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Energy conservation and conversion of electrical heating systems in detached houses

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Abstract

In this study, a Swedish house built in 1974, heated with resistance heaters was analysed. Different options for changing the heating system and electricity production were compared for this type of detached house, assuming coal-based electricity production as a reference. Changes in the fuel used, the electricity production technology, the end-use heating technology and the heat demand were analysed. The aim was to show how these different parts of the energy system interact and to evaluate the cost-effectiveness of reducing CO_2 emission and primary energy use by different combinations of changes. The results showed that the CO_2 emission and primary energy use could be reduced by 95 and 70%, respectively, without increased heating costs in a national economic perspective. The choice of end-use heating system had a greater influence than the energy conservation measures on the parameters studied. The energy conservation measures were less cost-effective in combination with the more energy-efficient heating systems, although the fact that they reduced the heat demand, and thus also the investment cost of the new heating system, was taken into account.

Keywords: Heating system; CO_2 emission; Mitigation cost; Fossil fuel; Biomass; Electricity supply; Boiler; Heat pump; Resistance heaters

1. Introduction

A major transition in energy systems is necessary to reduce CO_2 emission sufficiently to tackle climate change [1]. The residential and service sector will play an important role in the changeover of energy systems in Europe, since a large part of the total final energy use is consumed as heat and electricity in buildings (in Sweden 35%) [2]. The energy use during the residential period of houses is also typically much higher than the energy used for construction and demolition, and the building stock is renewed slowly [3]. Hence, existing houses have to be addressed to substantially reduce final energy use and CO_2 emission from the built environment in the near future. The peak in construction of new Swedish houses occurred in the 1960s and 1970s, and many of these houses have quite low energy efficiency since Swedish building codes that also focused on energy efficiency were not introduced until 1977. Therefore, there is a potential for increased efficiency on the demand side through energy conservation measures, which could be cost-efficient, at least when coordinated with renovation. Several studies on energy conservation in buildings show that improved insulation is profitable, especially for houses in cold climates [4], for houses in need of renovation [5], and if the *U*-value[1] is significantly improved [6]. Erlandsson et al. concluded that the manufacturing, transport, building and demolition of the extra insulation materials had a small pollutant effect compared with the reduction in emissions resulting from the decrease in heating requirements [6].

When comprehensively evaluating a heating system, one has to consider not only the demand but also the supply side, including fuel, end-use technology and large-scale heat and power supply systems. Biomass can play an increasing role in the transition from existing fossil fuel systems to renewable alternatives. Estimates show that the fuel production from forestry residues, energy crops and recycled wood material can be increased significantly in Sweden [7–9]. For large scale electricity generation, more efficient conversion technology and the use of cogeneration plants are examples of means of CO_2 mitigation, and for end-use technologies both heat pumps

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[1] *U*-value = 5.682/*R*-value.

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and domestic boilers are more resource efficient than resistance heaters [10,11]. Karlsson made an extensive comparison of energy supply systems for heating purposes which demonstrated the connections between different parts of the supply chain, such as fuel, end-use conversion and large-scale heat and power production technology [11]. The connection between the demand and the supply has not been studied in such detail. When several energy conservation measures are implemented together in a building, the effects interact and together influence the heat demand. The size of the heat demand in turn influences the suitable type and capacity of energy system. Hence, the optimal level of energy conservation depends on the optimal heating system, and vice versa, as noted by Gustafsson [12].

Twenty-three percent of the Swedish houses built in the 1960s and 1970s were designed for electric heating with resistance heaters as the end-use technology [13]. In this study different conversion options for such heating systems in detached houses are compared. Changes in the electricity supply technology, the end-use heating technology, the fuel used for electricity and heat production and the heat demand are analysed. The aim was to show how these different parts of the energy system interact and to evaluate the cost-effectiveness of reducing CO_2 emission and primary energy use by different combinations of changes.

In Section 2 we describe our methodology and the reference system. We then move stepwise through the analysis of changes in the reference system. Section 3 describes three alternatives for reducing energy demand in the reference house, Section 4 presents four alternatives for the end-use technology, and Section 5 presents three alternatives for the generation of the required electric power. Section 6 then describes the assumptions made for the fuel chains and in Section 7, the alternative systems are compared with respect to energy use, CO_2 emission and total cost. Section 8 give mitigation cost and biomass cost for conversions from the reference system and in Section 9 a final discussion is presented.

2. Methodology

Through the use of energy simulation software we studied a Swedish detached house built in 1974 and situated in Östersund, in the midwestern part of Sweden. The building has two floors with a total heated area of 236 m^2. Half of the ground floor has its walls underground and is considered a basement. It is electrically heated by resistance heaters and the heat demand (space heating and domestic hot water heating) was calculated to be 41 MWh/year.

The basis for comparison between different energy systems is a functional unit that can be applied to all systems considered. The functional unit was here chosen to be the energy needed to heat the house for 1 year. In comparative studies it is also important to use the same system boundaries for all systems, since the choice of boundaries may influence the outcome [14]. Here, the whole energy system chains were included, from natural resources to useful energy services in the house, and the total remaining lifetime of the house in question was considered. Hence, all upstream processes and not only the end-use conversion were evaluated. The energy incorporated in materials and facilities, such as plant buildings and electric wires, was not included, but is expected to be very small [11]. A detailed description of the energy system chains is given by Karlsson [11]. In the present study, four variables in the energy chains were changed: the heat demand as a result of applying energy conservation measures, the end-use conversion technology, the electricity supply technology and the type of fuel (natural resource), as illustrated by the grey boxes in Fig. 1.

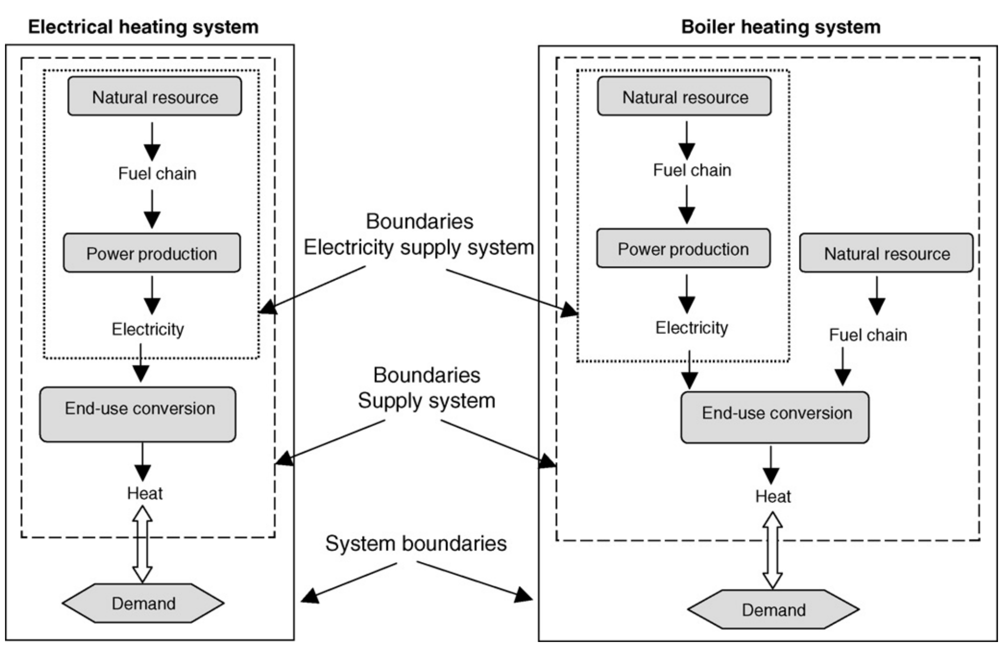

Fig. 1. Energy chains of an electrical (left) and a boiler (right) heating system, that are both analysed here. The dashed lines show the boundaries of the overall supply systems and the dotted lines the boundaries of the electricity supply systems. The supply system interacts with the heat demand, which is also included in the system boundaries. The fuel chains include recovery, refining and distribution of fuels.