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Improved efficiency for distribution and use of district heating: A simulation study of retrofitting a Swedish apartment complex from the 1970's

Magnus Åberg[a,*,1], Jonas Carlsson[b], Annica M. Nilsson[a]

[a] Built Environment Energy Systems Group, Dept of Engineering Sciences, Uppsala University, Sweden
[b] Energy consultant, ekoPerspektiv AB, Motala, Sweden

ABSTRACT

Important features of the next generation of district heating systems are low distribution heat losses and low distribution temperatures. The purpose of this transition is to compensate for reduced heat demand densities caused by increased energy efficiency in buildings. In Sweden a majority of multi-family residential buildings are connected to district heating networks that are up to 50 years old. This study investigates the possibility to improve building energy efficiency and simultaneously reduce distribution temperatures and losses for a Swedish apartment complex built in the 1970's. The results show that a combination of better insulated building envelopes and ventilation heat recovery can reduce the heat demand in the studied apartment complex by 53%. The improved building energy performance significantly reduces the required supply temperatures for space heating and reduces heat distribution losses to some extent. The heat distribution losses can be reduced further (up to 49%) by replacing central hot water preparation with apartment based heat exchangers. This eliminates heat losses from pipes for domestic hot water supply and hot water circulation. The study concludes that a potential cost-synergy occurs when a holistic strategy is adopted and conventional energy efficiency measures are combined with reduced distribution losses.

1. Introduction

Between the years 1965 and 1974, one million residences were built in Sweden as a result of a political decision made by the government to solve the housing shortage of that time. A majority of the residences were built in large areas with multi-family residential apartment complexes. This was an extensive expansion of the Swedish building stock that has subsequently become known as "The million-homes programme" [1]. Today, a large number of the million-homes programme buildings are in need of renovation, mainly due to their age [2–5]. In the recast of the Energy Performance of Buildings Directive [6], the ambition to reduce primary energy use and CO_2-emissions is clear. For the EU member states, the directive requires that all new buildings and all existing buildings that undergo major renovation should be near zero energy buildings from 2021. The EU: s commitment to energy efficiency is further emphasised by the recent communication on 'Clean Energy for All' [7]. The package proposes a primary energy reduction target of 30% by 2030 compared to year 2007. In order to meet both the EU targets and the commitments of the Paris Agreement 2015 the EU renovation rate must increase from the current 1% per year to 2–3% per year [8]. Tuominen et al. [9] estimates that the average potential to reduce the building energy use in the EU member states is 10% until 2020 and 20% until 2030. For the Swedish building stock, evaluations show a technical potential to reduce the energy use with more than 50% [10]. To reach this potential, energy efficiency measures in Swedish million-homes programme buildings are necessary. The resulting reduction in energy demand for space heating and domestic hot water will have second-round effects for the district heating system.

About 90% of Swedish multi-family residential buildings, including a majority of the million-homes programme buildings, currently utilise district heating for space heating and domestic hot water. District heating is often produced from waste energy resources, such as excess heat from thermal power generation, waste incineration, and industrial processes. District heating is often claimed to have a public value in the sense that it provides a possibility to utilise low exergetic energy sources that would otherwise have been wasted. There is a risk that improved building energy efficiency that lowers the demand for district heating reduces the competitiveness of district heating in comparison to other residential heating systems. This is because of the relatively high distribution heat loss. According to Lund et al. [11] who introduced the concept, *fourth generation of district heating* (4GDH) are efforts to reduce distribution heat losses in district heating systems necessary, and one of the main challenges, in order to meet future building energy efficiency improvements.

Lower supply and return temperatures in distribution networks can reduce distribution losses and have been a main focus in district heating research in recent years. Several studies focus on development and assessment of low-temperature distribution piping and district heating

* Corresponding author.
E-mail address: magnus.aberg@angstrom.uu.se (M. Åberg).
[1] Visiting address: Lägerhyddsvägen 1, SE-75121, Uppsala, Sweden.

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substations. The aim is to achieve distribution supply temperatures as low as 35–55 °C, and yield return temperatures as low as 20 − 25 °C [12–16]. Of these studies, several focus on heat supply for new or planned buildings, and not for older existing buildings [13–16]. Furthermore, most of the mentioned studies focus on buildings and district heating in Denmark. In many aspects, district heating in Denmark and Sweden is similar. However, in Denmark, the share of district-heated single-family buildings is significantly larger in Denmark, and in northern Sweden the outdoor temperature is lower. Thus, there is a need for investigating aspects of low-temperature district heating supply for existing multi-family residential areas in Sweden.

Reduced distribution temperatures can be achieved locally within a district heating distribution network. By separating a part of the grid from the main grid, a secondary distribution network is created where temperatures, pressure and mass flow can be adapted to local heat users. Different secondary distribution network layouts for new low energy buildings have for example been compared in [17,18]. However, secondary distribution networks could also be used to achieve step-wise reductions of distribution temperatures in existing district heating networks. In residential areas built during the years of the million-homes programme and before that, secondary distribution networks are relatively common. The reason for this could be that district heating was established in many Swedish cities in the 1970's and the 1980's, which was after the construction during the million-homes programme. In many cases, residential areas with apartment complexes had small local heat distribution networks with oil boilers placed in the centres that supplied heat to the buildings. When district heating was established, these small area-networks were commonly connected to the district heating system by replacing the oil boiler with a heat exchanger, examples of this are described in [19]. It is, therefore, reasonable to assume that a significant number of these secondary distribution grids are still in use or have been replaced with similar distribution grids. The latter is the case in the residential area studied here.

Previous studies on energy efficiency improvements in buildings constructed during the million-home program show a significant potential to reduce the demand for space heating and hot water. A pilot project in Alingsås, Sweden adopted a deep renovation strategy to convert apartment buildings constructed in 1970 to passive house standard. The renovation decreased the total energy use with approximately 60% and significantly improved the technical status of the buildings [20]. Ramírez-Villegas *et al.* [21] studied a similar apartment building but in a different geographic location and simulated the energy use and district heating CO_2 emissions for four different renovation packages. The results show that the measures reduced the energy use with up to 43% and lowered the CO_2 emissions with up to 15%. The effect of energy renovations on greenhouse gas emissions from district heating has also been studied by Lidberg *et al.* [22]. The authors evaluated the energy use and greenhouse emissions for renovation packages applied to a district heated apartment complex constructed between 1969 and 1971. The renovation packages achieved heating reductions ranging from 20% to 46%. The renovation package that included measures to the building envelope decreased the greenhouse gas emissions more than the package that included ventilations measures, even though both packages achieved the same reduction in district heating use.

A few studies have also investigated building supply temperature requirements in relation to the energy performance of existing buildings [23–25]. Ostergaard and Svendsen [24] showed that existing Danish buildings built in the 1900's can be supplied by low-temperature district heating to a large extent without decreasing indoor comfort. Brand and Svendsen [25] found that small refurbishments of an existing single-family house built in the 1970s allow for a reduction of the supply temperature to below 60 °C for 98% of the year. Furthermore, Yang et al. [26] as well as Bøhm et al. [27] concluded that heat losses from domestic hot water circulation in existing multi-family buildings in Denmark are between 23% and 70% of the domestic hot water demand. Yang further states that decentralised, instead of centralised hot water preparation can potentially reduce heat losses by up to 30% [26].

The aim of this study is to investigate the possibility to combine reduction of heat demand in existing Swedish million-homes programme buildings with lowered distribution temperatures, and distribution heat losses. The investigation is conducted as a case study of a district-heated million-homes programme apartment complex in Uppsala, Sweden. The research questions answered in the study are:

- How does a reduced heat demand affect the required distribution temperature for space heating and the distribution heat losses in the studied apartment complex?
- To what extent can the heat distribution losses be reduced when the central domestic hot water preparation and the hot water circulation are replaced by apartment-based heat exchangers in the studied apartment complex?

Two cases related to the questions are studied. In *Case A* the focus is on building energy efficiency improvements and to what extent these reduce heat distribution temperatures and losses. In *case B*, the focus is on reducing heat losses of the existing distribution system in the studied area by moving hot water preparation from central heat substations into the apartments.

2. The apartment complex

The studied apartment complex consists of 77 multi-family residential buildings that are owned and managed by a private housing cooperative named *HSB 53 brf Gräslöken* in the city of Uppsala, Sweden. The complex was built between the years 1970 and 1972 and is, hence, a part of the Swedish building-stock built during the million-homes programme. The complex is typical for this era because of its large number of apartments, uniformly designed buildings, and geographic separation from main roads. The buildings are two-story brick-façade buildings with exterior corridors (see Fig. 1). Each building contains 10 or 12 apartments and in total the complex consists of 832 apartments. In 1992, pitched roofs replaced the original flat roofs, and in 2005 extra roof-insulation was added that reduced the demand for heating by 9% [28].

A heat distribution pipe-network is used to supply space heating and domestic hot water to the residents (Fig. 2). Heat is supplied to the apartment complex via the city´s district heating system to three main district heating sub-stations (S1, S3, and S5). The heat is thereafter distributed to the buildings via the secondary district-heating networks that are owned and operated by the housing cooperative. The domestic hot water is heated centrally in the substations (S1-S5) and distributed to the buildings. In order to avoid growth of legionella bacteria and to reduce the time it takes for hot water to reach an open tap, hot water is circulated in a hot water circuit (HWC).

The piping of the secondary heat distribution networks in the complex was replaced in 2016 after substantial and expensive water-leakages had occurred in the system. During the network renovation the actual piping was replaced while the network configuration remained the same.

3. Description of studied cases

Two different cases are used to structure the calculations and the results in relation to the research questions. In *Case A* the focus is on building energy efficiency improvements and to what extent these can reduce the required level of heat distribution temperatures. Furthermore, the impact of the improved energy efficiency on the distribution losses is investigated. In *case B*, the focus is on modifying the existing distribution system so that hot water is no longer produced in the central heat substations of the area, but instead heat exchangers for