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LIFE CYCLE ENERGY PERFORMANCE: EXPLORING THE LIMITS OF PASSIVE “LOW ENERGY” BUILDINGS

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Summary

There is an increasing trend in reducing energy demand of buildings by improving building envelope thermal characteristics. Proven construction examples as used with the German PassivHaus standard achieve substantial reductions on the heating demand compared to mainstream construction, generally by using high levels of insulation together with ensuring excellent air tightness and minimizing of thermal bridges. However, the limits to which levels of insulation in a building can be increased and still represent overall life cycle energy savings are not clear. Particularly for temperate climates, adopting very-high insulation standards can lead to a danger of over specifying construction elements: once we reach certain levels of insulation, any extra material used can have larger energy costs or “embodied energy” than the energy it saves in the life cycle of the building. This paper presents the heating energy use of sample houses in the Irish maritime climate, and analyses the life cycle energy use including the embodied energy of the materials used. A 50-year perspective is presented, and conclusions about the limits to which the heating energy consumption can be lowered by “passive” means on a particular climate are drawn. This paper demonstrates the life-cycle benefits of optimizing the building design ensuring a correct orientation and sizing of the openings, but respecting certain limits when using energy intensive insulation materials.

1. Introduction

Reducing heating energy demand in buildings by means of insulation is recognized as one of the most cost-effective methods for saving energy and reducing CO₂ emissions (COMMISSION OF THE EUROPEAN COMMUNITIES 2006). Building regulations around the world are changing to include more strict limitations of heat transfer on construction elements. Voluntary standards such as the PassiveHaus (Passive House Institute) introduced a more radical approach defining strict limits for the heating demand (15kWh/m² per year), which are normally achieved by ensuring high levels of insulation, together with ensuring excellent air tightness and minimizing of thermal bridges. The potential savings of the application of these type of standards are very high, not only in colder countries but also in maritime climates such as in Ireland (Kondratenko, Brophy et al. 2006). However, as the building envelope performance improves, a higher amount of materials are generally needed, and some of the most commonly used materials like polystyrene have gone through a very energy intensive manufacturing process before they are installed in a buildings, which reduces the net energy savings achieved thorough its life cycle.

Some voluntary assessment methods such as LEED (US Green Building Council) or BREEAM (Building Research Establishment) do account for embodied energy issues, together with a wide range of other environmental impact issues. More detailed LCA tools as SIMAPRO (PRé Consultants) or ATHENA (ATHENA Institute) also offer the possibility of analyzing in detail a wide range of environmental aspects of materials including embodied energy. This paper focuses on a simplified assessment of heating energy demand including embodied energy of materials. While this is not as exhaustive an analysis as the above mentioned environmental assessment methodologies and LCA tools, the authors believe it provides a useful insight when applied with official calculation tools as part of building regulations or national rating systems. In this paper, the methodology is used to explore how far can the energy demand in a building be decreased by “passive” means, including the increase on the levels of insulation, to a level which is no longer a benefit from a life-cycle energy performance perspective, because the additional energy savings of any further improvements are counteracted by the embodied energy of the materials used.

2. Case Study

This case study analyzes the heating demand of a sample house in Ireland. 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 (Peel, Finlayson et al. 2007). Figure 1 shows the annual solar radiation in Europe, where we can observe that levels in Ireland would have similar levels to those in Central and Northern Europe. This fact together with the mild temperatures means that in Ireland it should be possible to reduce the heating demand by passive strategies, and also might indicate that certain design strategies could be more useful than the mere increase of building envelope insulation levels.

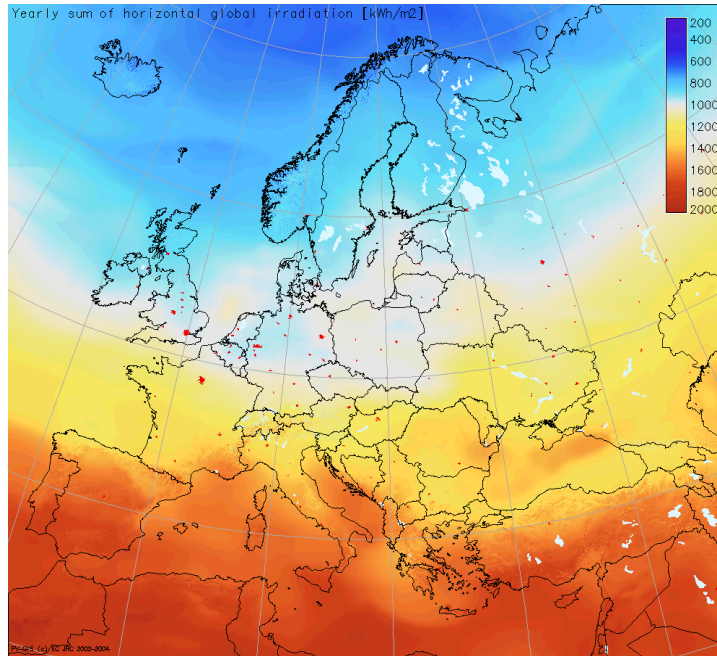


Figure 1. Yearly global irradiation on horizontal surface [$\text{kWh}\cdot\text{m}^{-2}$] (Suri, Huld et al. 2007)

For this study the house size and type was selected from examples in the Irish Building Regulations Technical Guidance Document L (Minister for the Environment Heritage and Local Government 2006; Minister for the Environment Heritage and Local Government 2007).

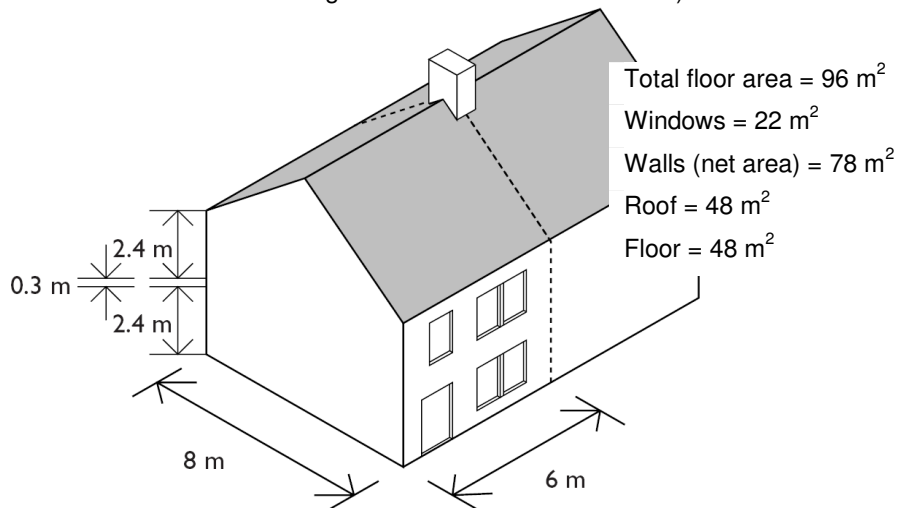


Figure 2. Case study semi-detached dwelling characteristics

These details of the house correspond to a semi semi-detached two storey house, which is the most common type in Ireland. Total area of the windows is set to 22 m² with an east-west orientation, which could also represent a typical situation

Our BASE CASE scenario for the case study corresponds to a house complying with the insulation levels from the 2006 Building Regulations, but including some additional energy efficient features such as the reduction of thermal bridging to a value of 87 W/K for the whole house, the limitation of infiltration and ventilation heat losses by air tightening the house (up to 0.60 ach at 50 Pa) and including mechanical heat recovery ventilation with an efficiency of 85% and an specific fan power of 1.0 W/l *s.

A range of improved U values from the BASE CASE have been considered, the maximum upgrade achieving levels of 0.1 W/m² K, which is a value already reached in some Irish Passive House constructions. Table 1 shows the different upgrades and U values considered:

Table 1. U values of construction elements for the five building envelope insulation options studied [W/m² K]

	BASE CASE	UPGRADE 1	UPGRADE 2	UPGRADE 3	UPGRADE 4
Walls	0.27	0.21	0.15	0.12	0.1
Floor	0.25	0.2	0.15	0.12	0.1
Roof	0.16	0.14	0.12	0.11	0.1

Table 2 shows the thickness of the insulation layer needed to achieve the U values for each construction element. Calculations were carried according to the EN ISO 6946 (CEN 1997). The additional insulation material selected to lower U values was polystyrene, which is still one of the most widely used insulation materials in Irish construction. Physical properties of the polystyrene used in this case study are 20 kg/m³ density and 0.034 W/mK thermal conductivity.

Table 2. Thickness of insulation layer [mm]

	BASE CASE	UPGRADE 1	UPGRADE 2	UPGRADE 3	UPGRADE 4
Walls	115	150	210	265	315
Floor	85	120	170	215	270
Roof	255	285	325	365	425

Two options for windows are also considered, a first option is a double glazing unit with an U value of 2.2 W/m² K, which would correspond to a typical window installed to comply with building regulations, and a second option of a triple glazed argon filled window with a U value of 1.0 W/m² K, which corresponds to current practice of Passive House designs in Ireland.

To account for the differences between typical and passive solar design strategies, different window sizes and orientation are also considered. The original option of 22 square meters of East / West oriented windows is compared with North/South orientations, and with an increase in windows areas on the south façade. This approach will serve to check benefits of window sizing and orientation on reduction of heating demand, while ruling out daylight issues, although it is understood that the use of daylight will improve with increasing window sizes. The following three additional sets of options are considered:

- A first set considers a change just on the orientation of the windows, maintaining the same house design and window area, but with an equal distribution of windows between south and north, instead of an East/West orientation.
- A second set of options considers an increase of 25% on the total window area, placing the additional area on the south façade.
- A third set of options considers an increase of 50% on the total window area, placing the additional area on the south façade.

As a result of the explained variations of building envelope, window type, and windows size and orientation, a total of 40 possible combinations of options are studied. Each option has been assigned an ID, with the following codes:

- Envelope insulation levels: BASE, UP1, UP2, UP3, UP4 for the 5 envelope insulation options.
- Glazing type : 2G for Double glazing, 3G for Triple glazing
- Glazing orientation: OR represents a North/South orientation
- Glazing area: +25%, +50% represents an increase to the total window area, added to the south façade

As an example, the option UP2_3G_OR_25% would correspond to the case study with the envelope UPGRADE 2, triple glazing, a north south orientation and with an additional 25% glazing area on the south façade.

3. Calculation Methodology for Heating Demand and Embodied Energy

3.1 Heating Demand

The heating demand for the different options was calculated with the DEAP Irish calculation methodology (Sustainable Energy Ireland 2007). Space heating demand in DEAP is calculated for an 8-hour daily heating schedule, between 7-9am and 5-11pm, which is considered a typical schedule. The setpoint temperature is considered 20 degrees Celsius for the living room area (which represents 30% of the total space) and 18 degrees for the rest of the occupied space. DEAP calculation of the heating demand is based on the European standard EN ISO 13790 (CEN 2004), and considering, on a monthly basis, only sensible heat and the following components of the energy balance:

- Transmission losses between heated space and external environment (including thermal bridging).
- Infiltration and Ventilation losses (accounting for air tightness of the house and the effect of heat recovery mechanical ventilation.)
- Internal heat gains
- Solar gains

The results for the monthly heating demand of three of the options, and of annual heating demand of the 40 options considered are displayed on Figures 3 and 4:

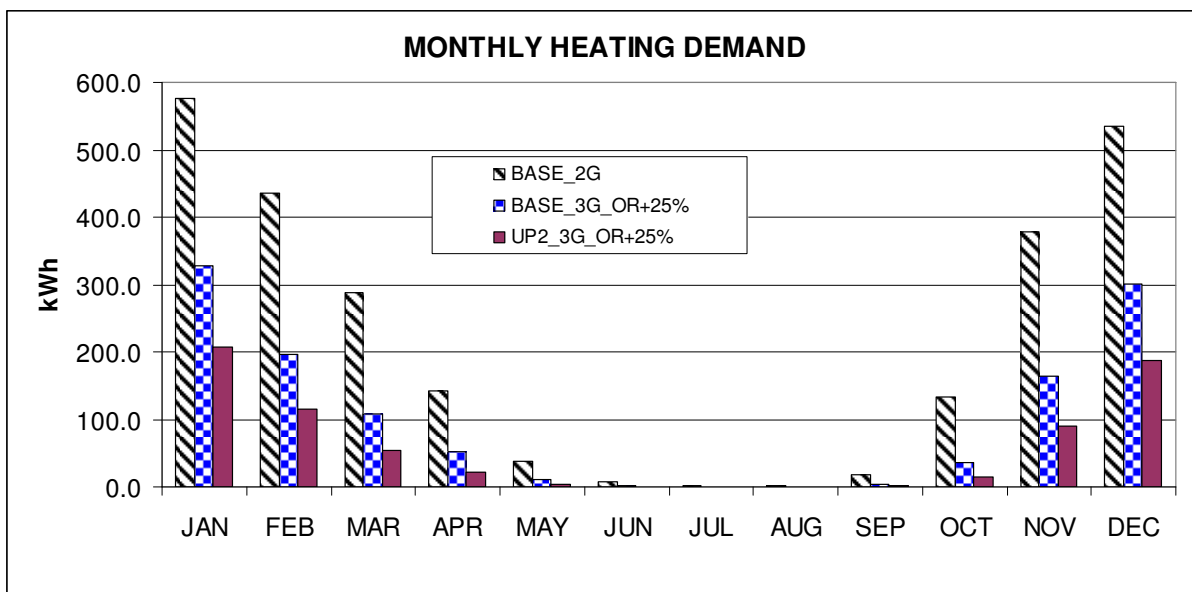


Figure 3. Comparison of monthly heating demand for three of the options

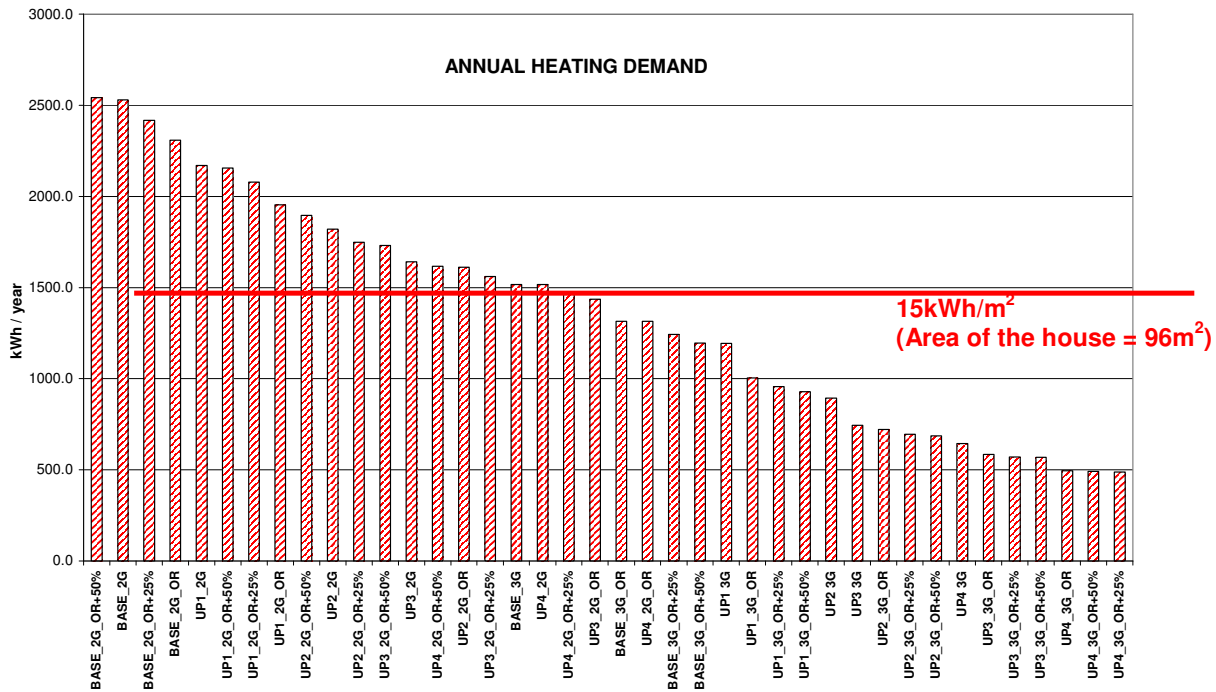


Figure 4. Comparison of heating demand for the 40 different options

From these figures we can observe that the upgrade of insulation levels from the base case to UP1, UP2, UP3, UP4 has a progressive impact on the reduction of heating demand. It is also very noticeable the impact of the change in the glazing type, where the inclusion of the triple glazing windows has, in most cases, as much impact in terms of heating demand as it has the maximum upgrade of insulation levels. The options with a south/north orientation have a consistently lower heating demand as expected due to the higher solar gains. The increase in the areas of glazing on the south façade, when using the double glazing windows, in most cases increases the heating demand. For triple glazed windows, the annual heating demand slightly decreases when increasing window areas on the south facades, in all cases except for the most insulated option (UP4) where due to the super-insulation solar gains usage would not be enough to offset heat losses through the window.

These first results are what we would expect from an annual heating demand analysis. We can observe that more than half of the options considered will be for example below the threshold of 15 kWh/m² per annum which is one of the pre-requisites for PassivHaus standard, the progressive energy savings as we increase the insulation levels.

3.2 Consideration of embodied energy

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 from the initial base case (BASE_2G). The differential embodied energy referred to the BASE_2G is considered only for the construction elements most directly related to the energy performance, which for this study on heating demand will be the insulation of the building envelope and the windows. All other elements that are not directly related to the energy performance in use of the building or that can be considered the same as the reference base case are then neutralized.

The consideration of embodied energy of materials will be in all cases from “cradle to site”, which will consider all the energy used on from the extraction of raw materials, to manufacturing and transport to the building site.

To calculate the differential embodied energy of each of the options, information was sourced from the following references:

- The embodied energy of building envelope upgrade materials from the Inventory of Carbon and Energy ICE v1.5 (Geoff Hammond and Craig Jones 2006). For polystyrene insulation, a value of 88 MJ/kg was used.
- Embodied energy of upgrading windows was approximated from Weir and Muneer (1998) and Asif, Davidson et al. (2001). The upgrade of windows from double glazing with U value of 2.2 W/m² K to triple glazed windows with a U value of 1.0 W/m² K was considered as 500 MJ per m².

The total differential embodied energy for each of the options, with relation to the basic case, was calculated. 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 (2007), and representative for the life of the materials of a building before undergoing major renovations.

Figure 5 shows the comparison of energy options in the same way as Figure 4, but adding the annualized embodied energy for each of the options as calculated for the upgrade of insulation levels or of the windows as a differential from the option BASE_2G. This analysis will give an additional life-cycle perspective of the total energy use and another view on the limits of reduction of energy use by improving building envelope characteristics.

As a first observation, we can note that the differences in the overall energy use (space heating plus annualized embodied energy) between the options with the lower space heating demand is very small. The best option from this life cycle perspective would be the UP3_3G_OR, which is the second best insulation upgrade. That means that upgrading the insulation beyond the limits set on UP3 using polystyrene as the insulation material, would have a negative effect from a life cycle perspective for this case study dwelling in a temperate climate.

The high relative importance of orientation is also clear to observe, as insulating options UP4 with an East/West orientation will have a higher overall energy use (including embodied) than options with insulation two levels below (UP2) and a North/South orientation.

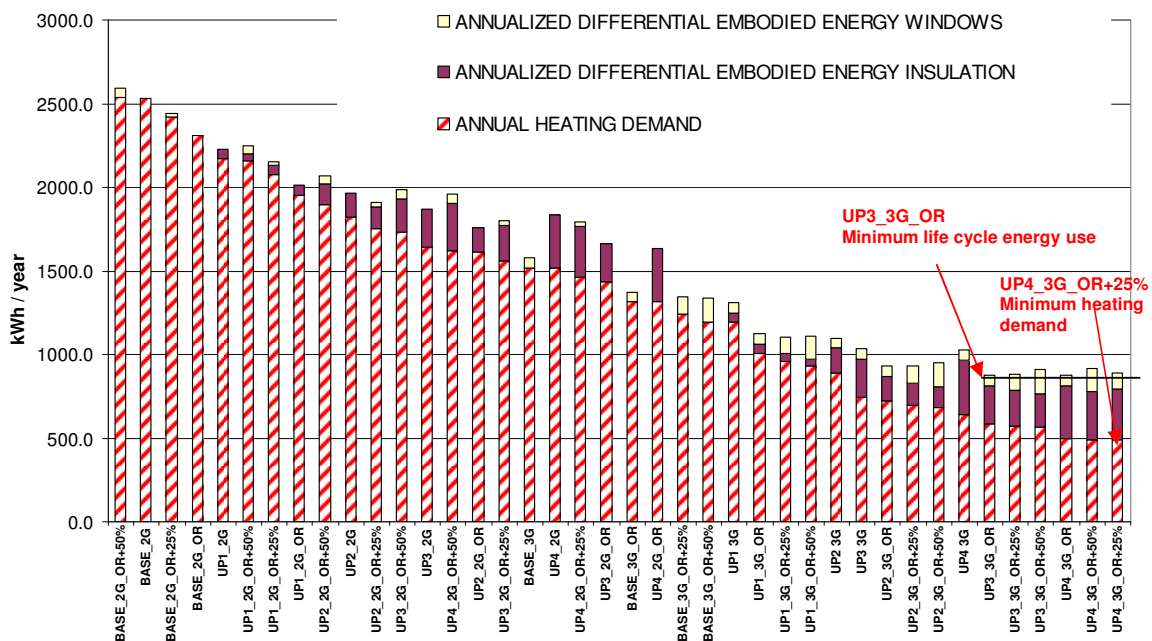


Figure 5. Comparison of heating demand and annualized differential embodied energy (related to the BASE_2G option) for the 40 different options

4. Conclusions

This paper has presented a very simplified approach to study the limits of reduction of heating demand from a life cycle perspective. The analysis added an annualized differential embodied energy factor to the space heating demand of different building design options. The heating demand was calculated according to the current official Irish calculation methodology for energy assessment of dwellings, while the embodied energy of materials was sourced from various references, annualized to a lifetime of 50 year and presented as a differential value related to the option BASE_2G.

The results show how high insulation levels using energy intensive materials such as polystyrene could lead to a higher overall life cycle energy use (over 50 years) than less insulating options. This aspect highlights the importance of choosing low energy intensive materials when pursuing extremely low energy demands, and also the need to carefully study the design alternatives for very low energy buildings, as aspects as orientation and opening sizing would have more beneficial effects from a life-cycle perspective than the mere upgrading of construction materials and elements.

As a final conclusion, this paper with its simplified inclusion of embodied energy adds a life-cycle perspective to the heating energy demand calculation, giving a hint to the dangers of over-specifying insulation levels, which is particularly relevant for mild climates such as that of Ireland and many parts of Western Europe.

The paper also exposes the need for methodologies to allow for this type of calculations in a simplified manner that could be readily available to architects, designers and engineers, perhaps together with official energy assessment tools, to avoid potential situations where no overall life-cycle energy benefits are being achieved by upgrading building envelopes with energy intensive materials.

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