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Retrofitting Buildings: Embodied & Operational Energy Use in English Housing Stock †

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Abstract: This study is aimed at assessing the impact of the insulation refurbishment of the English housing stock on the embodied energy needed for the various refurbishment scenarios and their corresponding operational energy use reductions. An embodied energy model comprising 22 million homes has been constructed, enabling the assessment and comparison of operational and embodied energy use due to the insulation refurbishment of various applicable building elements. Results indicate that mineral wool, sheep wool and expanded polystyrene (EPS) are the optimum insulation materials for cavity walls, cold pitch roofs and warm pitched roofs, respectively.

Keywords: embodied energy; operational energy; insulation; English housing stock

1. Introduction

More than 75% of English housing stock are constructed before 1980, when energy efficiency was not a concern in building design [1]. As illustrated in Figure 1a, a 2016 estimation suggests that 20% of English homes have uninsulated cavity wall and 10% have less than 100 mm loft insulation [1]. Only 1% of the English housing stock is renewed each year with new buildings [2]. Therefore, existing buildings must be refurbished in an energy-efficient manner to significantly reduce the energy usage of the housing stock.

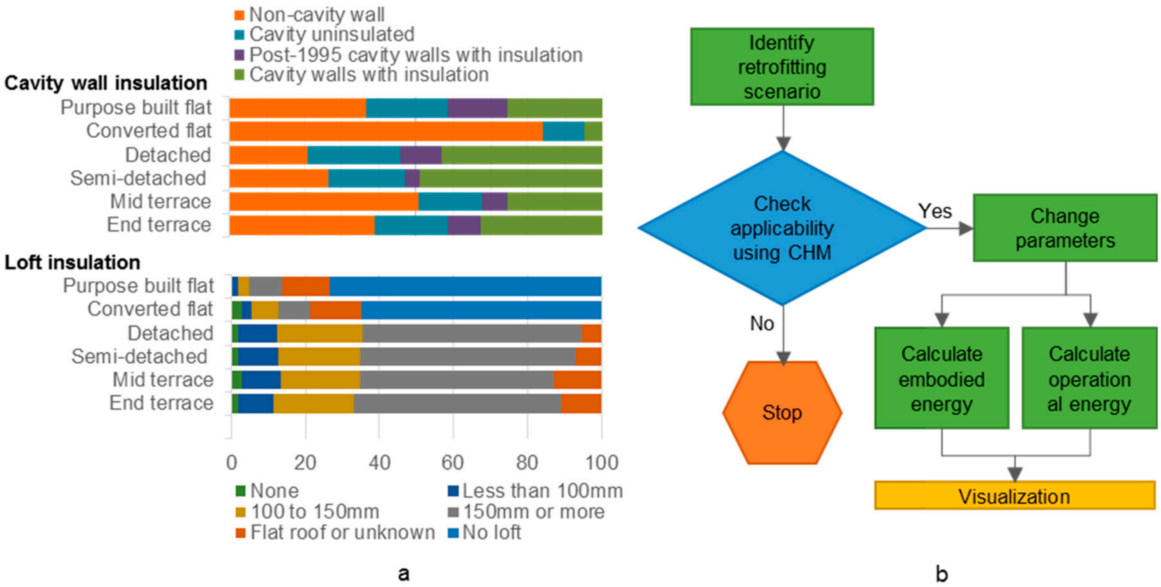

Figure 1. (**a**) Insulation in walls and lofts in the English Housing Stock, and (**b**) project methodology.

The energy used throughout a building's life cycle can be split into operational and embodied energy. Operational energy is defined as the energy consumed through the use of a building. Appliances, lighting, heating and other systems all contribute to operational energy. Embodied energy can be defined as the energy consumed throughout the production, maintenance and demolition of a building [3,4]. Recent studies suggest that embodied energy is of greater importance in reducing building energy [5]. Hence, to justify a refurbishment as energy-efficient, operational energy gains must be compared to the initial embodied energy costs as part of a life cycle analysis [6].

In order to identify the optimum strategy for refurbishing the English housing stock, this paper identified insulation refurbishment options and assessed their embodied energy and operational energy use. A model was created in Microsoft Excel based on the Cambridge Housing Model (CHM) [7]. The model addressed the applicability of each case from the English Housing Survey [1] data to each building element and calculated the embodied energy values and operational energy values.

2. Method

The steps of the project method are shown in Figure 1b. First, the most commonly used insulants were selected, as listed in Table 1. The walls and roofs are considered because of their significance in building heat loss, which also make them the preferred insulation refurbishment options. Follwoing this, applicable cases were identified from the CHM. Using the data in Table 2, the embodied energy values were calculated. First, total required mass of insulants was calculated for the applicable dwellings from the CHM data. The refurbishments were then applied to the CHM and the change in operational energy was be calculated. This calculation is done by changing the existing *U*-value of the building element to the new estimated *U*-value for the applied insulant. Finally, the operational energy gains were compared, which is calculated by subtracting the operational energy usage of refurbished homes from the operational energy usage prior to the refurbishment.

Table 1. Selected Insulation materials.

Building Element	Insulation Material			
External walls	Cellular glass			
Internal walls	Cellular glass			
Cavity walls	EPS	Mineral wool	Rockwool	
Cold pitched roofs	Cellulose	Sheep wool	Mineral wool	Rockwool
Warm pitched roofs	EPS	Rigid Polyurethane		
Flat roofs	Cellular glass			

Table 2. The properties of insulation materials

Insulation Types	Density (kg/m^3)	Embodied Energy (Mj/kg)	Embodied Carbon (kg CO_2/kg)	Thermal Conductivity (W/mK)
Mineral wool	25	16.6	1.28	0.034
Rockwool	30	16.8	1.12	0.039
EPS	12	88.6	3.29	0.039
Rigid Polyurethane	24	101.5	4.26	0.023
Cellular Glass	120	27		0.43
Cellulose	40	3.3		0.04
Sheep wool	22	2.45		0.039

3. Results and Discussion

For flat roofs and internal and external walls, cellular glass is the only applicable insulation. It is therefore considered as the optimal insulation for both of these building elements. The comparison of insulants of cavity wall, cold pitched roof and warm pitched roof are discussed below.

Figure 2 illustrates the operational energy, embodied energy and operational gains due to new insulants. The operational gains are shown as negative value in the left-hand chart. Mineral wool is found to the best insulant, considering both operational gain and embodied energy for cavity wall insulation. The greatest operational gains for cavity wall insulation are found to be for converted flats for all investigated insulation materials, closely followed by semi-detached buildings.

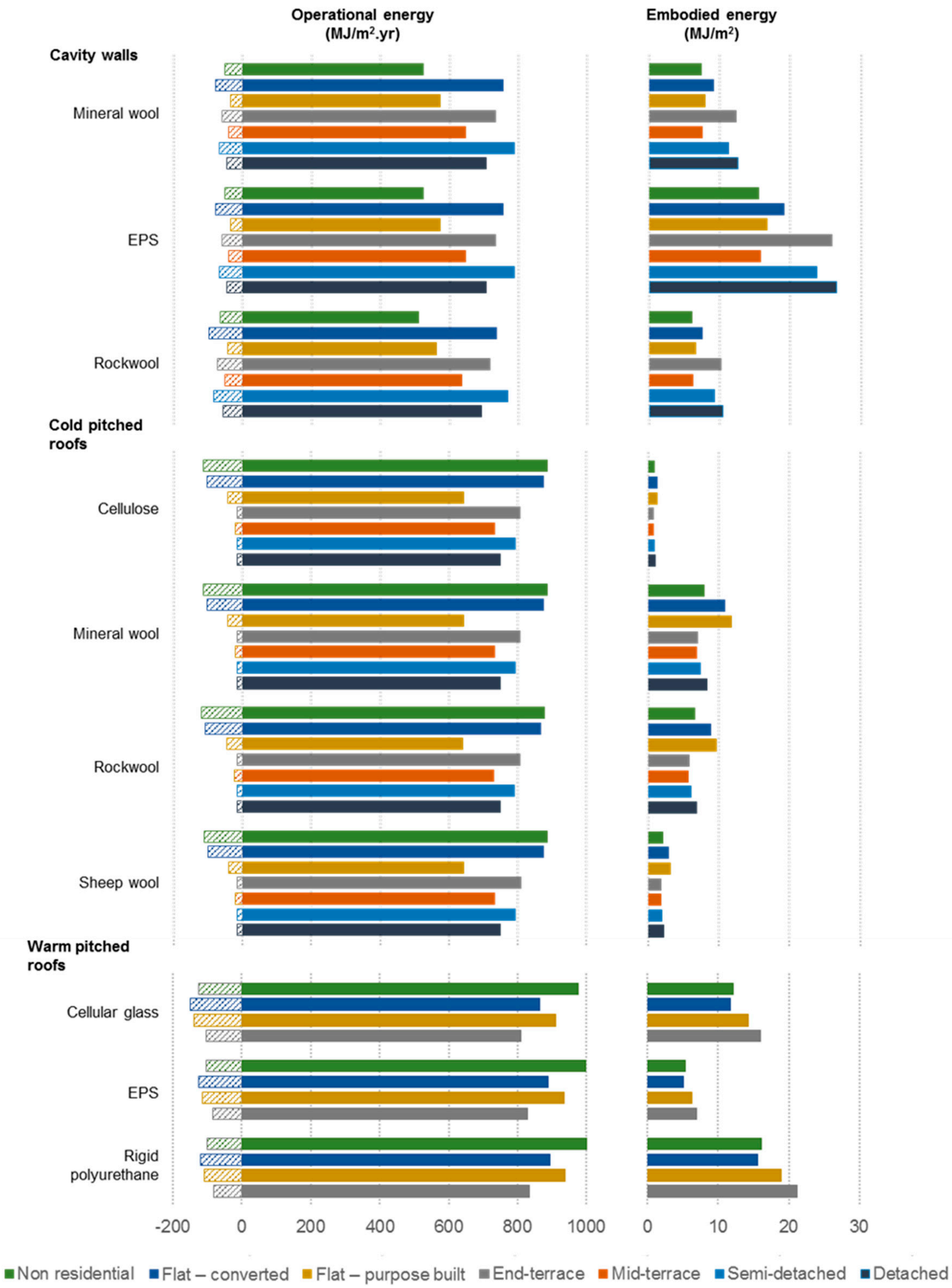

Figure 2. Operational energy and embodied energy of different type of insulants.

Sheep wool and EPS were found to be the optimal insulants for cold pitch roofs and warm pitched roofs respectively considering both operational gains and embodied energy. In both the cases the refurbishing converted flats will provide the highest level of operational gains.

4. Conclusions

This research compared the most commonly used insulation materials considering embodied energy and operational energy gains after retrofitting in the English housing stock. Mineral wool, sheep wool and EPS were found to be the optimal insulants for cavity walls, cold pitch roofs and warm pitched roofs, respectively. Though the model incorporates twenty-two million homes of England, only seven types of insulation materials were considered. In future, this evaluation can be carried out for other insulation materials.

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