15th European Roundtable on Sustainable Consumption and Production
(15th ERSCP)
2012, May 2 – 4, Bregenz, Austria

The Life Cycle Energy Consumption of Zero-Energy Houses

Van Holm, M.[1*], Himpe, E.[2], Trappers, L.[23], Debacker, W.[1], Janssens, A.[2], Delghust, M.[2], Moens, J.[2]
[1] Flemish Institute of Technological Research (VITO), Unit Transition Energy and Environment, Boeretang 200, B-2400 Mol, Belgium

[2] Ghent University, Department of Architecture and Urban Planning, Jozef Plateaustraat 22, B-9000 Gent, Belgium

[3] Present affiliation address: Catholic University College Ghent, Department of Industrial Engineering, Gebroeders De Smetstraat 1, 9000 Ghent, Belgium

**marlies.vanholm@vito.be*

Abstract

Taking the building sector's huge impact on the environment into consideration, the European Union aims at 'nearly zero-energy' buildings by 2021, imposing strict requirements for the (non-renewable) operational energy consumption. The life cycle energy consumption of these nearly zero-energy buildings is an aspect of growing interest, encompassing both the life cycle embodied energy and end-of-life energy in building products, and the operational energy use throughout the building service life. Moreover, in Belgium zero-energy houses have to meet the passive house requirements in order to enjoy tax benefits. This contribution examines the life cycle energy consumption for various scenarios of zero-energy houses by means of Life Cycle Energy Analysis, thus examining whether passive house requirements are useful from the perspective of life cycle energy consumption. For the various zero-energy house scenarios, an analysis is provided of the contribution of the different components, such as building construction materials and building services, to the total life cycle energy consumption.

Results reveal that a zero-energy house roughly consumes 2 to 4 times less non-renewable life cycle energy than a typical Belgian passive house, and 3 to 5 times less than a house following current standard building practice. Secondly, the results demonstrate that there is no clear distinction in favor of either passive or standard zero-energy house scenarios. In essence, the lower embodied energy in building services in the passive house scenarios counterbalances the higher building construction embodied energy and vice versa for the standard house. As a conclusion, passive house requirements are not considered an essential criterion for zero-energy houses from a life cycle energy point of view. The research however reveals that the choice of building construction materials and of building services types are the determining factors influencing life cycle energy consumption. Large energy savings up to 30 kWh/year/m² can be obtained through a proficient choice of building materials and building services for zero-energy houses. Regarding the embodied energy in building constructions, a timber frame house and massive brick house can be equally energy efficient. Looking at the embodied energy in building services, the embodied energy in wood pellets and in photovoltaic panels reveal to be of major importance.

Keywords

life cycle energy analysis; embodied energy; zero-energy; passive house; building materials; residential buildings

Introduction

Taking the building sector's huge impact on the environment into consideration, the European Union aims at 'nearly zero-energy' buildings by 2021, imposing strict requirements for the (non-renewable) operational energy consumption for new buildings and major renovations within the recast EPBD. According to the European Council a nearly zero-energy house is a house *"that has a very high energy performance"* and in which *"the nearly zero or very low amount of energy required should be covered to a very significant extent by energy from renewable sources, including energy from renewable sources produced on-site or nearby"* (EP 2010). However, in this general definition, essential characteristics of zero-energy buildings, such as the accepted renewable energy supply options and requirements for the thermal performance of the building envelope, are left unspecified. In this study, a zero-energy house is defined as a grid-connected house in which primary energy from renewable sources balances the primary energy requirements for heating, cooling, domestic hot water supply and auxiliaries on a yearly basis. The following energy sources are considered renewable within this study: wind and solar energy, biomass and heat in water, soil and air. Requirements for the thermal performance of the house are investigated.

As the operational energy demand in zero-energy houses is decreasing and almost entirely covered by renewable energy, the (non-renewable) energy use during the life cycle phases before and after the operational phase, i.e. the embodied energy and end-of-life energy, becomes more and more important in relative terms (EC 2010). Furthermore an absolute increase in embodied energy occurs since zero-energy houses generally require a larger amount of building materials and building services than conventional houses (Verbeeck 2010 and Thormark 2002). Finally, when yearly operational energy use is reduced to zero, the life cycle energy becomes a decisive parameter in comparing the energy performances of houses (Hernandez 2010).

This paper discusses the results of a study undertaken by the Ghent University and the Flemish Institute for Technological Research examining the life cycle energy consumption for various scenarios for zero-energy houses by means of Life Cycle Energy Analysis (Himpe, 2012, under review). In a parameter analysis of a case study house, several design options, including variations in building materials (i.e. building construction and building services) and thermal performance of the dwelling (i.e. passive and standard building envelopes), are investigated through life cycle energy analysis. Main research questions:

1. What is the life cycle energy consumption of a zero-energy house? What is the difference between zero-energy houses and non-zero-energy passive and standard houses? How important is the share of life cycle embodied and life cycle end-of-life energy in the life cycle energy consumption of these houses?
2. What is the difference in life cycle energy use between a passive zero-energy house and a standard zero-energy house? Do passive house requirements for zero-energy houses in the Belgian climate lead to lower life cycle energy consumption?

Methodology

2.1 Case study house

The object of this study was an existing detached single-family house with a 143 m² net floor area. The formal aspects and orientation of this house were fixed and zero-energy scenarios were designed. First, a differentiation in thermal performance of the building envelope was made, resulting in 'passive' and 'standard' zero-energy house concepts. The passive variant meets the Belgian passive house requirements, whereas the standard variant is more commonly insulated according to the Belgian EPBD-regulations for 2014 (EPB 2010). Net energy demands for space heating and cooling are lower than respectively 15 and 70 kWh/year/m².

For both ‘passive’ and ‘standard’ zero-energy concepts, different types of building constructions (including masonry and lightweight timber frame constructions), building materials (including a broad range of insulation, construction and finishing materials) and building services for HVAC and RES (e.g. heating and DHW: geothermal and air-source heat pumps, solar heat systems and wood pellet furnaces; electricity: photovoltaic; ventilation: balanced system with a heat exchanger versus a demand-controlled simple exhaust system) were combined and investigated (Himpe 2011).

2.2 Life cycle energy analysis (LCEA)

In accordance with the research questions, life cycle energy analysis was selected as a method to investigate the benefits in terms of energy of different zero-energy house scenarios and to counterbalance the focus on operational energy use by discussing it using its own values, namely energy. As LCEA is a variant of life cycle assessment (LCA), the general methodology of the research was inspired by the LCA framework in the ISO 14040 and 14044 standards (ISO14040:2006 and ISO14044:2006). The different phases of the LCEA thus include: definition of the goal and scope of the analysis, the inventory of life cycle energy data, the calculation and aggregation of different kinds of energy consumption and the interpretation of the results.

Goal and scope definition: The reference basis for the comparison or functional unit is a case study single-family house with an estimated service lifetime of 60 years. Apart from the operational energy of the house, which is the energy used for the operation of the building during its 60 years estimated service lifespan, also the life cycle embodied energy and end-of-life energy in the building materials were assessed. The embodied energy is the energy required before the operational phase, including the energy for manufacturing of the building products and transport of the finished materials and components to the building site. The end-of-life energy is the energy used after the operational lifespan, including the end-of-life treatment and transportations. In this study, the energy for construction and deconstruction of the building and for building maintenance was disregarded because of its negligible impact expected (Gao 2001 and De Meester 2009). The energy related to the replacement of building materials and components by identical parts during the 60 years building service life was included in the embodied energy and end-of-life energy. Thus embodied and end-of-life energy consumption are in the context of this study to be interpreted as life cycle embodied and life cycle end-of-life energy use.

Inventory of life cycle energy data: The Swiss ecoinvent database (version 2.2) was selected as a source for the input data on the embodied and end-of-life energy of building materials and related processes (Ecoinvent 2010). Some of the data records were modified by VITO in order to make them more representative for the Belgian situation.

Calculation and aggregation of energy use over the lifespan of the building: For calculation of the life cycle embodied and end-of-life energy, the Cumulative Energy Demand method was selected (Frischknecht 2007). This method is provided by the ecoinvent database for estimation of the primary energy use related to the life cycle of products. For this study, the feedstock energy in biomass sources was adapted: in cases where biomass was used as a construction material (and not as a fuel) the feedstock energy was erased. The operational energy use of the houses was calculated by means of the Flemish EPBD-software (version 1.4.2) (VEA 2012), which is a quasi-steady state model for estimating the energy end use for heating, cooling, domestic hot water and auxiliary energy. As some of the default and average values for parameters were considered to be inadequate, they were replaced by more exact and up to date variants, e.g. the primary energy factors were harmonised with those from the ecoinvent CED method and primary energy factors were calculated for the embodied energy in wood pellets.

Results

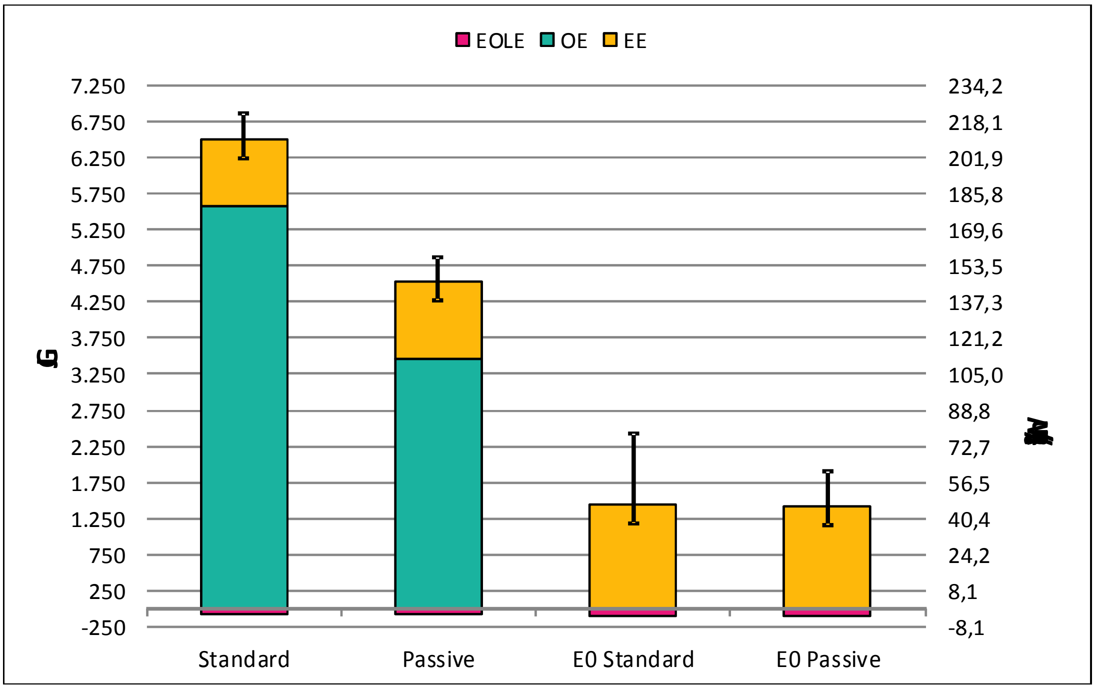

Figure 1: Non-renewable life cycle embodied (EE), operational (OE) and end-of-life (EOLE) energy for standard, passive, standard zero-energy and passive zero-energy houses (Himpe, 2012, under review).

Figure 1 represents the non-renewable life cycle energy use of standard and passive zero-energy and non-zero-energy reference scenario houses. Those four reference houses are all composed of building materials which are common in Belgian building practice (i.e. a brick masonry house). Further, the standard and passive non-zero-energy scenarios were equipped with a condensing boiler for heating and domestic hot water production, and electricity use from the national grid. The zero-energy houses were provided with a geothermal heat pump and a photovoltaic installation. Moreover, the spread in life cycle embodied energy, due to variations in building materials and services, is depicted.

The non-renewable primary energy use during the operational phase of the building service life was about 180kWh/year/m² (net floor area) for the standard house and 112 kWh/year/m² for the passive house, whereas for the zero-energy house, the operational energy was obviously zero. On the other hand, the life cycle embodied energy in the zero-energy scenarios was respectively 33 and 56% higher than in comparable non-zero-energy passive and standard scenarios, because of the higher embodied energy in the building services for renewable energy supply. An average passive or standard zero-energy house thus used about 46 kWh/m²/year of non-renewable embodied energy over a service lifespan of 60 years. Comparison of the non-renewable life cycle energy use of standard, passive and zero-energy houses showed that a zero-energy house performs typically two to four times better than a passive non-zero-energy house and three to five times better than a standard non-zero-energy house.

In the standard and passive non-zero-energy reference houses, embodied energy accounted for 10-19% and 19-29% of the life cycle energy use. Thus embodied energy contributes significantly to the life cycle energy use of houses and it can introduce variations in life cycle energy use of about 10%. Furthermore, it was estimated that on average 8% of the embodied energy in the houses is recovered through end-of-life treatment based on current Belgian practice.

Regarding the zero-energy houses, an even larger spread in embodied energy could be observed in figure 1 as the variation between the lowest and highest values was about 35 kWh/year/m² which is 50% of the life cycle energy use of the least energy-efficient zero-energy scenario. This issue is more closely observed in figure 2, where different zero-energy house scenarios are arranged in order of increasing life cycle and life cycle embodied energy. The scenarios include four passive and four standard zero-energy scenarios, combining least and most energy efficient building construction scenarios (Con- and Con+) according to an extensive sub-study in (Himpe 2011), with two relevant building services scenarios, i.e. one with a geothermal heat pump (Geo), representative for various heat pump scenarios, and one with a pellet furnace and solar heat system (PelSol). In addition to the embodied energy in building construction materials and building services, a fraction of embodied energy for production and transport of wood pellets during the service life of the building is included in scenarios with a pellet furnace.

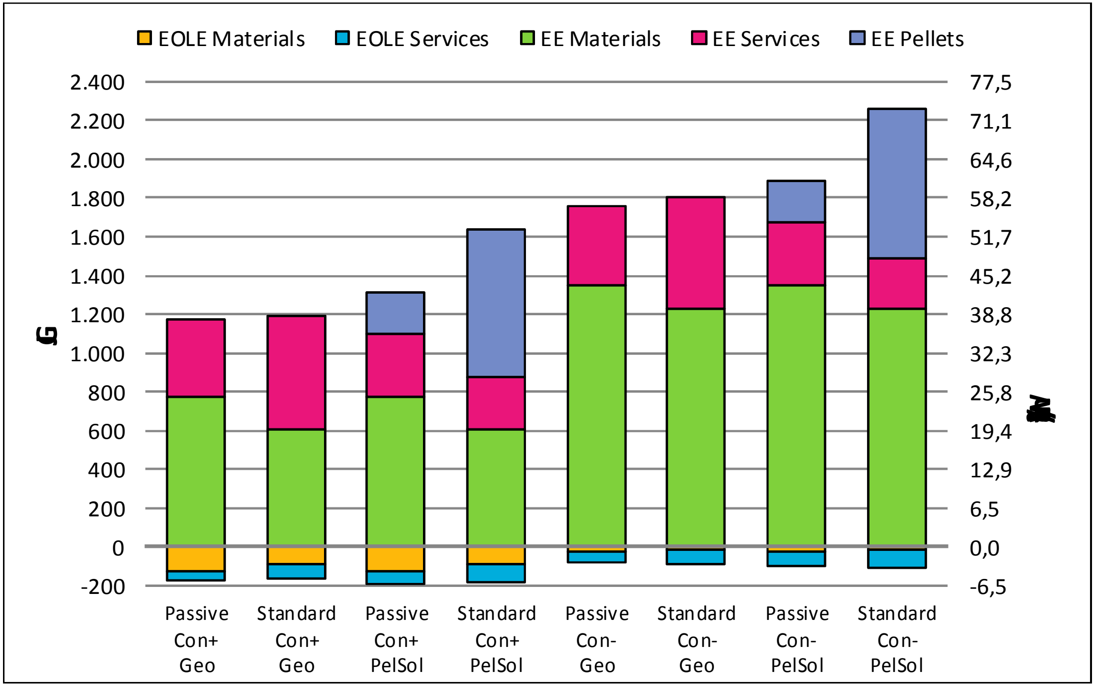

Figure 2: Non-renewable embodied (EE) and end-of-life (EOLE) energy of standard and passive zero-energy houses (Himpe, 2012, under review).

Observation of the zero-energy scenarios arrangement in figure 2 first and foremost revealed the vast impact of the building construction material choice on the life cycle embodied energy, since the four best case building construction houses (Con+) were shown to be the first four in the ranking. They did perform approximately two times better than the worst case building constructions (Con-) for both passive and standard building constructions. In a more detailed study timber frame constructions were demonstrated to be not intrinsically more energy efficient than masonry brick constructions, as best case timber frame and masonry scenarios had more or less equal life cycle energy. On the other hand, the worst case scenario was clearly a masonry scenario. It was concluded that not the choice of building construction type, but rather the entire material choice (ranging from structural and insulation materials to inner and outer finishing materials) influences the life cycle (embodied) energy of the building construction.

When taking a look at the embodied energy in building services and wood pellets in figure 2, the passive heat pump scenarios (Geo) had a slightly lower embodied energy than the PelSol scenarios. Regarding the standard scenarios, the difference was more clearly as the PelSol case had a significantly higher embodied energy than the Geo case, due to the production and transport of wood pellets during the operational phase. Further research uncovered the large share of the production of photovoltaics in the embodied energy of the building services, i.e. more than half of the embodied energy in case of the heat pump scenarios.

The passive and the standard scenarios alternatively appeared throughout the ranking. This demonstrated that there is no clear distinction in favour of either passive or standard zero-energy house scenarios and that the choice of materials and building services types are the determining factors. In essence, the lower embodied energy in building services in the passive house scenarios counterbalances the higher building construction embodied energy and vice versa for the standard house. This can be seen very clearly for the heat pump scenarios (Geo) in figure 2. As a conclusion, passive house requirements are not considered an essential criterion for zero-energy houses from a life cycle energy point of view. Zero-energy houses with a standard insulation level can be as energy-efficient.

Conclusions

Results reveal that a zero-energy house roughly consumes 2 to 4 times less non-renewable life cycle energy than a typical Belgian passive house, and 3 to 5 times less than a house following current standard building practice. Secondly, the results demonstrate that there is no clear distinction in favor of either passive or standard zero-energy house scenarios. In essence, the lower embodied energy in building services in the passive house scenarios counterbalances the higher building construction embodied energy and vice versa for the standard house. As a conclusion, passive house requirements are not considered a useful or essential criterion for zero-energy houses from a life cycle energy point of view. The research however reveals that the choice of building construction materials and of building services types are the determining factors for the life cycle energy consumption. Large energy savings up to 30 kWh/year/m² can be obtained through a proficient choice of building materials and building services for zero-energy houses. Regarding the embodied energy in building constructions, a timber frame house and massive brick house can be equally energy efficient. For the embodied energy in building services, the embodied energy in wood pellets and in photovoltaic panels prove to be of major importance.

Acknowledgements

The authors would like to thank Jelle Laverge (Ghent University) and Carolin Spirinckx (VITO) for their valuable contributions to this study.

References

De Meester B., Dewulf J., Verbeke S., Janssens A., Van Langenhove A. 2009. Exergetic life-cycle assessment (ELCA) for resource consumption evaluation in the built environment. Building and Environment 4:11-17.

Ecoinvent centre. 2010. ecoinvent reports. www.ecoinvent.org/documentation/reports, St-Gallen.

EPB. 2010. Verstrenging EPB-eisen in 2012 & 2014 - principieel akkoord Vlaamse Regering. EPB-nieuwsbrief, Brussels.

European Commission. 2010. Energy-efficient buildings PPP: Multi-annual roadmap and longer term strategy. European Commission, Luxembourg.

European Parliament and the Council. 2010. Directive 2010/31/EU of 19 may 2010 on the energy performance of buildings. Official Journal of the European Union, Brussels.

Frischknecht R., Jungbluth N. 2007. Implementation of Life Cycle Impact Assessment Methods, data v2.0(2007). Ecoinvent Centre, Dübendorf.

Gao W., Ariyama T., Ojima T., Meier A. 2001. Energy impacts of recycling disassembly material in residential buildings. Energy and Buildings 33:553-562.

Hernandez P., Kenny P. 2010. From net energy to zero energy buildings: Defining life cycle zero energy buildings (LC-ZEB). Energy and Buildings 42:815-821.

Himpe E., Trappers L. 2011. De totale energieconsumptie van een nulenergiewoning. Master Thesis. Ghent University, Ghent.

Himpe, E., Trappers, L., Van Holm, M., Delghust, M., Debacker, W., Janssens, A. and J. Moens, "Life cycle energy analysis of a zero-energy house", under review for Energy and Buildings.

ISO14040:2006. 2006. Environmental management - Life cycle assessment - Principles and Framework. International Organisation for Standardisation, Geneva.

ISO14044:2006. 2006. Environmental management - Life cycle assessment - Requirements and guidelines. International Organisation for Standardisation, Geneva.

Thormark C. 2002. A low energy building in a life cycle – its embodied energy, energy need for operation and recycling potential. Building and Environment 37:429-435.

VEA 2012. Energieprestatieregelgeving EPB - EPB software. Vlaams Energieagentschap: energiesparen.be.

Verbeeck G., Hens H. 2010. Life cycle inventory of buildings: A calculation method. Building and Environment 45:1037-1041.