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Novel low temperature heat distribution technology

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ABSTRACT

Lower future heat demands and lower availability of non-fossil high temperature heat supply are expected future market conditions that restrain the long-term viability of contemporary district heating systems. Hence, current district heating technology should be enhanced to increase system performance in new heat distribution areas.

This paper aims to outline a proposal for technical improvements required to achieve lower annual average return temperatures in new residential buildings to improve viability in future market conditions. The proposed technical solution consists of three principle changes: three-pipe distribution networks, apartment substations, and longer thermal lengths for heat exchangers. The three technical modifications aims at addressing system embedded temperature errors. Furthermore, a simulation model was developed to assess the proposed technical solution concerning different energy performances of buildings and different thermal lengths in heat exchangers.

The results show that implementation of the three technical modifications reaches time-weighted annual average return temperatures of 17–21 °C with supply temperatures of about 50 °C. The results also verify the increased necessity to separate the network return flows into delivery and recirculation flows in residential substations as energy performance in buildings increase.

1. Introduction

1.1. Situation

District heating systems are important tools in achieving sustainable energy systems. Local heat distribution enables recovery of excess heat, which converts heat previously considered wasted into a resource. Utilisation of excess heat flows decreases the overall demand of the primary energy supply. This is the fundamental idea of district heating technology [1]. Lower primary energy demand entails attributes that are attractive to our contemporary society: (i) decreased dependence of energy imports, (ii) less environmental effects, (iii) less strain on scarce energy resources, and (iv) lower energy system costs, which is also one of the main conclusions by the Heat Roadmap Europe project [2].

The European Union (EU) has adopted a common framework of measures to promote energy efficiency and to ensure the achievement of the reduction target of primary energy demand for 2020 [3], and further actions are planned for 2030 [4]. As buildings account for 40% of the total energy demand within the EU, they constitute a major component to achieve the energy efficiency target. New buildings and existing buildings that undergo major renovations shall meet minimum requirements for energy performance. In addition, all new buildings occupied and owned by public authorities are to be built as nearly zero-energy buildings from 2019 and all others from 2021 [5]. Thus, lower energy demands for space heating are anticipated in future building stock.

Increased energy performance of buildings is both a challenge and an opportunity in district heating systems. The challenge is that economic margins of heat distribution decrease with lower linear heat densities [6]. The opportunity is that higher energy performance of buildings is an important prerequisite for future low temperature operation, as space heating in these new and refurbished buildings can be sufficiently supplied at lower temperatures.

Contemporary district heating system designs have developed around a norm of high temperature heat supply, originally supplied by fossil primary energy sources. As the societal norm steers towards the application of the precautionary principle to mitigate anthropogenic climate change, the availability of a high temperature heat supply from fossil-fuel sources will decrease. Other sources of high temperature heat supply, such as incineration of societal waste and biomass, are also expected to be less viable in a

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Nomenclature

3GDH	Third generation district heating
4GDH	Fourth generation district heating
4GDH-2P	Fourth generation district heating two-pipes
4GDH-3P	Fourth generation district heating three-pipes
CEN	Comité Européen de Normalisation
DOT	Design outdoor temperature, °C
EU	European Union
ICT	Information and communication technologies
LMTD	Logarithmic mean temperature difference for heat exchanger, °C
NTU	Number of heat transfer units for heat exchanger
SMHI	Swedish Meteorological and Hydrological Institute
A	Heat transfer surface area for heat exchanger, m^2
c_p	Specific heat capacity, J/kg, K
d_i	Inner pipe diameter, m
d_o	Outer pipe diameter, m
ε	Overall heat transfer effectiveness for heat exchanger
K	Overall heat transfer coefficient for heat exchanger, W/m^2, K
L	Trench length of pipes, m
λ	Friction factor
$\dot{m}$	Mass flow rate, kg/s
R	Heat capacity rate ratio for heat exchanger
ρ	Fluid density, kg/m^3
t_s	Supply temperature, °C
t_a	Average ambient temperature, °C
Δt_s	Specific supply temperature drop, °C/m
$\Delta t_{s\ drop}$	Supply temperature drop, °C
$\Delta t_{max\ hex}$	Max temperature difference for heat exchanger, °C
$\Delta t_{max\ s\text{-}a}$	Difference between the supply and ambient annual average outdoor temperatures, °C
$T_{balance}$	Building balance-point temperature, °C
T_{indoor}	Indoor temperature, °C
v	Flow velocity, m/s

long-term perspective. According to the EU waste hierarchy defined in Directive 2008/98/EC on waste [7], energy recovery through incineration is the least favoured option in waste management, when landfill bans are implemented for combustible and organic waste. Increased competition for biomass feedstock is expected because of the higher demand for purposes other than direct energy conversion, such as manufacturing of new materials and fuels for the transportation sector [8,9].

1.2. Opportunity

These expected changes prompt the development of a contemporary district heating system design to be better adapted to future conditions. The collective terminology for this development is fourth generation district heating (4GDH). The term was defined by Lund et al. [10]. The common denominator for 4GDH is lower system temperatures, with envisioned temperature levels of 50 °C in the supply pipe and 20 °C in the return pipe as annual averages. By adapting to the inaccessibility of a high temperature heat supply, the integration of a low temperature heat supply is the preferred option. These heat sources are associated with low variable costs and are mostly provided by renewable primary energy sources and recovery of excess heat. This emerging situation constitutes a major monetary opportunity for 4GDH. Furthermore, low temperature operation entails synergistic supply benefits from a system perspective as follows [10]:

(i) utilisation of more industrial excess heat becomes accessible,
(ii) utilisation of more geothermal heat becomes accessible,
(iii) utilisation of more heat from cooling processes becomes accessible,
(iv) solar thermal collectors operate at higher efficiencies,
(v) heat pumps utilise ambient heat sources with lower demand of electricity,
(vi) efficiency of flue gas condensation improves,
(vii) more electricity can be extracted from combined heat and power plants, and
(viii) heat losses in distribution networks decrease.

1.3. Current knowledge

Despite the well-known benefits of low temperature operation, literature study has provided no documented source identifying a district heating system with an annual average return temperature below 30 °C. One study included seven low temperature district heating networks, where the annual average return temperatures varied between 32 and 44 °C [11].

The heat supply transition towards lower temperatures and the end use transition towards lower heat demands have created a need for an enhanced distribution system design that facilitates low temperature operation. As future conditions presuppose low temperature operation, achieving low return temperatures has become essential. Well-functioning substations and secondary heating systems achieve low return temperatures [12]. A recent study indicates that three out of four customer substations displayed temperature errors [13]. Although an important topic, temperature errors are not the focus of this paper.

Concurrent research on low temperature operation has developed into several interesting topics. The subsequent paragraphs present a brief review of existing literature divided into five topics regarding district heating and low temperature to establish the novelty of the results presented in this paper. Low temperature district heating operation has been a part of the scientific discourse since at least the 1980s [14–17]. It also appears that interest in the subject among the scientific community has been invigorated during the 2010s.

The first topic focuses on the supply of low temperature heat sources and the benefits gained from them. Østergaard et al. assessed a scenario utilising a geothermal heat supply to achieve a fossil-fuel independent energy system [18]. The possibilities to utilise old mines as low temperature resources have been tested in the Netherlands [19]. Assessment of the system performance effects from the lower temperature levels regarding the supply originating from combined heat and power plants and heat pumps have been analysed in Ref. [20]. A study analyses different heat supply concepts for four cases in Austria [21]. Assessment comparing the supply by combined heat and power plants or heat pumps for low temperature and ultra-low temperature district heating is found in Ref. [22]. A detailed study assessed the heat supply with central heat pumps and decentralised booster heat