	0.10 W/m2K	NO	Occupant control, room dependant, intermittent.

CALCULATION METHODOLOGY

This study will compare the heating demand and differential embodied energy between the various building design options.

Heating Demand EnergyPlus [8] dynamic simulation tool was chosen for the analysis, as it allows for detailed heating and ventilation with sub-hourly analysis of a number of zones within the house, which is particularly useful for the naturally ventilated house. It also allows a detailed study of the performance of the house during the summer to prevent overheating.

For both the passive house and the naturally ventilated buildings, the following parameters, which relate to the internal gains and affect the heating demand, have been assumed.

- Occupancy number: 4 people
  Bedrooms: 11pm-08am
  Living Rooms: 08am–11pm

- Lighting average energy use during occupancy hours:
  Living room: 3 W/m2
  Bedroom: 1 W/m2

- Other equipment average energy use and gains during occupancy hours (including cooking)
  Living room: 5 W/m2 (concentrated at evening times)
  Bedroom: 2 W/m2 (concentrated at late night and early morning hours)

To calculate the heat demand, a set point of 21 ^{0}C is considered for the whole houses with MVHR. For the naturally ventilated houses, a set point of 21 ^{0}C on the living room and a set point of 18 ^{0}C on the rest of the rooms have been considered. This temperature is only maintained during occupancy hours in the naturally ventilated options. The results for the monthly heating demand of the four options are compared in Figure 5.

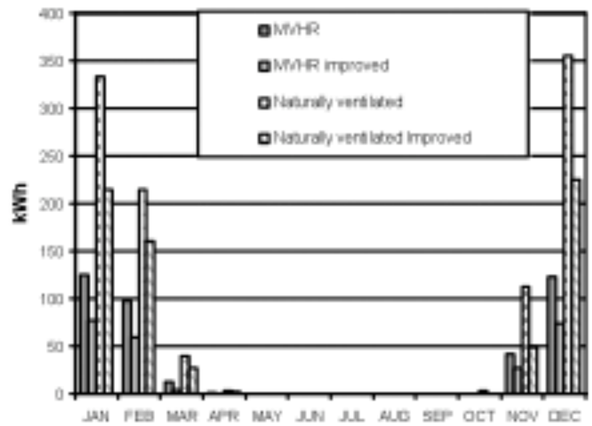

Figure 5: Monthly heating demand for the four different options

We can observe that the heating demand is minimal, and even for the worse case which is the naturally ventilated option with no additional insulation, achieving the desired conditions would only require a total of 1061 kWh for the full year.

Consideration of Embodied Energy (EE) To simplify the consideration of embodied energy, without the need of a full inventory of all building materials, we propose to use a differential comparison of the proposed building options. In this case, from the four options, two have additional insulation across the building envelope, and two have a MVHR installation, so those aspects will represent additional embodied energy. Only those elements are considered, for comparison purpose all other elements on the four building options that are equal (building structure, windows, internal partitions, etc) are neutralized. It has been assumed that the insulation upgrade used polystyrene, an energy intensive material, which is still widely used in Ireland. The upgrade of the insulation levels would represent around 150mm of additional insulation across the building envelope.

The consideration of EE of materials will be in all cases from "cradle to gate", which will consider all the energy (in primary form) used on from the extraction of raw materials, to manufacturing until the product leaves the factory gate. To calculate the differential EE of each of the options, information was sourced from the following references:

- The EE of building envelope upgrade materials from the Inventory of Carbon and Energy ICE v1.6a [9]. For polystyrene insulation, a value of 88 MJ/kg was used. The lifetime of the insulation was taken as 50 years, with no maintenance.

- Embodied energy of the MVHR and associated systems was roughly estimated by the authors based on simple inventory analysis of quantities of materials, approximate input-output analysis using economic data, and references to other HVAC systems from [10]. The total primary energy of the system was estimated to 12000 MJ, with a lifetime of 25 years, and the maintenance approximated to 10% of the EE (1200 MJ) over those years.

The total differential EE of the mentioned elements that differ between the different options was calculated and the values were annualized for a 50-year period, which is a value widely used in literature, as shown in a review of case studies by Sartori and Hestnes [11]. 50 years is a value that can be considered representative for the life of the materials of a building before undergoing major renovations. Table 2 shows the differential EE for each of the options, compared with the lower insulation option with no MVHR and Table 3 shows the annualized EE for the options, taking into account the service life and the maintenance, where applicable.

Table 2: Differential embodied energy from a BASE, in MJ

OPTION ID	OPAQUE ENVELOPE	MVHR unit
MVHR	No additional EE	MVHR EE= 9000MJ
MVHR Improved	Average 150mm additional polystyrene EE = 66,000 MJ	MVHR EE= 9000MJ
Naturally ventilated	No additional EE	No additional EE
Naturally ventilated improved	Average 150mm additional polystyrene EE = 66,000 MJ 0.10 W/m^2K	No additional EE

Table 3: Annualized differential embodied energy from a BASE , in kWh/year

OPTION ID	OPAQUE ENVELOPE	MVHR unit
MVHR	No additional EE	147 kWh/year
MVHR Improved	366 kWh/year	147 kWh/year
Naturally ventilated	No additional EE	No additional EE
Naturally ventilated Improved	366 kWh/year	No additional EE

RESULTS

Life Cycle Energy Use Figure 6 shows results adding the annualized differential embodied energy and the MVHR electricity use to the annual heating demand for each of the options. The heating demand and the MVHR electricity are multiplied by the Irish national primary conversion factor of 2.7 to show in the primary energy graphic. The heating is assumed to be supplied directly by electric resistance heaters. This approach is taken to simplify the comparison between the different options.

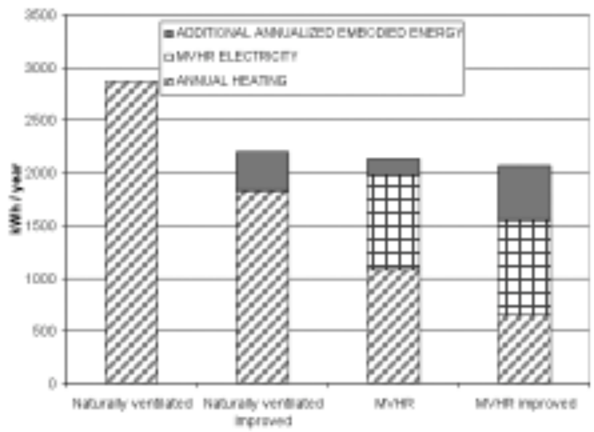

Fig 6: Annual primary energy use for heating, MVHR electricity, and annualized EE, in kWh.

On a first observation, we can note that on the MVHR option, the electricity use together with the annualized embodied energy of the MVHR amount to nearly 1,000 kWh of primary energy. For the MVHR improved option, which has some additional insulation, the reduction on heating is practically equivalent to the additional embodied energy of the insulation, so this option would not be ideal as other options such as renewable energies would give us a higher net energy return. On the contrary we can note that the application of additional insulation to the proposed design works for the naturally ventilated option, where the savings are far greater than the added embodied energy

With this simple analysis we could state that the two more attractive options for this study from a life-cycle energy perspective are the MVHR (without improved insulation), and the naturally ventilated house with improved insulation. Both options would have (considering heating with electricity) very similar annual primary energy use, including annualized embodied energy.

If instead of multiplying the heating use by the factor of 2.7 for using electricity we would use a fuel with a primary energy conversion factor closer to 1, naturally ventilated options would be in a favourable position. An interesting perspective can be added by comparing those two options in terms of comfort, potential for further energy savings, and analyzing subjective user parameters and preferences.

Comfort conditions In the calculations presented, which have shown similar life cycle energy use, the house with MVHR would have an evenly distributed temperature through the whole house during all times of the year. For the naturally ventilated house, we will have slightly colder bedroom area (18 ^{0}C) in the winter, and for the summer, although the house has been designed with large opening areas and has been provided with a shading structure, we would still need to put special care on managing the windows to prevent overheating. With this in mind the preference of one house or another might come to a personal preference for the user. Some occupants might prefer the absolute controlled environment provided by the MVHR, where others would prefer to be able to allow more or less ventilation in separate rooms, at different times of the day and influenced by seasonal or daily weather changes and they would probably have an inclination towards the naturally ventilated house.

Potential Energy Savings The 'naturally ventilated improved' option accounted for direct heating by electric resistances to bring the house to the desirable comfortable conditions. However the calculation was also performed without using any heating systems, which is called a 'free running mode', and the conclusion was that conditions would not be extremely uncomfortable. Figure 7 shows the temperatures on the living room during a typical winter week (20-26th January), for the main living area of the building in free-running mode, and we can observe that there is a very limited number of hours when the temperature drops below 18 ^{0}C. The advantage of the naturally ventilated option is that it would support the possibility of a house without any additional heating in this climate. Perhaps additional clothing or blankets could be considered for the very few days that we would be away from the optimum comfort conditions.

The advantages and potential additional savings in the MVHR option, for a building as efficient as the proposed, is not as high. Most of the primary energy use would come from the electricity use of fans, and the option of stopping the ventilation system could not be appropriate, as without the heat recovery the temperatures would drop a little bit further than in the example of the improved naturally ventilated option. At the same time the occupants might not be used to providing adequate ventilation when the MVHR is not working, so IAQ could be compromised. Therefore, further potential energy saving from the original design are not as likely in MVHR option as in the naturally ventilated option.

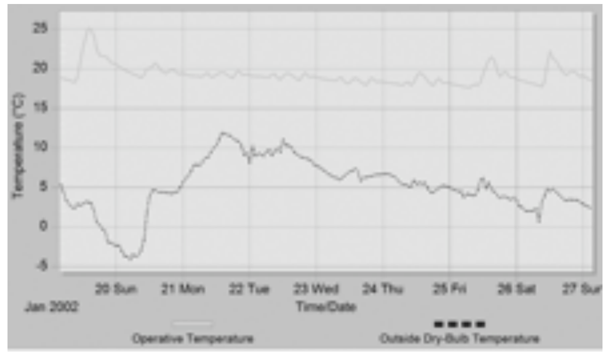

Fig 7: Outside and living room temperatures on a typical winter week, for the 'free running' natural ventilation improved option.

Final Conclusion The evaluation of the suitability of MVHR in maritime climates such as UK and Ireland is complex. In buildings with optimized design as is presented here, the advantage of the MVHR is lower than in more common designs. In this proposed prototype design, most of the ventilation losses are offset by the solar gains, so not as much savings are achieved by the MVHR. Considering the electricity use and the embodied energy of the MVHR, for an optimised design the MVHR option becomes comparable to a naturally ventilated house with further insulated building envelope.

Using MVHR has advantages for users that desire no interaction with the house and a homogeneous and constant temperature. Naturally ventilated houses would suit those that are prepared to experiment with slight changes in temperatures between rooms and are willing to actively control the ventilation and indoor air quality of their homes. In this case, some further energy savings are possible as there is a potential for having naturally ventilated houses without any heating system without compromising too much comfort.

It should be also noted that the commissioning and on-site quality control for these type of naturally ventilated houses should be even more strict as than for houses with MVHR, as details not properly addressed (thermal bridging, air leakages) could mean that comfort would be further compromised and perhaps additional heating would be used. In case of appropriate design and quality control the option of occupant controlled naturally ventilated houses could compete or be preferable to houses with MVHR, depending on the attitude of the users.

The option of energy efficient, naturally ventilated houses could be particularly useful for social housing in maritime climates, as would guarantee a minimum degree of comfort even if the small required heating supply is not provided by the occupants to reduce costs.

For houses with MVHR systems, if the systems are stopped to reduce electricity costs, it could lead to potential problems of IAQ and reduced comfort.

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