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Effects of heat and electricity saving measures in district-heated multistory residential buildings

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HIGHLIGHTS

- We analyzed the potential for energy savings in district heated buildings.
- Measures that reduce more peak load production give higher primary energy savings.
- Efficient appliances increase heat demand but give net primary energy savings.
- Efficient appliances give the largest net primary energy savings.

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ABSTRACT

The effects of heat and electricity saving measures in district-heated buildings can be complex because these depend not only on how energy is used on the demand side but also on how energy is provided from the supply side. In this study, we analyze the effects of heat and electricity saving measures in multistory concrete-framed and wood-framed versions of an existing district-heated building and examine the impacts of the reduced energy demand on different district heat (DH) production configurations. The energy saving measures considered are for domestic hot water reduction, building thermal envelope improvement, ventilation heat recovery (VHR), and household electricity savings. Our analysis is based on a measured heat load profile of an existing DH production system in Växjö, Sweden. Based on the measured heat load profile, we model three minimum-cost DH production system using plausible environmental and socio-political scenarios. Then, we investigate the primary energy implications of the energy saving measures applied to the two versions of the existing building, taking into account the changed DH demand, changed cogenerated electricity, and changed electricity use due to heat and electricity saving measures. Our results show that the difference between the final and primary energy savings of the concrete-framed and wood-framed versions of the case-study building is minor. The primary energy efficiency of the energy saving measures depends on the type of measure and on the composition of the DH production system. Of the various energy saving measures explored, electricity savings give the highest primary energy savings for the building versions. In contrast to the other heat savings measures, VHR gives lower primary energy savings as it also increases electricity demand. Primary energy savings for the building versions are lower where the minimum-cost DH production system includes cogeneration unit compared to where the minimum-cost DH production system comprises heat-only boilers. The primary energy savings are mainly from peak and medium-load boilers even though these production units cover a small share of the total DH production. This study shows that it is essential to consider the interaction between end-use energy saving measures and supply systems for district-heated buildings, to estimate the primary energy efficiency of energy saving measures.

1. Introduction

The European Union's 20/20/20 strategy sets targets to reduce greenhouse gas emissions by 20% below 1990 levels, to increase the share of renewable energy to 20% of the total energy mix, and to reduce primary energy use by 20% compared with projected levels, all by 2020 [1]. Improving energy efficiency in all end-use sectors is considered an important means to reach these targets. The European Union energy efficiency plan introduced in March 2011 emphasized the need to implement measures to improve energy use in buildings and identified measures that may contribute to lower energy use and CO_2 emissions in the building sector [2]. These include energy-efficient thermal envelope retrofit measures

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Nomenclature

BAU	business-as-usual
BIGCC	biomass integrated gasification combined cycle
BST	biomass-based steam turbine technology
CHP	combined heat and power
CST	coal-based steam turbine technology
DH	district heat
FGCC	fossil gas combined cycle
GEC	green electricity certificate
HOB	heat-only boiler
LHV	lower heating value
O&M	operation and maintenance
VHR	ventilation heat recovery

for existing buildings, efficient electric appliances, and efficient energy supply systems.

In the residential and service sector of Sweden, which accounted for 40% of the total final energy use in 2011 [3], increased attention is being placed on end-use energy savings in the existing building stock [4]. Studies show that there is a large potential to reduce energy use in the Swedish building stock by implementation of heat and electricity saving measures [5–7]. Janson [8] documented experiences in the construction of buildings with an energy efficiency level meeting the passive house standard [9] and reported on examples of existing Swedish multistory buildings that have been retrofitted to meet the passive house standard. Similar projects in Austria and Germany are reported by Reinberg [10] and Peper [11], respectively. In Sweden, a large number of apartments buildings constructed between 1962 and 1975 as part of the million homes program are expected to undergo major renovations in the coming years [12,13]. The building stock consists of a variety of buildings with different thermophysical properties, and this might influence the performance of different energy saving measures. For example, building frame material may affect the energy use for building operation through the mechanism of thermal mass [14].

District heating and cogeneration systems are an important part of a comprehensive strategy to reduce the climatic impacts of the built environment in the EU, including Sweden [15,16]. In Sweden, district heating accounts for approximately 50% (about 50 TWh) of the total space and tap water heating [17], and 92% of multistory buildings are district heated [3]. In 2011, biomass accounted for approximately 47% of the total energy input for the Swedish DH production [3]. The Swedish government energy policy aims at further increasing the share of biomass. Policy instruments to realize this include environmental taxes on fuels and green electricity certificate (GEC) market for electricity producers and customers [3]. The inclusion of social costs of CO_2 emissions can increase the attractiveness of environmentally favorable technologies. For example, Gustavsson et al. [5] showed that a damage cost of CO_2 emissions corresponding to the 550 ppm scenario and the business-as-usual (BAU) scenario of CO_2 concentration of Stern et al. [18] improves the economic competiveness of biofuels in district heating systems.

District heat production systems may be based on a combination of different production units and technologies with varying specific investment costs. They are normally designed to minimize the DH production cost while satisfying country-specific legislation. The selection of cost-optimal DH production units is influenced by several dynamics, including fuel price, socio-political and economic context, taxation regimes, heat demand, and expected utilization time of units. The utilization time of district-heat production units varies and is small for the units that cover peak-load heat demand. Base-load production units have large utilization times and are often based on combined heat and power (CHP) technology, which can coproduce both heat and electricity [5]. However, base-load production units may not be operated at their rated capacities during periods of low heat demand such as during summer. Changes in DH demand may influence the operation of base-load units, and this may consequently affect the coproduction of electricity.

Moreover, changes in electricity use of buildings and in coproduction of electricity from CHP plants may have system-wide implications for the electricity supply system. In Nordic countries, where marginal electricity is considered to be supplied from fossil fuel plants [19], changes in electricity use may have significant consequences for CO_2 emissions and dependence on imported fossil fuels. Therefore, electricity saving measures may be important to reduce fossil fuels use and should be considered in the overall context of supply systems.

Wood fuels are important energy resource in Sweden, where they are commonly used for heat and power production. Some studies showed that in cost-optimized DH production systems, wood fuels can be used instead of fossil fuels and could supply approximately 97% of the fuel [5,20]. Still, fossil fuels remain viable for peak-load production, and may account for up to 4% of the fuel for DH production in optimally designed systems [5]. The Swedish government target is to increase the renewable energy share to at least 50% of the total energy use by 2020 [21]. Moreover, the government aims to make heating in the residential and commercial sector oil-free by 2020 and has a vision of zero net greenhouse gas emission by 2050 [22,23]. Hence, exploring energy supply systems, including DH production, that do not depend on fossil fuels (oil in particular) is important also in the Swedish context. The use of biomass for DH and electricity production is suggested to increase in Sweden, where biomass production can potentially be doubled in the long run [24,25]. In the context where greenhouse gas emissions and energy security are key concerns, various pathways have been suggested for sustainable energy systems, including the use of 100% renewable energy for electricity and DH production, with biomass playing a central role [26,27].

The economic viability of district heating systems may depend on heat density which is the total yearly heat demand in a specific area, and hence, reduced heat demand in buildings could be a concern for such system owners. These days, energy efficiency measures are being adopted to reduce heat demand in buildings and the use of cogeneration and district heating systems are being encouraged. End-use heat and electricity saving measures may change the profile of buildings' energy use and, as a result, the heat load profile of a district heating system. Consequently, this may alter the DH production cost and the primary energy use for DH production.

Some studies have been conducted on the effects of end-use energy saving measures in district-heated buildings [6,7,26,28,29]. Most studies have focused on the cost-effectiveness of energy saving measures in district-heated buildings [28,29]. The impacts of energy saving measures have often been studied based on estimated annual average heat demand or DH production. Gustavsson et al. [5] analyzed the effect of heat-saving measures on a wood-framed district-heated building, including the dynamics of the annual profile of final energy savings and the annual profile of DH production. Few studies have considered both heat and electricity saving measures in district-heated buildings, as was done by Difs