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Necessary Measures to Include more Distributed Renewable Energy Sources into District Heating System

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Abstract

Low temperature district heating (LTDH) can increase the integration of renewable and waste energy sources that have lots of reliability and acceptance issues. This article aims to identify necessary measures to enable connection of the distributed heat sources into the LTDH. An energy balance model for an area was developed on annual level. The heat supply model included a central plant and distributed plants. A multiobjective, genetic optimization was used. The results showed that the investment cost, electricity price, and heat pump performance influenced higher share of the distributed energy sources into the central district heating (DH) system. Further, bigger building area showed to be more suitable to export heat to the central DH system.

Keywords: *Low temperature district heating; Renewable energy sources; Distributed energy sources; Optimization*

Nomenclature

$Q\ (kWh)$	heat
$A\ (m^2)$	building area
$q\ (kWh/m^2)$	specific heat demand

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$p\ (-)$	percentage of a building type
$COP\ (-)$	coefficient of performance for a heat pump
$\dot{W}_C\ (kW)$	compressor power
$n\ (-)$	number of energy supply plants
$\tau\ (h)$	operation time
$q_{sol}\ (kWh/m^2)$	total specific annual solar irradiation
$A_{sol}\ (m^2)$	area of the solar collectors
$\eta\ (-)$	the average efficiency of the solar collector
$C(EUR)$	total cost
$c\ (EUR/kWh)$	specific cost per unit of energy
$f_{HP}\ (EUR/kW)$	specific investment cost for the heat pump
$f_{sol}\ (EUR/m^2)$	specific investment cost for the solar collectors per unit of area
Subscripts	
HP	heat pump
i	counting different building types
Tot,h	total heat demand
WH	waste heat
sol	solar
add.inv	additional investment

1. Introduction

Use of renewable energies and waste energy is highly necessary and required by national and international regulations [1]. Future district heating and cooling (DHC) systems will be based on completely renewable energies from solar, waste heat, and geothermal energy. This will imply that many distributed systems have to be available to deliver their heat to the central system as shown schematically in Fig. 1.

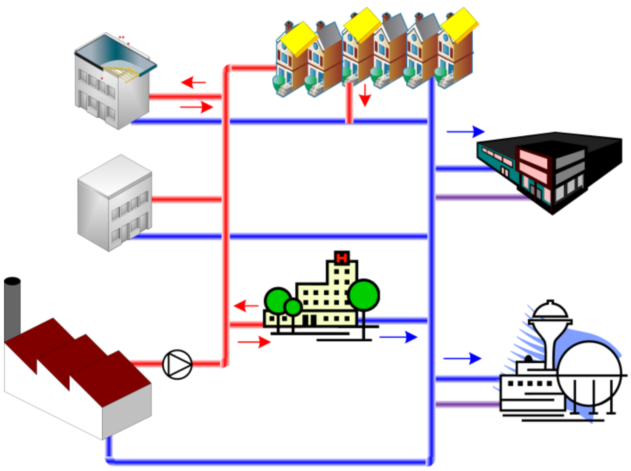

Fig. 1. Future DH system including distributed heat sources

For example building complexes may become a new district heating (DH) partner by exporting excess heat. To enable transition to the renewable energy society and secure energy supply for future development of society, integration of distributed energy systems is highly necessary. This will induce a new actor at the DH market called "prosumer" [2] that may be treated as third party access. A customer that both produces and consumes heat from DH is called prosumer. This concept offers great opportunities for successful utilization of solar heat into the DH and supports the transition to smart thermal grid. The concept of “prosumer” is already known from application in power sector [3, 4]. In the DH context, this will imply that customers may have possibility to deliver excess heat from distributed renewable energies (e.g. solar heat, heat pumps, and waste heat) to the DH network.

There are different approaches for the prosumer connections, depending on the DH network temperature level, delivered heat temperature level, and building requirements. Prosumer may deliver their heat into the supply or return line. Regarding, energy sources for the DH in the future, a thorough research on sustainable heat potentials at the European level shows that there is enough available heat, but policy measures are necessary for realization of all the potentials [5].

Low temperature district heating (LTDH) can substantially reduce total greenhouse gas emissions, increase reliability of the energy systems, enable transition to the renewable energy society, and secure energy supply for future development of society. LTDH can increase the integration of renewable and waste energy sources. However, renewable and waste energy sources have still lots of reliability and acceptance issues.

Nowadays datacenters need lots of cooling, while condensers of the cooling plants may provide heat for useful purpose. Integration of the excess heat may be done in the supply or in the return line of the DH system. Viborg DH in Denmark is an example where the surplus heat from the new Apple computer center will be rejected to the DH system. To provide heat for the DH system, high temperature heat pumps will be implemented, thus providing directly supply water for the DH system of approximately 55°C. To enable this, Viborg DH had a long-term plan for decreasing the DH temperature and distribution losses. Customers with the high temperature requirements will be grouped and provided with an additional heat pump for increasing the temperature level. In Trondheim, Norway, excess heat from cooling the datacenter at the university campus was utilized by connecting in the return line. The reason for this was currently high temperature level requirement for the existing buildings. To enable integration of the excess heat, the university campus separated from the main connection to the Trondheim DH by using heat exchangers and establishing own DH ring, see Fig. 2. In that way, it was possible to control the supply and return water temperature in the university DH ring and utilize excess heat from the datacenter. Proper control was enabled easily because university is property owner and has own maintenance service with a powerful building energy monitoring system for the entire campus. Currently, the excess heat may provide the base heat load in the range of 1 to 1.2 MW entire year.

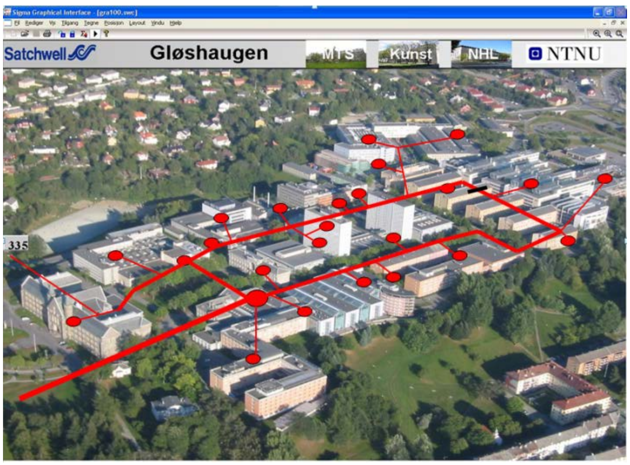

Fig. 2. Use of excess heat at NTNU in Trondheim, Norway [6]

In this study, possibilities and necessary measures to utilize more renewables from the distributed sources in DH system in Norway were analyzed. In the study, it was assumed that the distributed sources may be connected to the building area. Therefore, analysis of the area size and its possibility to deliver heat to the central DH was analyzed too. The objectives were to (i) identify the size of the building complex able to deliver heat to the DH system and (ii) identify the typical measures that may enable a higher share of renewables delivered by building complexes. The idea was that heat pumps, solar collectors, and waste heat recovery might be installed at different buildings and contribute to the DH system. An optimization analysis was carried out in order to determine the optimal size and amount of the heat sources with respect to DH cost, electricity cost, investment cost for these components, plant performance, and total heat demand. The aim was to get low cost for heating with a low investment cost at the same time. The optimization problem was hence defined as a multiobjective optimization problem with two objective functions: heat cost and investment cost.

The paper presents the international co-operative work in the framework of the International Energy Agency (IEA), the District Heating and Cooling including Combined Heat and Power (DHC|CHP) Annex TS1.

The article is organize as follows: first model for analysis of the DH system with distributed heat sources is presented. Potentials for heat interactions and analysis are given in the result section.

2. Methodology

To evaluate possibilities to utilize distributed heat sources at building complexes and their interaction to the DH system, a heat balance model for an imaginary building area with possibility for heat generation was developed. Since the aim of the study was to evaluate possibility and identify the most necessary measures in this new systems with distributed sources, the model was developed on annually basis.

For an imaginary building area, the total annual heat demand may be calculated as:

$$Q_{Tot,h} = \sum_i p_i \cdot q_i \cdot A \tag{1}$$

where p is the percentage of buildings of the certain type, q is the annual specific heat demand of the certain type, and A is the total building area. i is counting different building types.

In the case when heat pumps might produce heating and cooling for the buildings where they were located and in addition export heat to the DH grid, the total heat production from the heat pump over the year may be calculated as:

$$Q_{HP} = COP \cdot \dot{W}_C \cdot n_{HP} \cdot \tau_{HP} \tag{2}$$

where COP $(-)$ is coefficient of performance for the heating mode of the heat pump, $\dot{W}_C$ (kW) is the compressor power, n_{HP} $(-)$ is number of the heat pumps that might be installed in the imaginary area, and τ_{HP} (h) is the assumed operation time of the heat pump on the annual level. n_{HP} was calculated based on the number of office and commerical buildings at the area.

Heat provided from the solar collectors might be calculated as:

$$Q_{sol} = \eta \cdot q_{sol} \cdot A_{sol} \tag{3}$$

where q_{sol} (kWh/m^2) was total specific annual solar irradiation, A_{sol} (m^2) was area of the solar collectors, and η $(-)$ was the average efficiency of the solar collector.

In the future DH systems, all the heat has to come from the renewables, such as waste heat, solar, and geothermal. In that case the heat delivered from the central DH system can be expressed as:

$$Q_{dh,cen} = Q_{Tot,h} - Q_{HP} - Q_{WH} - Q_{sol} \tag{4}$$

In Equation (4), Q_{WH} (kWh) is available waste heat that might contribute to the DH system. The waste heat sources may be some industrial process or waste heat from high energy use buildings such as hospitals.

As explained before, the aim was to evaluate possibilities for a higher share of renewable energies into the DH system. Therefore, it was important to estimate additional cost for investment in the solar collectors and heat pumps as:

$$C_{add.inv} = f_{HP} \cdot COP \cdot \dot{W}_C \cdot n_{HP} + f_{sol} \cdot A_{sol} \tag{5}$$

where f_{HP} (EUR/kW) was the investment cost for the heat pump based on the condenser capacity and f_{sol} (EUR/m^2) was the investment for the solar collectors per unit of area. The total heat cost for such DH system was calculated as:

$$C_{heat} = c_{dh} \cdot Q_{dh,cen} + c_{el} \cdot \dot{W}_C \cdot n_{HP} \cdot \tau_{HP} + c_{wh} \cdot Q_{WH} \quad (6)$$

where c_{dh} (EUR/kWh) was district heating price, c_{el} (EUR/kWh) was electricty price, and c_{wh} (EUR/kWh) was waste heat price. The specific heat cost for heat was calculated as:

$$c_{heat} = C_{heat}/Q_{Tot,h} \quad (7)$$

The total cost for the heat and additional investment was:

$$C_{tot} = C_{add.inv} + C_{heat} \quad (8)$$

The total specific cost for heat was calculated as:

$$c_{tot} = C_{tot}/Q_{Tot,h} \quad (9)$$

To evaluate possibilities for a higher share of renewable energies into the DH system, the objective was to decrease heat production from the central DH system, while the total specific heat cost had to be low. Therefore, the optimization problem was defined as a multiobjective problem, where the objective function was defined as:

$$min\ (Q_{dh,cen}, c_{tot}) \quad (10)$$

where the optimization parameters were: $\dot{W}_C$, compressor power, n_{HP}, number of the heat pumps, Q_{WH}, available waste heat, and A_{sol} area of the solar collectors.

3. Results

Before the results are presented, the model and optimization input are introduced. Possible plant size, plant performance, and heat demand were assumed based on the literature review and statistical data. In this analysis, a building structure with high percentage of residential buildings was analyzed. Finally, the optimization results and the necessary measure analysis for different size of the area are given.

3.1. Model and optimization input

In this study, an imaginary area was assumed with four different building types: residential, multipurpose, office, and high energy use buildings. The high energy use buildings presented buildings such as hospitals or sport centers. Based on the national building energy use statistics and residential energy use [7], the specific heating use was defined for each building type and is given in Table 1. Specific heat demand was defined as 70 % of the total energy demand. This is a usual assumption for the Norwegian conditions.

Table 1. Building heat demand and area structure

Building type	Specific heat demand (kWh/m^2)	Building area structure
Residential buildings	119	66 %
Multipurpose buildings	154	20 %
Office buildings	140	12 %
High energy use buildings	280	2 %

A building complex may consist of different percentage of the above mentioned building types. Based on the

Norwegian statistics on the building stock [8], the building stock should have the structure as given in Table 1. This building structure presented a typical situation in a town with lots of residential buildings.

The other model input parameters are given in Table 2. These parameters were based on annual average values, because the introduced model was based on annual calculation.

Table 2. Model inputs

Parameter name and unit	Value
Heat pump operation time, τ_{HP} (h)	3 000
COP of the heat pumps, COP (-)	3
Total specific annual solar irradiation, q_{sol} (kWh/m^2)	400
Average efficiency of the solar collector, η $(-)$	0.75
Investment cost for the heat pump, f_{HP} (EUR/kW)	500 [9]
Investment for the solar collectors, f_{sol} (EUR/m^2)	300 [10]
District heating price, c_{dh} (EUR/kWh)	0.08
Electricity price, c_{el} (EUR/kWh)	0.1
Waste heat price, c_{wh} (EUR/kWh)	$0.3 \cdot c_{dh}$

The parameter values in Table 2 were defined based on the literature review in [9] and data for solar thermal collectors [10]. District heating and electricity price were assumed for the Norwegian conditions. The price for the waste heat was assumed, since still there is no clear indication on the price level for the waste heat.

In order to define an optimization problem, it is necessary to define the upper and lower bounds for the optimization parameters. In this study, the upper and lower bounds were defined based on the previous analysis of the energy supply plants within the research project Interact [11] and possibility to install solar collectors. Regarding possibility for the heat export from the heat pumps, it was assumed that the office, multipurpose, and high energy use buildings might have possibility to install big heat pumps and export heat when relevant. Based on the analysis of the energy supply plants, the installed compressor rate for the heat pumps was between 150 to 450 kW. To estimate potential number of the heat pumps, it was assumed that these buildings could have an average area of 10 000 m^2. By dividing the total area of the mentioned buildings, potential number of installed heat pumps was obtained. Consequently, the lower and upper bounds for the number of heat pumps were defined to be from 3 to 50. Regarding possibility for the solar collector area, it was assumed that the office, multipurpose, and high energy use buildings might get installed solar collectors on the roof. In the case that average building height is three floors, the potential area for installing solar collector was three times lower than the total building area. The lower and upper bounds for the solar collector area were defined to be from 1 000 to 11 000 m^2.

3.2. Possibility of building complex to deliver heat to the DH system

Firstly, an analysis on how different building area size influence amount of delivered heat to the central DH system is presented. Since building complexes may have different size as shown in [11], building area sizes from 20 000 to 100 000 m^2 were analyzed. In this analysis where the building complex interact with the central DH, it was assumed that only business related buildings might export heat to the central DH system. Regarding number of the heat pumps, it was assumed that on each 10 000 m^2 of this type of buildings, one heat pump of 100 kW compressor power would be installed.

Regarding size of the solar collector area, it was assumed that the area was three times lower than the total building area of this type. Based on these assumptions, the possible amount of heat to be delivered to the central DH system was estimated for different building complex size as shown in Fig. 3.

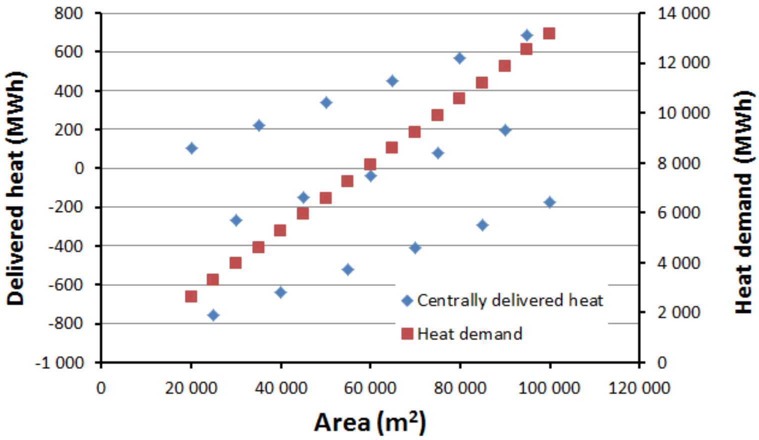

Fig. 3. Possibilities of different building area structure to interact with the central DH system

The possible amount of heat that might be delivered to the central DH system in Fig. 3 vary a lot depending of the area size. The reason for this was that one heat pump came on each 10 000 m^2 of business related buildings, and in the model the number of heat pump was a round number. Also, size of the solar collectors was related to the size of the business related buildings. Due to the high share of the residential buildings that were not contributing to the central DH system, just using directly the DH heat, amount of heat was varying depending on the business related building sizes e.g. their possibility to produce excess heat for the central DH system. In the case, when in a building complex business buildings dominated, a building complex might deliver much more heat to the central DH system than itself might have need for heat. In that case there is no so big variation in the delivered heat. The situation with a high percent of business buildings is not presented in Fig. 3. The results in Fig. 3 show that the bigger the building complex, more excess heat might be produced. This meant that a building complex might be an active prosumer and deliver lots of renewable heat to the central DH system for the Norwegian conditions. In addition, due to this high amount of heat, daily and annual heat storage systems would be necessary.

Based on the heat amount that might be provided from the building complexes, further analysis on the specific heat cost and total specific cost was performed as shown in Fig. 4.

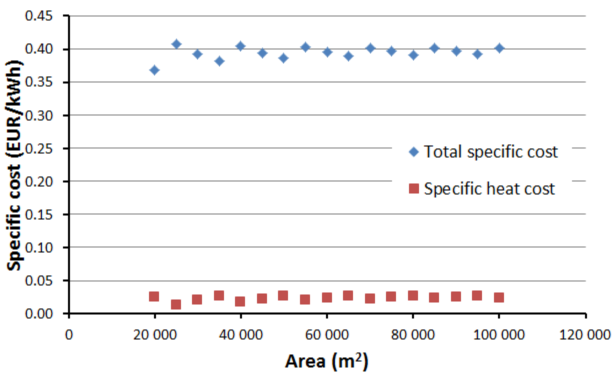

Fig. 4. Specific heat and total investment cost

To recall, the total specific cost included the additional investment for the heat pumps and solar collectors and heat cost. The results in Fig. 4 shows that the total specific cost in the area with the high share of residential buildings might achieve values lower than 0.05 EUR/kWh, which is the DH price for the solar DH, SDH Solar

District Heating [12]. This meant that the solution to utilize heat from the business buildings resulted in a very favorable DH cost.

3.3. Optimization results and measure analysis

The multiobjective optimizations were performed for the building area of 20 000 m^2 and 100 000 m^2 and for building area structure with the high share of residential buildings. To recall, the objectives were to decrease the amount of heat centrally delivered and to decrease the total specific cost. The Pareto frontiers for the mentioned building areas are given in Fig. 5. The optimal solutions may be chosen from the entire range of the Pareto frontiers. In this study, it was chosen that the optimal solutions are those where the total specific cost is the lowest. This meant that the total energy cost and additional investment per kWh of heat were the lowest.

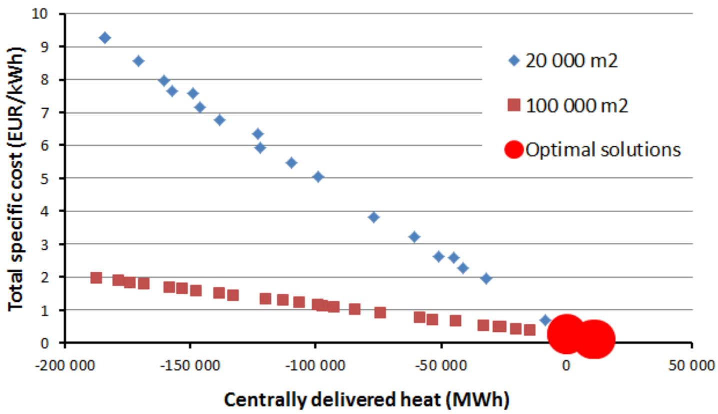

Fig. 5. Optimization results for small and big building complex area

When observing the Pareto frontiers in Fig. 5 for different size of the building area, it may be concluded that the bigger area had much higher possibility to produce heat with lower cost. For smaller area the investments for the heat pumps and solar collectors were high compared to the provided heat. It is interesting to note, that the optimal solution for the 100 000 m^2 area was still using about 10 GWh of the DH heat centrally delivered. The reason was that use of centrally delivered heat was still cheaper than use of the heat from the heat pump and solar collectors. The big area may become a big heat prosumer, but with the current prices, see Table 2, it was still not completely favorable.

To evaluate and suggest which measures might help to a higher share of renewables, a few scenarios with different measures were suggested. Firstly, measures to promote a single technology such as solar collectors or heat pump were suggested. Finally, a combination with different energy price, investment cost, and higher heat pump performance was suggested as the final measure, called “All the measures”. The reason to decrease the investment cost for the renewable energy technologies was that usually the cost should be lower in the future when the technologies are well established. In addition, to promote a higher use of renewables, many governments give support for the investment. Performance of a heat pump may be significantly improved if a proper heat pump is chosen for the observed load and if the temperature levels for heating and cooling are favorable. In the case of LTDH, the temperature in the DH network will become lower, enabling that the heat pumps might achieve a good average COP values. In addition, cooling loads in office buildings and data centers is usually stable over the year, allowing good operation conditions for the heat pumps between the cooling load and the LTDH network. The final measure combined all the benefits of low investment and high performance, but considered a higher electricity price in the future. A summary of the scenarios are given in Table 3.

Table 3. Measures to enable a higher share of renewables into DH

Scenario	Brief description
As input data	See Table 2
Lower investment for solar	$f_{sol} = 150\ EUR/m^2$
Heat pump advantage	COP = 4 $f_{HP} = 300\ EUR/kW$
All the measures	COP = 4 $f_{HP} = 300\ EUR/kW$ $f_{sol} = 150\ EUR/m^2$ $c_{el} = 0.15\ EUR/kWh$ $c_{wh} = 0.2 \cdot c_{dh}$

The results how the suggested measures (see Table 2) could help a higher penetration of the renewable energies into the distributed DH system are given in Fig. 6 for the 20 000 m^2 building area and in Fig. 7 for the 100 000 m^2 building area. Figs. 6 and 7 show the Pareto frontiers when the above measures were included.

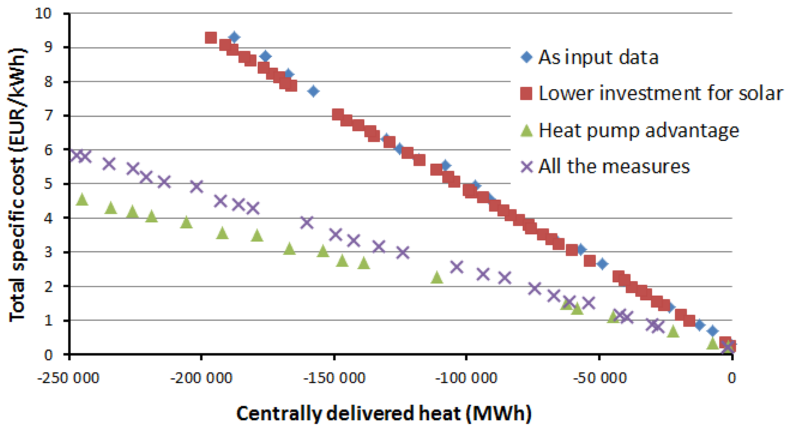

Fig. 6. Results of the measures implementation in the 20 000 m^2 building area

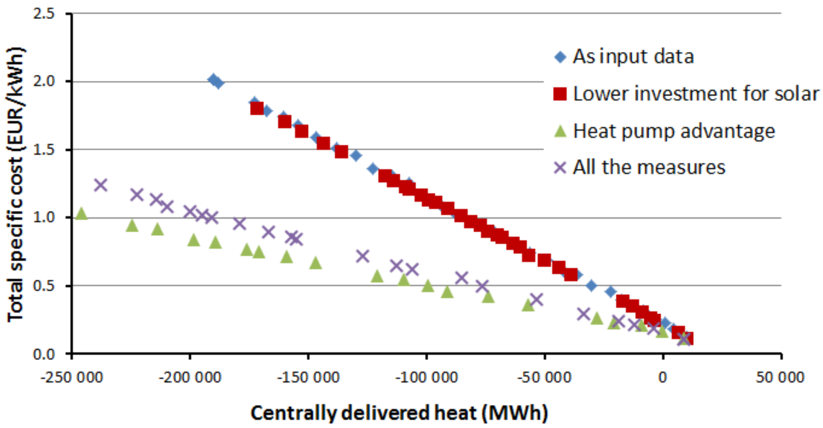

Fig. 7. Results of the measures implementation in the 100 000 m^2 building area

The results in Figs. 6 and 7 show that when only solar collectors would be cheaper for 50 %, the total specific heat cost would not be much lower. This means that a solely measure to enable cheaper solar collectors would not help a higher share of renewables for the Norwegian conditions. The second measure, where the heat pump performance was better together with the lower investment cost, gave much faster decrease of the total specific heat cost. The final measure, combining different measures, would not give significant decrease in the total specific heat cost as the measure with the heat pump. The conclusion from Figs. 6 and 7 is that better performance of the heat pump and lower investment cost may enable a higher share of the renewables from the prosumers. These prosumers were related to the building complexes. By comparing the results in Figs. 6 and 7, it may be concluded that the total specific heat cost is again lower for the bigger area, see Fig. 7, than for the small area. This means that the bigger area or building complexes should be considered as an active prosumer or a new partner to the central DH system.

4. Conclusion

The aim of the study was to identify some of the necessary measures to enable easier connection of the distributed heat sources such as solar and waste heat. Different sizes of building area including a high share of residential buildings were analyzed for the Norwegian conditions.

The energy balance model for the heat supply and demand on annual level was developed. The model was used for the optimization. Since the simple heat balance model was developed, heat storages were not considered in this study. Implementation of the heat storage may also increase the total specific cost.

The results showed that the building complexes might deliver a substantial amount of heat to the central DH system. The bigger the building area, the more heat might delivered. Sensitivity analysis of the results showed that the bigger area was less sensitive in the change of the parameters. All these meant that the big building complexes should be considered as an active prosumer or a new partner to the central DH system in the future.

For the current economic conditions, it was still favorable to use a big part of the heat from the central DH plant. By analyzing different measures to enable a higher share of the renewables into the DH system, it was found out that lower investment and better performance of the heat pump gave the best results and the fastest decrease of the total specific cost. The increase in the heat pump performance might be easily achieved in the LTDH, because the temperature in the DH network will become lower, enabling lower temperature rise for the heat pump. In addition, cooling loads in office buildings and data centers is usually stable over the year, allowing good operation conditions for the heat pumps between the cooling load and the LTDH network.

Future work should consider development of energy prices and operation issues to enable reliable heat delivery from renewables in the future.

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