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Comparison and discussion of heating systems for single-family homes in the framework of a renovation

Sophie Obyn *, Geoffrey van Moeseke *

Architecture et Climat, Faculté d'architecture, d'ingénierie architecturale, d'urbanisme (LOCI), Université Catholique de Louvain, 1 Place du Levant, 1348 Louvain-la-Neuve, Belgium

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ABSTRACT

In a global climate of environmental awareness, the expectations regarding energy performance of dwellings are increasingly high. Finding the appropriate heating system in such houses is sensitive. Such a system must meet reduced heating needs while not generating excessive emissions. Emissions would wreck the efforts to reduce the heating needs of these new or renovated homes. Moreover, in a context of economic crisis, the budget allocated to housing is limited. That is why the aim of this study is to evaluate and compare different systems in the framework of energy efficient renovation (i.e., nearly zero energy buildings) to identify which one best meets the current economic and environmental objectives.

Different systems are modelled and simulated using TRNSYS in an attached dwelling. They are then evaluated and compared on the basis of their investment, operating, and long-term costs as well as the emissions and primary energy consumption they generate.

The main conclusion is that the performance of the heating installation is not the most important factor when choosing a heating system for highly insulated houses. The optimum system identified from an environmental and economic point of view is the recovery of the existing heating installation, followed by installation of a gas-condensing boiler.

1. Introduction

In a global climate of environmental awareness, the expectations regarding energy performance of dwellings are increasingly high. The exigencies in application in the Belgian context, which is the focus of this paper, are presented in Section 1.2. Finding the appropriate heating system in highly insulated houses is sensitive, as mentioned by Vakiloroaya et al. [1]. Such a system must meet reduced heating needs while not generating excessive emissions. Indeed, such emissions would wreck the efforts to reduce the heating needs of these new or renovated single-family homes. Moreover, in a context of economic crisis, the budget allocated to housing is limited. That is why the aim of this study is to evaluate and compare different heating systems' performance in an energy-efficient renovation of a home of reference. This evaluation is based on several criteria, such as investment cost, operating cost, indexed cost in the long term, primary energy consumption, and emissions production, as developed in Section 2.4. All investigations consider the Belgian context.

The purpose is therefore to compare different heating systems to identify the advantages and disadvantages of various proposals and draw conclusions about their relevance in the context of a house with a drastically reduced heating need. Therefore, we consider passive and low-energy Belgian townhouses.

1.1. Outline of the paper

The article is organised as follows. After presenting the Belgian context and the existing contributions in Sections 1.2 and 1.3, the methodology, the studied house, and the evaluated systems are described in Section 2. The raw results are presented in Section 3. Finally, a discussion of the results is developed in Section 4, and the conclusions are presented in Section 5.

1.2. Belgian context

The regional energy policy for Walloon dwellings is briefly described in this section. On December 16, 2002, the European Directive for Energy Performance of Buildings (EPBD) [2] was adopted. The Member States had to transpose this directive into their national law. In Belgium, this was done at a regional level. This means that three energetic exigencies, termed EPB, were defined for Flemish, Brussels-Capital, and Walloon regions. These

* Tel.: +32 10 47 21 42; fax: +32 10 47 21 50.
E-mail addresses: sophie.obyn@uclouvain.be (S. Obyn), geoffrey.vanmoeseke@uclouvain.be (G. van Moeseke).

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regulations are based on stationary methods using a monthly energy balance for EPB calculations. The last version of Walloon exigencies [3] considers maximum values of a heat transfer coefficient (U_{max}) of 1.8 W/(m^2 K) for windows; 1.1 W/(m^2 K) for glazing; 0.24 W/(m^2 K) for external walls, roofs, and ceilings; 0.3 W/(m^2 K) for external floors; and 2.0 W/(m^2 K) for external doors.

In the Brussels-Capital region, the same values of U_{max} have been in application since January 1, 2014. Nevertheless, to meet the objectives of the European Parliament and Council's Directive of 19 May 2010 [4], the region implements the "Exigences PEB Passives 2015" [5]. This limits annual heating needs to 15 kWh/m^2 and imposes a level of airtightness of 1 h^{-1} for 2015, decreasing to 0.6 h^{-1} by 2018.

Moreover, numerous guides and studies since 2009 [6–9] have studied the regional and national dynamics of sustainable construction. These studies seek to sensitise and inform architects and others working in and out of the construction field about energy consumption in buildings and the concepts and principles of renovation. They also proposed a priority order in the renovation context in terms of economic and environmental issues.

1.3. Existing contributions

In the last six years, many studies have focused on the reduction of energy consumption, at international [10–14] and national levels. Nationally, Audenaert et al. [15] and Versele et al. [16] performed an economic analysis of passive and low-energy houses compared to standard houses in 2008. In 2009, Achten et al. [17] investigated the cost-effectiveness of energy-saving measures in the Flemish region. Unlike Audenaert et al. [15] and Versele et al. [16], they considered the economic and environmental dimensions. Another study was conducted by Renard et al. [18] in 2008, considering the Walloon region. The conclusion of all these researches is that the economical optimum for a renovation is the low-energy level (i.e., with a consumption of 30 kWh/(m^2 year).

In 2007, Verbeeck [19] concluded that a high efficiency or condensing boiler is a good solution for the heating system and that when a larger budget is available, a heat pump is a good alternative. He noted also that solar collectors can further decrease energy consumption but are beyond the economic optimum. On other hand, Vrijders and Delem [20,21] evaluated in 2009 the economic and environmental impact of energy housing renovation, calculating energy demand with Flemish EPB software. They considered four insulation levels (standard renovation according to Flemish exigencies, low-energy, very low-energy, and passive dwellings) and three types of fuel (electricity, gas, and pellets) with or without a solar collector for hot water. They concluded that (1) low-energy and passive house alternatives show similar cost efficiency; (2) without financial stimuli, a low-energy dwelling with a solar boiler combined with a condensing gas boiler would be the best option; (3) most studied alternatives (low-energy, very low-energy, and passive) score substantially better than standard renovation with similar cost efficiency; (4) when combining costs and environmental impact, no single optimum can be identified (a financially passive dwelling with a solar boiler combined with a condensing gas boiler is the best option, but a passive dwelling with a solar boiler combined with a pellet furnace has the lowest environmental impact in terms of the eco-indicator). In 2012, Audenaert et al. [22] continued their evaluation, searching for the cheapest heating system that generates the best E-level, using Flemish EPB software. "The analysis clearly indicates that a condensing gas boiler in combination with the heat exchanger is most advantageous: it is the cheapest heating system and generates the lowest E-level. This makes the condensing gas boiler the best choice for all dwelling types."

Laurent Georges et al. published a study on new houses [8,23] considering the same methodology of Achten et al. [17], De Coninck et al. [24], and Renard et al. [18], mainly focusing on heating systems applied to energy-efficient dwellings in the Walloon context. In their work, three levels of energy consumption were considered: 15 kWh/(m^2 year) according to the Passivhaus standard, 30 kWh/(m^2 year) for new low-energy houses, and 60 kWh/(m^2 year) for typical houses. Moreover, the choice of the evaluated systems is based on different sources (gas, wood, and electricity), and different systems are evaluated for each of these sources. The method used is derived from a simplified model of reality, as it is a statistical energy analysis based on an annual balance independent of the habitation's architecture.

The results of this study indicate that within a single-family home with a passive heating need of 15 kWh/(m^2 year), three optimal solutions for heating systems emerge: gas boilers, log boilers, and wood stoves. Moreover, even if all electrical systems are the least expensive investment, they create much primary energy consumption and enormous CO_2 emissions. They are then not an option from an environmental point of view.

Some major differences appear between the study of Georges et al. [8,23] and the present study. Out study is based on a reference building in which thermal behaviour is studied. Indeed, the method used here is a dynamic energy analysis performed with the multizone dynamic simulation software TRNSYS 17, as done by Deng et al. in 2011 [14]. Secondly, this work takes place in the context of an energy-efficient renovation (from 3 to 30 kWh/(m^2 year)). Therefore, the study focuses, among other things, on the recovery of the existing heating system. It consequently not only compares new systems but also studies the profitability of replacing the old installation. Indeed, a survey was conducted in Belgium in 2007 to evaluate the quality and the comfort of Belgian housings [25]. A major observation was that less than 28% of boilers are less than 5 years old. This means that the possibility of conservation of the existing heating installation in the context of a housing retrofitting is an issue. Thirdly, the criteria used for the different systems' comparison has been extended to include an assessment as comprehensive as possible for each of them.

To conclude, the present research follows Verbeeck [19], Vrijders and Delem [20,21], Deng et al. [14], and Georges et al. [8,23], considering the Walloon context, actual prices, and the dynamic evaluation of energy consumption. Our work mainly focuses on the Walloon context and uses a dynamic calculation method. In terms of objectives, it focuses on heating systems applied to energy-efficient houses (from 3 to 30 kWh/(m^2 year)).

2. Method

There are several ways to ascertain the optimum heating system for a refurbished, single-family house. We compared different systems in an energy-efficient reference building, and we realised the benchmark of house retrofit examples in Belgium presented on the LEHR website [26]. We chose a real and representative single-family home as a reference building. The first step in an energy retrofit is to reduce the net energy needed by insulating of the building envelope and diminishing infiltration and ventilation losses. After that, we must choose an adequate and proper heating system and use an efficient energy supply system. We also must have sufficient information about the chosen house to model it and compare systems, for different heating needs (by varying the level of building insulation), in order to draw conclusions on their relevance. This method allows isolating the parameter "system" and making against-projects that focus on the heating installation. The choice of number and range of heating need levels are based on existing contributions [15–18,20,21]. To do this, the first step