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Heat planning for fossil-fuel-free district heating areas with extensive end-use heat savings: A case study of the Copenhagen district heating area in Denmark

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HIGHLIGHTS

- We investigate how much heating consumption needs to be reduced in a district heating area.
- We examine fossil-fuel-free supply vs. energy conservations in the building stock.
- It is slightly cost-beneficial to invest in energy renovation from today for a societal point of view.
- It is economically beneficial for district heating companies to invest in energy renovations from today.
- The cost per delivered heat unit is lower when energy renovations are carried out from today.

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ABSTRACT

The Danish government plans to make the Danish energy system to be completely free of fossil fuels by 2050 and that by 2035 the energy supply for buildings and electricity should be entirely based on renewable energy sources. To become independent from fossil fuels, it is necessary to reduce the energy consumption of the existing building stock, increase energy efficiency, and convert the present heat supply from fossil fuels to renewable energy sources. District heating is a sustainable way of providing space heating and domestic hot water to buildings in densely populated areas. This paper is a theoretical investigation of the district heating system in the Copenhagen area, in which heat conservation is related to the heat supply in buildings from an economic perspective. Supplying the existing building stock from low-temperature energy resources, e.g. geothermal heat, might lead to oversized heating plants that are too expensive to build in comparison with the potential energy savings in buildings. Long-term strategies for the existing building stock must ensure that costs are minimized and that investments in energy savings and new heating capacity are optimized and carried out at the right time.

1. Introduction

1.1. Meeting future long-term objectives

The Danish government has a long-term goal of having no need to use fossil fuels by 2050. By 2035, the goal is that the energy supply mix for buildings (electricity and heating) should be based on Renewable Energy (RE) sources (Danish Ministry of Climate, Energy and Buildings, 2011; Danish Energy Agency, 2010a). The European building stock accounts for about 40% of all energy use (Lechtenböhmer and Schüring, 2011). To meet the future energy goal, the energy consumption of the existing building stock will have to be reduced by increasing energy efficiency and converting the present heat supply from fossil fuels to renewable energy sources.

Investigations have shown that the energy consumption of existing buildings can be reduced by approximately 50–75% (Kragh and Wittchen, 2010; Kragh, 2010; Lund et al., 2010; Rasmussen, 2010; Tommerup et al., 2010), but that it will take significant investments to reach such low levels (Kragh and Wittchen, 2010). The existing building stock will remain in existence for many years, so a focus on energy savings in this segment is unavoidable. Future energy systems will have to be based solely on renewable energy sources, which is a challenge for society.

1.2. Future district heating systems

District Heating (DH) is a sustainable way of providing Space Heating (SH) and Domestic Hot Water (DHW) to buildings in

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densely populated areas (Persson and Werner, 2011). DH systems are already established in many countries, but like the rest of the energy supply system, they face new challenges in the future. In Iceland and Turkey, a large share of the DH supply is based on geothermal heat, and some DH systems are also supplied from geothermal heat in China and the U.S.A. In countries like Denmark, Sweden, and Finland, the DH supply comes mainly from combined heat and power generation plants (CHP) (Gustafsson and Rönnqvist, 2008). The DH systems in Denmark will have to be converted from the present supply technologies based on fossil fuels to 100% renewable energy sources. Questions have been raised about whether there is a need for DH-systems in the future, since SH-demands will decrease to very low levels. The economic feasibility of future DH-systems has thus been questioned. A study of the DH-net in Malmö, Sweden, (Gustafsson, 1992) found the overall economic feasibility of DH systems to be problematic when end-use consumption in buildings is reduced. The overall costs strongly depend on the characteristics of the buildings and the district heating system (Gustavsson, 1994a, 1994b). However, a recent study in Denmark (Lund et al., 2010) has shown that even with a reduction of 75% in SH demand, it is beneficial to supply heat from DH. The study also shows that an expansion of the DH-network from the present 46% share of the total heat supply in Denmark to a 63–70% share would be beneficial. With low-temperature operation (a supply temperature of 55 °C and a return temperature of 25 °C), it has been shown that DH supply for low-energy buildings is competitive with the best alternatives, such as individual heat pumps (Lund et al., 2010; Dalla Rosa and Christensen, 2011). Low-Temperature District Heating (LTDH) is a cost-efficient and environmentally friendly way of supplying heat with linear heat densities down to 0.20 MWh/(m year) (Dalla Rosa and Christensen, 2011). LTDH reduces heat losses from the distribution pipes, and heat supply from renewable sources becomes more appropriate and efficient when low-temperature applications are implemented (Dalla Rosa et al., 2011).

1.3. The conversion to fossil-fuel-free societies with extensive end-use energy savings

Recent studies have investigated the potential in converting the existing energy system into a 100% renewable supply system in two local authorities in Denmark: Frederikshavn (Østergaard and Lund, 2011) and Aalborg (Østergaard et al., 2010). Both studies covered the heating, electricity and transport sectors and included energy-saving measures, but the focus was on the supply side and on production technologies. Both studies concluded that it is technically and economically possible to convert to a fossil-fuel-free society and that geothermal heat will play an important role in future district heating systems. A study from Sweden (Gustavsson et al., 2011) investigated how the end-use heat savings in buildings will affect district heating production, including costs and primary energy savings, but it included the use of fossil fuels. In the future, however, conversion to RE-supply will be as important as end-use heat savings.

The present paper considers both end-use-savings and 100% RE-supply, but has a more detailed focus on when and to what extent it is worth implementing end-use savings in the building stock. It describes a method for making use of the existing DH system in the future energy infrastructure of the Copenhagen area with the aim of society being fossil-fuel-free in 2050. The scope is limited to the heating sector, excluding other sectors such as electricity generation and the transport sector. The electricity sector will also have to be fossil-fuel-free, and much of the future electricity production will be based on fluctuating and vulnerable resources such as wind. If electricity is used for heating purposes, large, costly storage units may be required to meet peak loads. The use of DH in appropriate areas will protect the electricity sector from increasing peaks in very cold periods. That is why electricity for heating purposes is not considered in this study.

The focus of this paper is on the implementation of geothermal heat sources for future DH-systems, as well as on heat produced from municipal solid waste incineration.

Socioeconomic calculations of various energy renovation strategies are carried out and discussed. The cost per delivered unit of heat in buildings is estimated for the various scenarios based on the energy renovation strategies.

We have taken a very general approach with the aim of providing an overall picture for planning future heat sourcing with regard to heat savings and supply in the existing building stock. The cost of new buildings is generally not included in any of the scenarios, since it is assumed that when a new building is constructed, it automatically fulfils the energy requirements of the Danish Building Regulations. This means that the cost will be incurred whichever renovation strategy is carried out.

2. Methods

2.1. Background and approach for the case study

The investigation takes a long-term perspective and deals with the period up to 2070. According to current energy policy, coal will be phased out by 2030 (Danish Ministry of Climate, Energy and Buildings, 2011), but according to the Heat Plan of Copenhagen (CTR et al. 2009) coal will already have been phased out by 2025. This study assumed that fossil fuels will be phased out before 2025 and replaced with waste for incineration, geothermal energy and biomass.

Some CHP plants have already been converted for biomass in Denmark, but according to research (EEA (European Environment Agency) 2006) the biomass potential in Europe will only account for approximately 15–16% of the total primary energy demand in 2030. Furthermore the study (Ericsson and Nilsson, 2006) concludes that the biomass resource is limited and with the slow implementation of RES-policy in Europe it is unlikely that the biomass targets will be reached. This study therefore assumed that the biomass resource will be seen as a temporary solution only available until 2040, after which it will relocate to other sectors, i.e. the transportation sector that will have to be fossil-fuel-free by 2050. This is in good agreement with recommendations and other similar case studies (Danish Energy Agency, 2010a; Dolman et al., 2012). So this study focused on other renewable energy resources. This is in good agreement with the considerations in (Østergaard and Lund, 2011; Østergaard et al., 2010), although those studies still assume that a small amount of the available biomass-resource for CHP will be exploited indirectly for heating purposes.

Geothermal sources should be considered as a mix of various energy sources in the future heat supply infrastructure. Waste heat from industry could also be used in combination with either geothermal or solar heat, but the potential has been estimated to be low (3%) in the Copenhagen area, because the industrial sector is small (Danish Energy Agency, 2009). Geothermal water under Copenhagen can be tapped at temperatures of 73 °C at a depth of 2000 m (Mahler and Magtengaard 2010), so heat pumps are assumed not to be needed to further elevate the temperature of the water. Mahler and Magtengaard (2010) can be mentioned among newly developed geothermal heating plants in Denmark.

The priority of the utilization of the resources in this study was:

1. Waste for incineration;
2. Geothermal energy;
3. Biomass; and
4. Fossil fuels.