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Life cycle inventory of buildings: A contribution analysis

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ABSTRACT

A companion paper presented the life cycle inventory (LCI) calculation model for buildings as a whole, developed within a global methodology to optimise low energy buildings simultaneously for energy, environmental impact and costs without neglecting the boundary conditions for thermal comfort and indoor air quality. This paper presents the results of a contribution analysis of the life cycle inventory of four typical Belgian residential buildings. The analysis shows the relative small importance of the embodied energy of a building compared to the energy consumption during the usage phase. This conclusion is even more valid when comparing the embodied energy of energy saving measures with the energy savings they realise. In most studied cases, the extra embodied energy for energy saving measures is gained back by the savings in less than 2 years. Only extremely low energy buildings might have a total embodied energy higher than the energy use of the utilisation phase. However, the sum of both remains small and the energy savings realised with these dwellings are large, compared to the energy consumption of average dwellings.

1. Introduction

When improving the energy performance of buildings, extra materials and components are applied, resulting in a higher embodied energy, being the energy needed for the production and transport of all these materials and components. In order to assess the overall impact of energy saving measures on the energy use over the life span of a building, a life cycle inventory of the building as a whole is a useful tool. In the literature, several reports can be found on life cycle assessment (LCA) studies on buildings as a whole in Sweden [1–3], Germany [4], USA [5,6], France [7] and Australia and New Zealand [8–10]. Due to the one-of-a-kind character of these buildings and the building tradition that may quite differ from country to country, it is not evident to draw general conclusions from these case studies. Nevertheless, all case studies emphasise the importance of the operational phase, when comparing the environmental impact of the different life cycle phases of a building [2,3,5–7].

This was also the conclusion of the EL^2EP project that developed a global methodology for life cycle optimisation of extremely low energy dwellings for energy, emissions and cost [11]. The underlying life cycle inventory (LCI) calculation model is presented in a companion paper. This paper first presents the goal of the LCI study, followed by a detailed description of the Belgian reference dwellings to which the LCI is applied. Subsequently the focus of the contribution analysis is described. Finally, the results of the contribution analysis are presented and discussed.

2. Methodology

2.1. Goal of the LCI

Apart from establishing a LCI database to incorporate in the global optimisation methodology, a more important underlying goal of the LCI was to analyse the relation between energy savings realised with extremely low energy dwellings and the embodied energy needed in the creation of these dwellings. After all, compared to common dwellings, extremely low energy dwellings demand an extra input of materials and products, such as extra insulation or photovoltaic modules. If the extra embodied energy in these extra materials would be much larger than the energy savings they realise during the usage phase, then the final goal of developing extremely low energy dwellings would not be reached. Apart from energy, the LCI also considered global warming potential and emissions of CO_2, SO_x, NO_x and particulates. In this paper only the results for energy are presented, but results for emissions can be found in [11].

2.2. Reference dwellings and energy saving measures

For the contribution analysis, four reference dwellings are used that are designed to represent as good as possible the statistical

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Table 1
Overview of the geometrical data for the four typical Belgian residential buildings.

	Terraced house	Semi-detached house	Detached house	Non-compact house
Heated air volume [m^3]	494	521	529	557
Heated floor area [m^2]	143	147	153	149
Heat loss area [m^2]	232	330	395	611

average of the Belgian residential sector: one terraced dwelling, one semi-detached house and two individual dwellings (one with a simple square plan and one with a non-compact plan). An overview of the heated floor area, heated air volume and heat loss area for all dwellings is given in Table 1. To assess the impact of the energy saving measures, the non-insulated version of the dwellings is defined as the reference situation.

The energy saving measures are applied to both the building envelope and the heating system. The envelope-related energy saving measures consist of insulation, glazing, solar shading and air tightness. Insulation measures are taken for the roofs, attic floor, façade and ground floor. Both wood frame and massive building envelopes are considered. In case of wood frame, a wooden frame with a thickness of 14 cm is considered. In case of massive building envelope, both variants with a cavity wall (9 cm outer brick leaf, cavity, 14 cm light weight inner brick leaf) and with a massive wall (14 cm inner brick leaf) are considered. Sloped roofs always have a wood frame structure, finished with air tightness foil and gypsum board on the inside and PE foil and roof tiles on the outside; flat roofs have a wood frame structure in case of a wood frame building and a 15 cm hollow core reinforced concrete structure with 6 cm light concrete top coat in case of a massive building. An EPDM is used as finishing layer at the outside and stucco plaster on the inside. The ground floor is always made of 15 cm reinforced concrete, 7 cm light concrete top coat and ceramic tiles. The insulation thickness in each envelope component (roof, wall, floor) can vary from zero to a maximum of 30–40 cm and different types of insulation material can be applied (mineral wool, PUR, EPS, XPS, cellular glass, cellulose fibre).

Different glazing types are considered with a U-value varying from 2.8 W/m^2 K to 0.4 W/m^2 K and a g-value (transmittance of direct and indirect solar energy) varying from 0.76 to 0.21. Also the impact of the glass spacer is taken into account and two types of glass spacer are considered. Different types of window frames are considered, made from wood, PUR, PVC and/or aluminium with a U-value varying from 6 W/m^2 K to 0.65 W/m^2 K. Only building variants with acceptable thermal comfort in summer are considered. To realize this without active cooling, different types of movable internal or external shading systems are considered.

Also internal elements, such as floor slabs and inner walls, and finishing materials, such as stucco plaster, gypsum board, ceramic tiles, roof tiles, bitumen, air tightness foils, cement mortar, etc. are taken into account. In the case of wood frame construction, all inner floor slabs and inner walls are made of a wood frame construction of 14 cm, finished with gypsum board. In case of massive construction, all inner floor slabs are made of 1 cm stucco plaster, 15 cm hollow core reinforced concrete, finished with 7 cm light concrete top coat and ceramic tiles; the inner walls are made of 9 or 14 cm light weight bricks, finished with stucco plaster.

The system-related measures include all kinds of systems for production, storage, distribution, emission and control of heat, ventilation systems with or without heat recovery and both thermal and electrical solar systems. Traditional systems, such as high efficiency boilers, condensing boilers, radiators and floor heating as well as more innovative technologies are considered, such as heat pumps, cogeneration of heat and power and renewable solar energy systems. Depending on the energy performance of the building, the dimensions of the heating systems are determined based on the design heat load according to EN12831 (Heating systems in Buildings – Method for calculation of the design heat load). The ventilation system is designed according to NBN-D50-001 (Ventilation in residential buildings).

The embodied energy for production of all building materials and components, transport to the building site and replacement during usage is calculated with the partial LCI models, based on the ecoinvent database [14], as explained in the accompanying paper. The energy consumption for heating during the usage of the building is calculated through a coupling of the dynamic building simulation program TRNSYS15 and the multi zone air flow program COMIS. The weather data are hourly average data for the Test Reference Year of Brussels, Belgium. Due to the mild Belgian climate, no active cooling is adopted. Depending on the heating system, the energy carrier used is natural gas, fuel or electricity. Also the auxiliary electricity consumption for pumps and fans is taken into account in the primary energy consumption during usage of the building. In case of gas and fuel, the primary energy conversion factors are 1, whereas for electricity, the conversion factor for Belgium is 2,5.

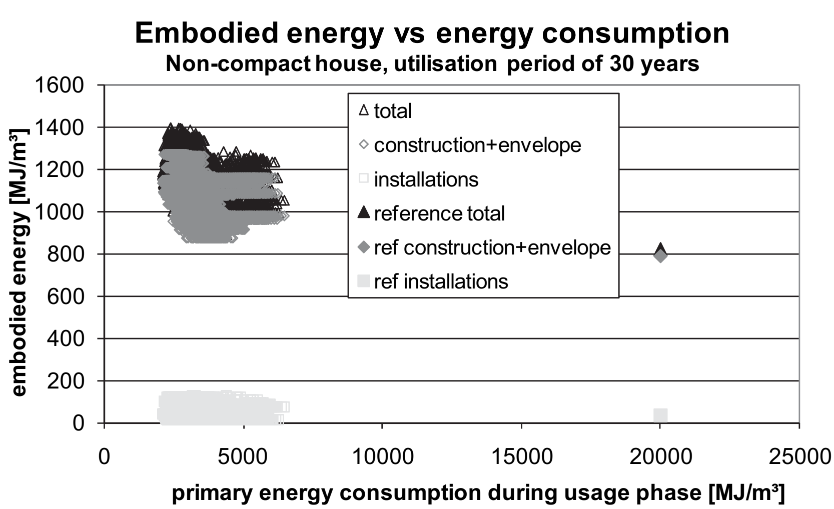

Fig. 1. Embodied energy and primary energy consumption for the non-compact house during usage phase of 30 years.