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Environmental impact of energy refurbishment of buildings within different district heating systems ☆

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HIGHLIGHTS

- Energy refurbishment of a multi-family house within a district heating system.
- Changes in purchased energy, primary energy use and CO_2 emissions are analyzed.
- Four energy refurbishment packages and four district heating systems are included.
- Purchased energy savings are not correlated to the change in environmental impact.
- It is more important to reduce electricity use than heating demand.

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ABSTRACT

The refurbishment of existing buildings is often considered a way to reduce energy use and CO_2 emissions in the building stock. This study analyses the primary energy and CO_2 impact of refurbishing a multi-family house with different refurbishment packages, given various district heating systems. Four models of typical district heating systems were defined to represent the Swedish district heating sector. The refurbishment packages were chosen to represent typical, yet innovative ways to improve the energy efficiency and indoor climate of a multi-family house. The study was made from a system perspective, including the valuation of changes in electricity use on the margin. The results show a significant difference in primary energy use for the different refurbishment packages, depending on both the package itself as well as the type of district heating system. While the packages with heat pumps had the lowest final energy use per m^2 of floor area, air heat recovery proved to reduce primary energy use and emissions of CO_2-equivalents more, independent of the type of district heating system, as it leads to a smaller increase in electricity use.

1. Introduction

District heating (DH) is a common way of heating buildings in urban areas in Northern Europe. In Sweden, about 91% of all energy used for space heating and domestic hot water (DHW) preparation in multi-family houses is based on DH [1]. European DH production in general and Swedish DH in particular has low environmental impact, by mainly using heat from municipal solid waste (MSW) incineration, industrial waste heat (IWH) and secondary biofuels [2,3]. Nevertheless, the energy refurbishment of multi-family houses will also be required in Sweden in order to achieve EU goals to increase energy efficiency by 27% in terms of supplied energy and reduce greenhouse gas emissions by 40% by 2030 [4]. Supplied energy is also referred to as primary energy (PE) and can be defined as the total energy in terms of natural resources that is used to produce energy for final use, e.g. electricity. PE use is promoted in new and current directives as an indicator for energy efficiency for buildings [5,6].

Many DH plants, including 40% of Swedish DH plants [7], produce electricity and heat simultaneously, so-called cogeneration plants (CHP). Research shows that CHP plants could be crucial in

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Nomenclature

CHP	combined heat and power
CO_2	carbon dioxide
DH	district heating
DHS	district heating system
DHW	domestic hot water
EAHP	exhaust air heat pump
ERP	energy refurbishment package
FMS	fixed model structure
HO	heat only
IWH	industrial waste heat
MSW	municipal solid waste
MVHR	mechanical ventilation with heat recovery
PE	primary energy
PEF	primary energy factor
SFP	specific fan power

future energy systems in order to cut CO_2 emissions as they are more efficient than separate heat and electricity production, and they could help meet the demand for electrical power and may function as a buffer in the energy system [8]. It has also been concluded that energy renovation of buildings with CHP-based district heating can be problematic, as a reduction of the heating demand can affect electricity production in a negative way [9–11].

A substantial proportion of the existing residential building stock in Europe was constructed within the first decades following the Second World War [12]. In Sweden, this is largely represented by the so-called Million Homes Program, following a governmental initiative to build one million dwellings between 1965 and 1975 [13]. This part of the building stock represents an area with great potential for energy savings [14,15], and the age of these buildings makes refurbishment an urgent issue [16]. Many studies have addressed the energy saving potential, costs and PE impact of various energy refurbishments of district heated multi-family houses, including [17–25]. Dodoo et al. [17] assessed the primary energy impact of installing mechanical ventilation with heat recovery (MVHR) in residential buildings with different heating systems, showing limited benefits of such systems in district heated houses. Gustavsson et al. [18] analyzed how PE use and costs of DH production are affected by the energy refurbishment of an apartment building, including façade and roof insulation, improved windows, doors and water taps and MVHR. They found that the optimal level of refurbishment depends on the type of district heating system as well as taxation models for fossil fuels. Liu et al. [19] performed simulations of eleven multi-family houses with different construction, number of apartments, and heating and ventilation systems. Their results showed a good potential for energy saving and reduction of CO_2-emissions, although some refurbishment measures were deemed unprofitable compared to not refurbishing the buildings. Gustafsson et al. [20] analyzed the life cycle cost and environmental impact – in terms of primary energy consumption, CO_2-emissions and non-renewable energy consumption – of renovating a district-heated Million Homes Program house with an exhaust air heat pump (EAHP) or MVHR. Using data for primary energy use and CO_2-emissions of an average Swedish DH system, this study concluded that both of these energy systems would reduce the primary energy use and CO_2 impact of the house, compared to a system with only DH and exhaust ventilation. Swing et al. [21] used the same building and energy system models as in [20] to perform a deeper analysis of the calculated primary energy impact by varying the assumptions on DH production and allocation of impact between DH and electricity. They showed that the outcome is very much dependent on the type of DH system and which allocation method is used. The same models were also used by Lidberg et al. [22] to evaluate the refurbishment of a multi-family house placed in different district heating systems, showing that both packages with EAHP and packages with MVHR would reduce the primary energy impact of the house. Lidberg et al. [23] analyzed the impact on district heating and electricity production of energy refurbishment of a whole area of multi-family houses. They found that while all refurbishment packages reduced the fuel consumption of the district heating plant, as well as global greenhouse gas emissions, they also reduced electricity production through CHP. Furthermore, they found that envelope refurbishment measures result in larger reductions of greenhouse gas emissions than a refurbishment with MVHR that gives the same annual DH use, as the MVHR also increases the electricity demand of the house. Ramírez Villegas et al. [24] investigated different refurbishment strategies for Swedish multi-family houses in terms of greenhouse gas emissions from the local district heating system. Among their findings it can be noted that an option with only passive refurbishment measures gave almost exactly the same results as an option with only MVHR. Truong et al. [25] studied how including passive energy refurbishment measures and the installation of MVHR in a district heated building affect the primary energy use of the DH system under different environmental and socio-political scenarios. Assessing the refurbishment measures separately, they found that while MVHR gave the largest reduction in purchased energy, the largest primary energy savings were achieved by changing to more efficient electrical appliances.

This paper complements previous studies by combining the building perspective, in terms of purchased energy, and a system perspective, in terms of PE use and CO_2 emissions, on the refurbishment of multi-family houses within different types of district heating systems (DHSs). Four different DHSs are included, ranging from fossil fuel-based to biofuel-based and from heat only to CHP, as well as four energy refurbishment packages, combining passive measures with heating and ventilation systems. Specifically, it follows up on studies by Gustafsson et al. [20], Swing et al. [21] and Lidberg et al. [22] by including heating and ventilation system variants with MVHR and EAHP, and expanding them in terms of a system perspective.

2. Method

A typical multi-family house from the Swedish Million Homes Program period was simulated with four different energy refurbishment packages (ERPs): one with mechanical ventilation with heat recovery (MVHR), two with exhaust air heat pump (EAHP), and one with less extensive changes to the heating and ventilation systems. Both MVHR and EAHP have previously been shown to have the potential to reduce the purchased energy and primary energy (PE) use of buildings [17,19,20], whereas less extensive refurbishment could be less costly. All ERPs were based on the models of Gustafsson et al. [20]. The impact on PE use and emissions of CO_2-equivalents for different district heating systems (DHSs) were investigated by applying four different DHS models, using results from the building simulations in terms of energy use for the different ERPs as input data. The results from the DHS models, consisting of heat- and electricity production data as well as the fuel use, were used for calculations of PE use and emissions of CO_2-equivalents.

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