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Heat demand profiles of energy conservation measures in buildings and their impact on a district heating system

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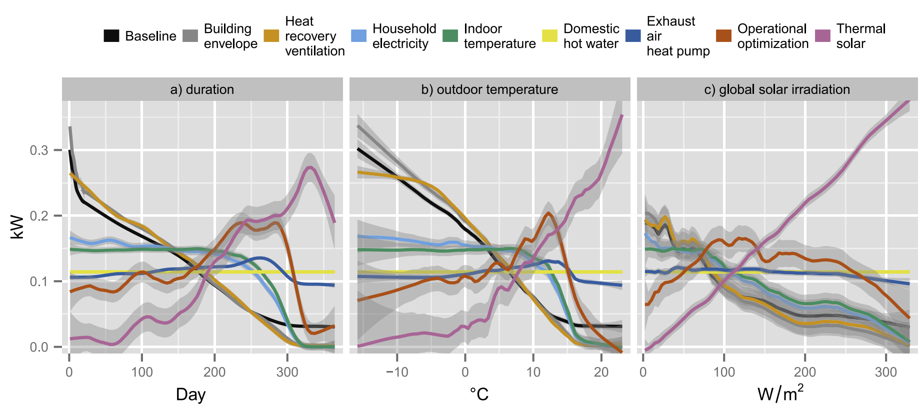
HIGHLIGHTS

- Energy savings impact on an low CO_2 emitting district heating system.
- Heat profiles of eight building energy conservation measures.
- Exhaust air heat pump, heat recovery ventilation, electricity savings etc.
- Heat load weather normalisation with segmented multivariable linear regression.

GRAPHICAL ABSTRACT



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ABSTRACT

This study highlights the forthcoming problem with diminishing environmental benefits from heat demand reducing energy conservation measures (ECM) of buildings within district heating systems (DHS), as the supply side is becoming "greener" and more primary energy efficient. In this study heat demand profiles and annual electricity-to-heat factors of ECMs in buildings are computed and their impact on system efficiency and greenhouse gas emissions of a Swedish biomass fuelled and combined heat and power utilising DHS are assessed. A weather normalising method for the DHS heat load is developed, combining segmented multivariable linear regressions with typical meteorological year weather data to enable the DHS model and the buildings model to work under the same weather conditions. Improving the buildings' envelope insulation level and thereby levelling out the DHS heat load curve reduces greenhouse gas emissions and improves primary energy efficiency. Reducing household electricity use proves to be highly beneficial, partly because it increases heat demand, allowing for more cogeneration of electricity. However the other ECMs considered may cause increased greenhouse gas emissions, mainly because of their adverse impact on the cogeneration of electricity. If biomass fuels are considered as residuals, and thus assigned low primary energy factors, primary energy efficiency decreases when implementing ECMs that lower heat demand.

1. Introduction

Energy conservation in the built environment is seen as an important measure towards mitigating climate change, increasing resource utilisation efficiency and thereby increasing energy supply security [1]. Whether to improve the supply side or the

Abbreviations: DH, district heating; DHS, district heating system; ECM, energy conservation measure; TMY, typical meteorological year; RMSE, root mean square error; HO, heat only (boiler); CHP, combined heat and power; FGC, flue gas condensing; EAHP, exhaust air heat pump; HRV, heat recovery ventilation; ERV, energy recovery ventilation; HDD, heating degree days; PE(F), primary energy (factor).

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demand side is an open issue. Jennings states that from a UK perspective "There is a primary conflict when considering the impact of an energy system retrofit decision in buildings: whether to improve the efficiency of supply side technologies, or whether to invest in demand side technologies with the intention of reducing primary energy requirements, and maintaining the embedded value of the incumbent supply side technologies" [2]. This conflict is even more apparent in countries like Sweden with a high penetration of district heating (DH). Especially, since a majority of these systems have high utilisation of secondary biomass fuels, waste incineration, waste heat sources and cogeneration of electricity. As pointed out by Gustavsson [3,4] these conflicts may be more difficult to manage within district heating systems (DHS) compared to other types of supply side technologies. This due to high capital investment needs and limited possibilities of alternative use.

A driving force for DH is its ability to provide heat in urban areas from centralised production units in a more resource efficient way than would be the case with separate heat production units at each site of heat demand. DH can utilise lower valued energy sources like industrial waste heat, bulky biomass fuel and municipality waste and improve resource utilisation by cogeneration of heat and electricity. DH can therefore play an important role in efforts aiming towards decarbonisation of energy systems (which the Swedish DH sector is a good example of as shown in Fig. 1). DH systems exist in most countries of the Northern hemisphere, but have their stronghold in Nordic countries and countries of the former Soviet Union. For most of these countries DH have a heat market share of over 40% of the building stock [5]. Today China shows the fastest DH sector growth and there also exist a large potential for DH growth in urban areas of many Central and Western European countries [5,6], while many DH systems of Nordic countries have matured and are addressing new issues when heat demand savings no longer can be met by extending the DH network.

Gustavsson's article series from 1994 [3,4] is a comprehensive case study of demand side energy conservation in Swedish DH systems and discuss on most topics still of concern today. It was concluded that there was a 30–60% energy conservation potential if considering both marginal operating costs as well as avoided future investments in DH production; that energy conservation would alter the shape of the heat load duration curve in a favourable way and therefore lead to higher utilisation rates of supply side investments; that higher share of biomass fuels and cogeneration of heat and electricity would lower fossil CO_2 emissions. In more recent papers [7–13] climate change mitigation, demand side energy conservation measures (ECMs) and their impact on electricity cogeneration has come into focus. Difs et al. [7] study demand side ECMs in the DHS of Linköping, Sweden, and their different impacts, considering both the local impact as well as the global impact (caused by cogenerated electricity being displaced by standalone production). It was shown that even if ECMs reduce the local emissions, the total CO_2 emission reduction could be closely to zero for certain ECMs in the studied DHS. Gustavsson et al. [8] and Truong et al. [9] investigate building ECMs and how these would have an impact on primary energy usage under different DH production configurations, considering the interactions between energy demand of the building and the combined heat and power (CHP) production. It was shown that electricity saving measures in buildings connected to systems with high share of CHP production yields high primary energy savings, mostly due the electricity saving itself but also partly due to increased cogeneration of electricity as saved electricity in buildings partly give place to new heat demand. Heat recovery ventilation had a less favourable impact, partly due to increased electricity demand at the building level. Individual DH systems differ considerably in fuel mix and production units (see Fig. 2) which makes it difficult to generalise results from case studies. Åberg [10] define four typical DH systems to represent the whole Swedish DH sector. The results show a general reduction of total CO_2 emissions in Swedish DH sector due to demand side ECMs, but also that the reduction potential depends on the production unit configuration of the DHS. Harrestrup and Svendsen [11] show in Danish study that ECMs that decrease the peak load could enable lower supply temperatures in the DHS, which increase possibilities for renewable energy sources. In a later paper by the same authors [12] the DHS of Copenhagen was studied. It was concluded that in order to reach Danish energy targets it would be similar costs to for demand side ECMs as to mitigate supply side to renewable production. It was argued that to implement demand side ECMs in a fast pace could be a better option, this to avoid a future situation with oversized renewable production capacity. Klobut et al. [13] state that in Finland the

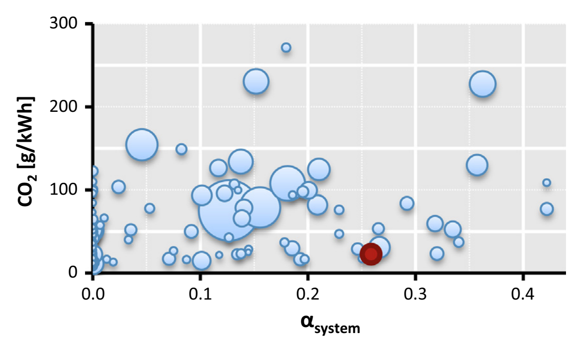

Fig. 2. The 100 largest Swedish DHSs in 2012. Eskilstuna is marked in red. Size of bubbles indicates the size of the system. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

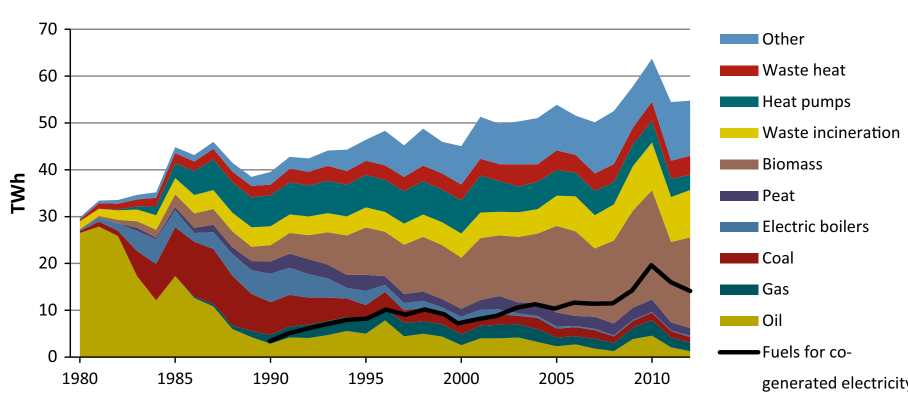

Fig. 1. The fuel mix of Swedish DH sector 1980–2010 and amount of fuels for cogenerated electricity (black line) for 1990 to 2012 [14,15].