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Comparing different building energy efficiency refurbishment packages performed within different district heating systems

T. Lidberg[a]*, M. Gustafsson[a,b], J A. Myhren[a], T.Olofsson[a,c], L. Trygg[d,e]

[a]*School of Technology and Business Studies, Dalarna University, SE-79188, Falun, Sweden.*
[b]*Fluid and Climate Technology, Department of Civil and Architectural Engineering, KTH Royal Institute of Technology, School of Architecture and the Built Environment, Brinellvägen 23, SE-100 44 Stockholm, Sweden*
[c] *Department of Applied Physics and Electronics, Umeå University, SE-901 87 Umeå, Sweden.*
[d] *Department of Management and Engineering, Linköping University, SE-581 83 Linköping, Sweden.*

Abstract

This study analyses the differences in primary energy (PE) use of a multi-family building refurbished with different refurbishment packages situated in different district heating systems (DHS). Four models of typical DHS are defined to represent the Swedish DH sector. The refurbishment packages are chosen to represent typical, yet innovative ways to improve the energy efficiency of a representative multi-family building in Sweden.
The study was made from a broad system perspective, including valuation of changes in electricity use on the margin. The results show a significant difference in PE savings for the different refurbishment packages, depending on both the package itself as well as the type of DHS. Also, the package giving the lowest specific energy use per m² was not the one which saved the most PE.

District heating; primary energy; energy efficient refurbishment; building simulation; multi-family building.

1. Introduction

District heating (DH) is a common way of heating buildings in Swedish urban areas. In Sweden about 91 % of all energy used for heating and domestic hot water (DHW) in multi-family buildings are based on DH [1]. The Swedish DH production has generally low climate impact, using mainly waste heat from domestic waste incineration, industrial waste heat (IWH) and secondary biofuels. Despite the relatively low climate impact, energy efficient refurbishment of multi-family buildings will be required to reach the goal within the EU to increase the energy efficiency with 27 % in terms of supplied energy until 2030 [2].

* Corresponding author. Tel.: +46243-73003.
E-mail address: tlb@du.se.

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Supplied energy is also referred to as primary energy (PE) and it can be defined as the total energy in terms of natural resources that is used to produce energy for final use, e.g. electricity.

Many studies have addressed the energy saving potential, costs and PE impact of various energy refurbishments of Swedish multi-family buildings, including Gustafsson et al.[3], Swing et al. [4], Dodoo et al. [5] and Liu et al. [6]. This study complements previous studies by applying a broad system perspective, and investigates the difference in PE use depending on the design of the district heating systems (DHS). The aim of this paper is to analyse to what extent different energy efficient refurbishment packages (EERP) performed on one multi-family building saves different amount of PE depending on how DH is produced within the system. Also, this study compares the savings in the buildings in terms of bought energy with the savings in terms of PE from a system perspective.

2. Case study description

2.1. Case study building and EERP

The building model used in the case study is based on an existing multi-family house situated in Borlänge, situated 250 km North West of Stockholm, Sweden. Due to the age and condition of the building, extensive refurbishment is deemed necessary. The house is typical for the period around 1970, when one million dwellings were built in Sweden [7]–[9]. It is a three-story building with four stairwells and 36 apartments, a heated floor area of 3900 m² and a basement with storage rooms and a parallel, single stage DH substation. The house has a rectangular footprint and is oriented with the long sides to East and West. The total energy use for heating and ventilation is around 130 kWh/(m²·y) before refurbishment. In addition to the existing building, four EERP were simulated, all of which included insulation of roof and façade, new windows and flow-reducing water taps.

The new heating and ventilation systems are described in Table 1. In EERP A, the ventilation system was changed to mechanical ventilation with heat recovery (MVHR) with specific fan power (SFP) of 1.50 W/(l·s). In EERP B, no changes were made to the heating or ventilation system except the ventilation fans were changed to more energy-efficient ones with lower specific fan power (SFP = 0.45 W/(l·s), compared to 0.70 W/(l·s) with the existing fans). In EERP C and D, an exhaust air heat pump (EAHP) with variable speed compressor [10] was added to the heating system, covering part of the loads for DHW (EERP D) and space heating (both). The heat pump was then connected in series with the DH substation, with the heat pump first, to get a low inlet temperature for the heat pump and improve the heat pump performance. The SFP of the exhaust fans was assumed to increase to 0.75 W/(l·s) when the exhaust air was used as source for the EAHP. In EERP A, C and D, some of the radiators were converted to ventilation radiators, which preheat the supply air and at the same time enables a reduction of the water temperature in the radiator circuit [11], [12].

Table 1. Description of the heating and ventilation systems before (0) and after refurbishment (A – D).

System	Heating	DHW	Ventilation	Radiators	Annual DH use [kWh/m²]	Annual electricity use [kWh/m²]
0 (ref.)	DH	DH	Exhaust	Traditional	122	4.6
A	DH	DH	MVHR	Traditional	41	5.2
B	DH	DH	Exhaust	Ventilation	79	3.5
C	DH+EAHP	DH	Exhaust	Ventilation	49	10
D	DH+EAHP	DH+EAHP	Exhaust	Ventilation	45	11

2.2. District heating systems

The DHSs used in this study are based on national statistics for Swedish DHSs defined by Åberg [13] with the purpose to generally describe the entire Swedish DH sector, and be able to analyse consequences of for example energy efficient refurbishment from a larger scale perspective. Four DHSs were defined and the total Swedish DH sector was divided between the four types of systems as shown in Table 2. The original DHSs where classified due to their ability to produce electricity as well as their use of fuel. The DH in these systems is produced with fossil, bio or domestic waste as fuel, alternatively by IWH or by heat pumps. The combustion of the fuels occurs either in combined heat and power (CHP) plants where electricity is co-produced or in heat only (HO) plants. DHS I mainly includes a large share of biofuel based HO production as well as some IWH and DHS II includes almost equal shares of fossil and bio CHP, as well as IWH and domestic waste incineration HO. DHS III is dominated by waste CHP and waste HO, as well as a quite large share of fossil HO and DHS IV is dominated by bio CHP and bio HO. More specific information about the DHSs are available in Åberg [13].

Table 2. The type DHSs share of the Swedish DH sector based on statistics from 2011 [13], the share of heat/electricity in each DHS and the total heat demand for each DHS.

System type	I	II	III	IV
Share of the Swedish DH sector	27.5 %	10.0 %	18.5 %	44.0 %
Share of heat/electricity production	100/0 %	76/24 %	87/13 %	82/18 %
Total heat demand [GWh/year]	13 000	5 000	11 000	23 000

3. Method

A multi-family building was simulated with four different EERP. To be able to investigate the impact on PE use in the different DHSs the building was fictively moved around in the defined DHSs, represented by four DHS models. The results from the building simulations in terms of energy use for the different EERPs were used as input data in the DHS models. The results from the DHS models, consisting of heat- and electricity production data as well as the fuel used for the same, were used for the PE calculations.

3.1. Building simulations

The case study building and all related systems were simulated in TRNSYS 17 [14], using weather data from Meteonorm [15] for the climate of Västerås, located in central Sweden. The model followed the methodology of Gustafsson et al. [3]. In the building model there were nine zones for the living area (three zones in a row on each floor), each representing three apartments. No heat transfer was considered between the zones, and outputs from the middle zones on each floor were multiplied by two to account for all 36 apartments. Heat gains from people, eight persons per zone, were set to 100 W/person, corresponding to and activity level of 1 met for an average-sized person [16], while electrical appliances contributed on average 4.10 W/m². Schedules for the presence of people and electrical gains in each zone were created using a stochastic probability model [17]. A similar method was used to generate a profile for the aggregated DHW use of the whole house, taking into account the non-simultaneity of draw-offs [18]. Set temperatures of 22 °C for space heating (of the apartments) and 50 °C for DHW draw-offs were applied.

For the existing case, a total ventilation rate of 0.65 h^{-1} was assumed, out of which 0.25 h^{-1} was infiltration due to leakage and open windows. The infiltration is assumed to decrease by 0.05 h^{-1} after the renovation of the facade, and by another 0.05 h^{-1} with MVHR. In addition to passive shading from balconies, all windows facing east, west and south were equipped with internal shading, which was applied when the total solar radiation on the façade exceeded 200 W/m² and removed when the radiation dropped below 150 W/m². Heat transfer to the ground was modelled according to ISO 13370 [19].

3.2. DHS modelling and PE calculation

A model used for cost-optimizing DHSs called FMS (Fixed Model Structure) was used to calculate the change in DH and electricity production for each EERP in each DHS. The model was developed by Åberg and Widén [20] and uses linear programming to cost-optimize the operation of a DHS. Each DHS in this study were modelled in its original form as well as after implementation of each EERP.

To be able to calculate the PE use, primary energy factors (PEF) were used [21], see Table 3. For each package in each DHS the change in electricity use in the building were considered as well as change in electricity production from CHP plants. The change in electricity production or use was assumed to influence the annual marginal production, i.e. condensing coal power (CCP) production. These power plants are assumed to have an efficiency of 35 % and PEF for fossil fuel as presented in Table 3.

Table 3. PEFs used in this study.

Fuel	PEF
Fossil	1.11
Bio[a]	0.0402
Domestic Waste	0.04
IWH	0
Electricity	2.38

[a] 99 % secondary biofuel with PEF 0.03 and 1 % primary biofuel with PEF 1.05.

4. Results

Fig. 1 shows the change in PE for each EERP in each DHS divided between PE from DH, from less local electricity production and from electricity used in the building. The changes are presented in actual numbers why the total heat demand of each DHS (see Table 2) must be taken into consideration when comparing the DHSs in between. The changes in electricity use and production mainly contribute with an increase in PE use, only a small decrease occurs with EERP B because of the change to more energy efficient fans. The change in DH production contributes to PE savings. In all DHS case B saves the most PE, varying between 4.4 % savings for DHS IV to 16.7 % for DHS I. The least PE is saved by case D in all DHS, varying from 2.4 % in DHS IV to 11.1 % in DHS III. The second most PE saving EERP is case A varying between 3.8 % in DHS IV to 13.7 % in DHS I and the third most PE saving EERP is case C varying between 2.5 % in DHS IV to 11.5 % in DHS I.

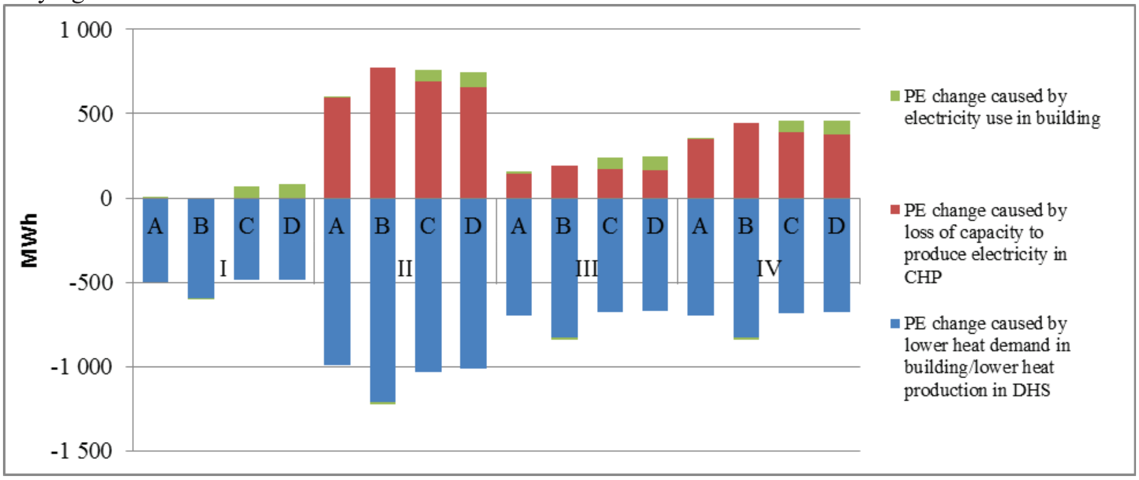

Fig. 1. Change in PE use for each EERP in each DHS, divided between electricity from production and use in building as well as from DH.

5. Discussion and conclusion

When comparing the results in Fig. 1 with the annual energy use for each EERP shown in Table 1 it indicates that the most energy efficient of the EERP, in terms of bought energy, is not the most PE effective one when considering a broad system perspective as in this study. The most PE effective EERP is B in all DHSs, and it has the highest use of DH and the lowest use of electricity in the building. The high use of DH contributes to advantageous opportunities to co-produce electricity in CHP plants and the low electricity use in the building leaves more available electricity on the market for other use leading to a reduced demand of electricity produced by marginal units. As CCP is assumed as the marginal production technology in this study, it will lead to a lower PE use since it has a high PE use per produced electricity unit. This emphasizes the importance of having a broad systems perspective when it comes to energy efficient refurbishment with the aim to maximize impact on resource saving.

The ranking between the EERP is the same within all DHS, independent of the amount of electricity produced within the DHS. The size of the savings is dependent on both the chare of electricity produced is the DHS as well as the fuel used in the system.

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Biography

Tina Lidberg is an industrial PhD student within the research school Reesbe since 2013. Her work focuses on energy efficiency improvement of multi-family buildings within district heated areas and how different refurbishment strategies influence the district heating system from an economic, environmental and resource perspective.

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