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# Possibilities for Transition of Existing Residential Buildings to Low Temperature District Heating System in Norway

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**Abstract**
*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. To enable successful transition to the LTDH, existing buildings need to undergo certain changes. Most of the existing residential buildings have heating systems based on the high and medium temperature level. Therefore, the aim of this study was to analyze the possibilities and challenges of introducing fourth generation district heating, also known as LTDH. Based on the building statistics in Norway, an end terrace house built before 1980 with a heating system consisting of only high temperature radiators was selected as a reference dwelling for the analysis. The analysis was extended with the dwelling built as the low energy and the passive house standard. Models were developed in IDA-ICE. The analyses were performed for different heating system sizes, energy efficiency scenarios, and control strategies. The most important conclusions were that the existing buildings, built before 1980, might be connected to the LTDH as long as sufficient heat was delivered. This means that the DH supply temperature could already be lowered outside the coldest periods. Even with the ambitious scenario for the residential building development, the total heat demand would decrease by about 18 % in 2050 compared to the current heat demand. This means that the DH would be still be needed in 2050.*

***Keywords - district heating system, residential buildings, low temperature system, control, energy efficiency measures***

## 1. Introduction

Requirements on energy demand for new residential buildings in Norway are becoming stricter as a measure to reduce $CO_2$ emissions. To meet these requirements, the use of renewable heating sources must be increased. District heating (DH) is viewed as one of the main alternatives, because it enables the use of varied energy sources in a faster and cheaper way than local solutions. However, as new buildings are being built to high standards with reduced space heating (SpH) demands, the demand density in the DH network is decreasing. The percentage of distribution heat losses is increasing. This means that delivering renewable heat is not efficient with today's DH systems [1]. To achieve this, a number of changes should be implemented, one of the most important is reduction of distribution temperatures from 80-120°C to 50-55°C [2]. This will reduce the heat losses and simultaneously enable the use of renewable low temperature energy sources; waste heat, solar, and geothermal heat among others [3].

The SpH system should be able to maintain the desired indoor temperature. The use of low temperature DH (LTDH) in combination with the low energy buildings is able to meet these requirements. However, the long life span of buildings means that the low energy buildings will only represent a small share of the total building stock for many years to come, so the main concern should be on the existing buildings. In older buildings the SpH systems are generally designed for the temperatures above 80°C. The SpH demand is also higher, especially if no significant improvement of the building envelope has been made since their construction. If the temperature in DH distribution is reduced, the heat output from these heating systems will also be reduced. This may cause discomfort. However, most existing buildings have undergone some refurbishment, the most common being replacement of windows. In addition, the existing SpH systems are oversized in many buildings, because designers want to feel confident that the solutions are reliable. In addition, the sizes of the installed radiators are standardized, while calculated values might be between two standardized values. This oversizing is in the region of 20-30 % [4] and provides the opportunity to reduce the distribution temperatures.

Another main reason for relatively high temperature levels in the DH system throughout the year is the temperature requirement for domestic hot water (DHW). In Norway, the requirements for DHW is 60°C at the tap and 70°C in storage tanks [5]. This is to avoid the spread and growth of Legionella bacteria, which mainly occurs in the temperature range of 20-50°C. According to Danish Standard the temperature of water used for personal hygiene should be able to reach 40°C, and water used for kitchen appliances should reach a minimum of 45°C [6]. This is reachable at a DH distribution temperature of 50-55°C. According to CEN/TR 16355 there is no temperature requirement, if the stored volume is below 3 litres, excluding volume of the heat exchanger, or if there is no circulation of hot water. In modern residential buildings connected to LTDH, this will likely be the case. In larger buildings, storage or circulation of water may be needed, but in this case there are multiple solutions to avoid the growth of bacteria. Thermal disinfection is a widely used and effective technique, but requires an additional heat source and is prone to clogging and may cause corrosion of the pipes [7-9]. Another alternative is UV radiation, which is effective and has very few negative effects, but has high installation and maintenance costs [10]. There are also numerous chemical treatments and ultrafiltration methods. However, the Norwegian Institute of Public Health requires better documentation if these methods are to be recommended instead of the temperature requirements of today.

Until now, several LTDH projects have been successfully realized. Some conclusions and the most important characteristics are explained. Seven low energy apartment buildings in Lystrup, Denmark, have been connected to the LTDH in an attempt to reduce distribution losses. This is done by reducing pipeline dimensions, setting the distribution temperature to 55°C, and using twin pipes. Booster pumps which raise the pressure in the area allows further reduction of the pipeline dimensions. For connection with the LTDH, storage tanks or high heat output heat exchangers are used. The use of DH storage tanks makes it possible to reduce the pipeline dimension as it reduces the peak demand. The total costs and benefits of these two alternatives are roughly the same, and both are viable solutions. The result is a reduction of energy use of 75 % compared to the traditional DH systems [11]. In Albertslund, Denmark, LTDH has been introduced for 1544 refurbished houses from the 1960's. The distribution network for DH was replaced by twin piping laid in shorter routes, and the houses were completely renovated to a standard close to today's low energy regulations. The houses were fitted with individual heat exchangers for instant heating of DHW. This design requires a higher peak power from the DH network, but eliminates the need for storage tanks. It is expected that this solution will result in a 62 % reduction in distribution heat loss. This is achieved at an extra cost of 20 million DKK and will result in a profit of 31 million DKK over the project lifetime of 50 years [12]. In Chalvey, England, a small scale LTDH network has been constructed, supplying ten zero emission houses. The houses are equipped with photovoltaics to cover their electricity demand, while DH covers the heat demand. Each house is equipped with a heat exchanger for DHW. Heat is produced using biomass, air to water heat pump, two ground heat pumps, and 20 $m^2$ of solar collectors. The DH central contains a large storage tank to cover peak load and increases the flexibility of the system. Heat production is optimized for a low temperature system of 55°C and the LTDH is completely based on renewable energies [13]. In all these examples, the introduction of the LTDH has produced good results when it comes to distribution loss savings, low temperature heat production, and customer satisfaction.

This paper investigates the possibility for transition of existing residential buildings to LTDH in Norway. The aim was to identify conditions and measures necessary for the transition of the existing buildings to the LTDH. The results in this paper are based on [14].

## 2. Methods

For investigation, a reference building that is a typical two-storey, three-bedroom, single-family house built before 1980, with an area of 122.2 $m^2$ was chosen, see Fig. 1. The unit is located at the end of a terraced building to represent the worst-case scenario. Since 50-65 % of residential buildings in Norway were built before 1980 [15], the aim was to resemble the most common building type in Norway. In addition, older buildings are expected to be the most challenging when transitioning to the LTDH due to high SpH demands and high temperature requirements. A multi-zone model of the building was developed in IDA-ICE 4.6.2 [16], and Climate data for Oslo, Norway, were used.

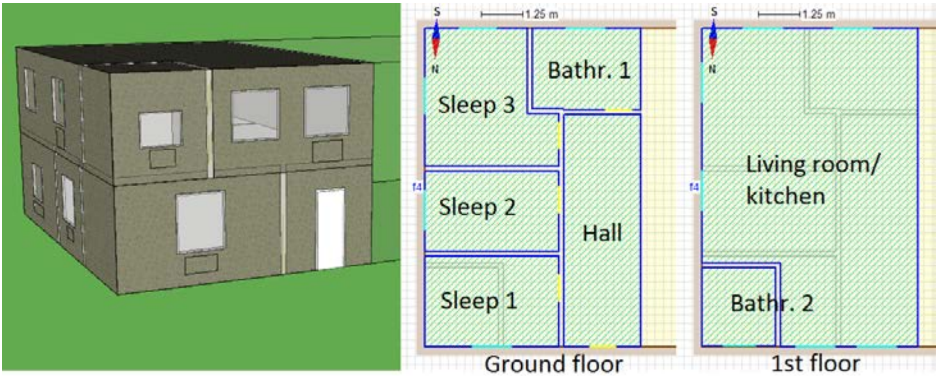



Fig. 1. Residential building

To calibrate the energy use of the reference building in Fig. 1, data from the Norwegian Energy Efficiency Agency, Enova, [17], statistical data, and standards were used. For buildings built around 1969, the average total specific energy use was 178 kWh/$m^2$ [18]. Radiators were chosen as the heating system in the reference building. This was the most common solution in houses built in this period, with temperature levels of 80/60°C [19]. Based on NS3031 [20], the SpH system was designed for an desired temperature of 21/19°C in occupied/non-occupied hours during the coldest period of the year. The sizing was done with a night setback of 2°C between 23:00 and 07:00 with a two-hour pre-heating period. The internal gains and electrical appliances were modelled based on the standard values [21] and to achieve an average energy use for electrical appliances of 25 kWh/$m^2$ [22].

After the model was calibrated for the reference energy use of the existing buildings, different supply temperatures were tested. Finally, the model was extended to include the following measures and scenarios:

- Measure 1: replacement of windows, which included decrease in the infiltration rate of the building.
- Measure 2: in addition to changing the windows, extra insulation of the walls was included.
- Measure 3: adding extra insulation to the roof, as well as insulating the walls and installing new windows.
- TEK10: is the Norwegian national regulation and poses the building energy requirement equal to the low energy building requirement [23].
- Passive house standard: the model was extended based on the Norwegian passive house standard requirements [24].

A brief summary of the building properties for Measures 1 to 3 are given in Table 1. The last two scenarios were included to illustrate how a transition to LTDH would affect the SpH system of modern buildings. The SpH systems in these buildings were designed at 60/40 °C according to their respective SpH demands. Finally, three different levels of oversizing and additional temperature levels were tested.

Table 1. Building properties before and after renovation

| Component | Value | After renovation |
|---|---|---|
| Window and door area per GFA (%) | 15 | 15 |
| U-value, walls (W/m$^2$K) | 0.5 | 0.22 |
| U-value, roof (W/m$^2$K) | 0.4 | 0.2 |
| U-value floor (W/m$^2$K) | 0.4 | 0.4 |
| U-value, windows (W/m$^2$K) | 2.8 | 1.2 |
| U-value, door (W/m$^2$K) | 2.00 | 2.00 |
| Thermal bridges (W/m·K) | Included in U-values | Included in U-values |
| Infiltration (ACH/air changes/h) | 4 | 3.4 |

## 3. Results

### 3.1. Sizing the SpH system

Based on the design weather data for Oslo, the necessary SpH demand for the reference building was defined. The total heat demand was found to be 5.17 kW for the reference building introduced in Fig. 1 and calibrated based on the statistical data. When the sizing was performed without a night setback, the required heat rate was 5.5 % lower than in the case of the night setback. This meant that the night setback oversized the SpH system. The radiators were designed to match the required heat output at temperature levels of 80/60°C. The resulting installed heat capacity was 5.33 kW. The SH systems in the buildings of TEK10 and passive house standard were designed in a similar way. The resulting installed heat capacities were 2.71 kW and 2.24 kW for the TEK10 and passive house, respectively. The oversizing of the SpH system was 3 % for the TEK10 house and 1 % for the passive house, due to the night setbacks.

### 3.2. Performance of LTDH in existing buildings

To assess the performance of the heating system and its ability to cover the heating demand of the building at reduced supply temperatures, dynamic simulations for an entire year were performed.

By reducing the DH supply temperature, the maximum temperature for DHW production was decreased too. This had a direct impact on the energy use, as the volumetric use of DHW did not increase as a result of the reduced temperature. Lowering the DHW temperature from 70°C to 50°C reduced the energy use for the DHW by 30.8 %. To enable this, storage for DHW must be avoided, or water treatment should be included as described in Introduction. The total energy demands for the different scenarios are shown in Fig. 2. By performing an extensive renovation of the reference building with Measure 3, the heating use was decreased by 42.5 %. This brought it close to the performance of the TEK10 building. The TEK10 building had a total energy use higher than that of the reference building with Measure 2 or 3, because there was no mechanical ventilation in the reference building. However, the $CO_2$ levels did not indicate a need for ventilation in this building.

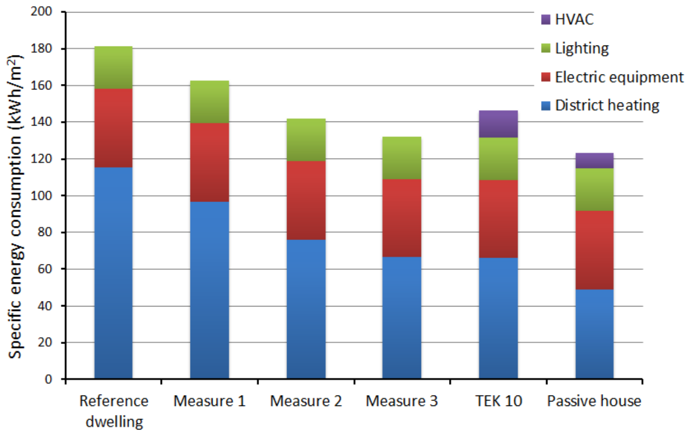
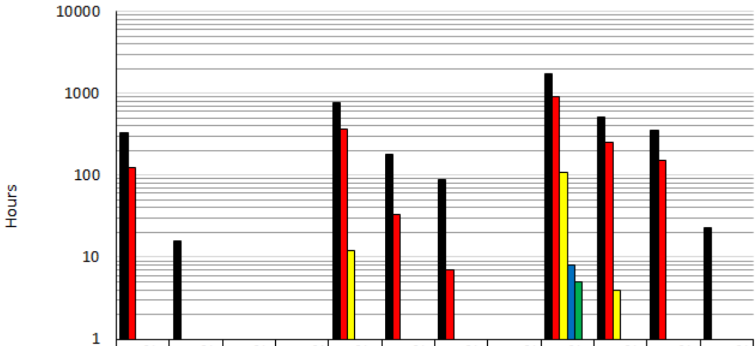


Fig. 2. Total energy demand of residential building in Norway

To estimate the performance of the LTDH in the existing and new buildings, the number of hours when the SpH system was unable to cover the heating demand in one or more zones throughout the year was estimated. This analysis was done for all the scenarios, including different DH supply temperatures and degrees of oversizing of the SpH system. The results are summed up in Fig. 3. Since all the combinations of oversizing and scenarios were able to cover the demand at 80°C of the supply temperature, these results are not included in Fig. 3. Please note that the vertical axis is logarithmic, to improve readability.

From Fig. 3, it might be concluded that the acceptable indoor temperature could be achieved throughout a year with the LTDH, because the deficiency occurred outside occupied hours and the total number of hours with lower indoor temperature was low. It can also be seen in Fig. 3 that the reference building without oversizing the SpH system was unable to meet the SpH demand at DH supply temperatures lower than 80°C. The LTDH with the supply temperatures of 60°C and 55°C could be possible through implementation of Measure 2, and even with 50°C with Measure 3. Duration curves for these scenarios are given in Fig. 4. It can be seen that the peak demand is significantly reduced through introduction of the different refurbishment measures. This will, in addition to reducing the energy use, reduce the total demand and make it possible to supply a larger number of buildings. In the TEK10 and passive house buildings, a supply temperature of 50°C was acceptable without any oversizing of the SpH system. The SpH systems in these buildings were already designed for low temperatures and the SpH demands were very low. With a 30 % oversizing of the SpH system, the supply temperature could be reduced to 60°C in the reference building. If Measure 1 was implemented, it would be possible to further reduce the DH supply temperature to 55 °C. In most buildings from this period, the windows would be already replaced at some point due to the fact that normal lifetime for windows is approximately 30 years. If Measure 2 was implemented, a supply temperature of 50°C would be sufficient to cover the heating demand.




| | 0 % 60 °C | 30 % 60 °C | 50 % 60 °C | 100 % 60 °C | 0 % 55 °C | 30 % 55 °C | 50 % 55 °C | 100 % 55 °C | 0 % 50 °C | 30 % 50 °C | 50 % 50 °C | 100 % 50 °C |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Reference building | 329 | 16 | 0 | 0 | 767 | 181 | 88 | 0 | 1750 | 513 | 358 | 23 |
| Measure 1 | 122 | 0 | 0 | 0 | 368 | 33 | 7 | 0 | 921 | 250 | 153 | 0 |
| Measure 2 | 0 | 0 | 0 | 0 | 12 | 0 | 0 | 0 | 109 | 4 | 0 | 0 |
| Measure 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 8 | 0 | 0 | 0 |
| TEK10 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 5 | 0 | 0 | 0 |
| Passive house | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

Reference building · Measure 1 · Measure 2 · Measure 3 · TEK10 · Passive house

Fig. 3. Number of hours during a year when indoor temperature of 21°C was not achieved

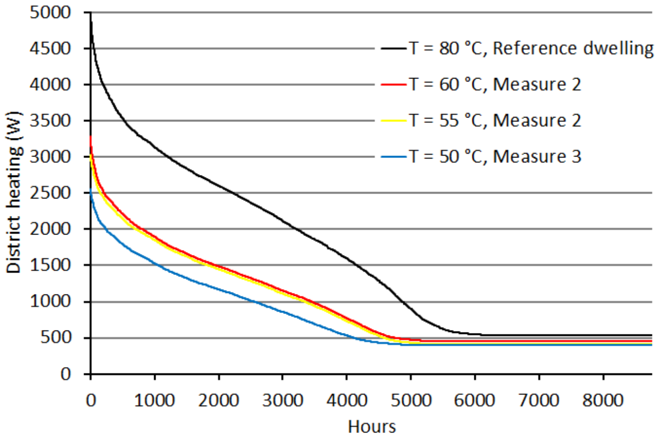



Fig. 4. Heating duration curves for LTDH without oversizing of SpH system

At 50 % oversizing, the same DH supply temperatures were required as with a 30 % oversizing and the number of hours with lower indoor temperature was reduced. An oversizing of 100 % enabled a reduction of the DH supply temperatures to 50°C for all the scenarios. To investigate the possibilities of reducing the DH supply temperature in the reference building with a 30 % oversized SpH system, influence of water mass flow rate on the radiator performance was estimated. Since a DH temperature of 60°C was already possible in this case, see Fig. 3, the effects of increasing the mass flow to enable a DH temperature of 55°C were estimated. It was found that the mass flow rate should be increased by 150 % (from 292 l/h to 438 l/h) to reduce the number of hours with insufficient heating to an acceptable level (from 181 hours to 30 hours). This would only slightly increase heat demand, from 105.7 to 107.4 kWh/m$^2$. This measure may be easily achievable, depending on radiator and piping capacity.

## 4. Discussion

It is worth noting that users of homes with a proportional heat price model in general choose indoor temperature that is almost 1-2°C higher than the users with the individual heat meters. Inhabitants in a passive house project in Norway were also found to choose the indoor temperature of 22-25°C [25]. If a higher indoor temperature of 23°C was used, the number of hours when the indoor temperature was not achieved increased. In that case, Measure 2 was necessary to enable the supply temperature of 60 or 55°C together with 30 % oversizing of the SpH system. Measure 3 could work properly at the supply temperature of 50°C. Hence, if the SpH system is designed for the indoor temperature of 21°C, it may not be able to cover the heating demand at a higher temperature of 23°C. Influence of natural ventilation through windows in the evenings was also analyzed, because it is a common habit in Norway. In all the cases, with 15 minutes of window ventilation every evening, an increase of 1.1 - 1.4 kWh/m$^2$ per year would appear in addition to an increase in the number of hours with a heating deficiency. The effects were greatest in the reference building, where the SpH system took longer time to raise the temperature after ventilation.

Based on the Norwegian building statistics of the current residential building stock and forecasts for the residential building development in Norway found in [26], an analysis on development of the heating demand until 2050 was made. This was a further analysis the results were combined with a forecast model. Based on the current statistics, there are 61.7 % of older buildings similar to the reference building, 35.1 % of intermediate buildings similar to renovated buildings, and 3.1 % of TEK10, and 0.1 % of passive houses. Linear models for the building stock development were assumed based on [26], where the growth rate for new buildings is 1.33, renovation rate is 1.5, and demolition rate is 0.6. In this study, an imaginary area presenting the current Norwegian residential building stock with a heat demand of 80 MW was introduced. By using the results on the heat demand, explained in Section 3 and linear models for the building stock development, a projection of the current and future heat demand in 2050 was obtained as shown in Fig. 5. In addition, Fig. 5 gives heat demand in the case of ambitious and conservative development of the building stock. A change of ± 20 % deviation of the normal development was introduced to produce ambitious and conservative development, respectively.

From Fig. 5 it may be concluded that even with the ambitious scenario for the residential building development, the total heat demand would decrease by about 18 % in 2050 compared to the current heat demand.

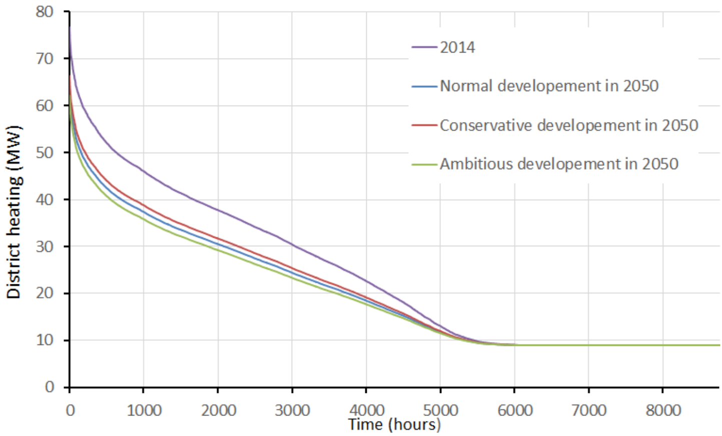



Fig. 5. Heat demand development for the residential building stock in Norway

This means that the DH would be still needed for most of the buildings in 2050. Based on this, the LTDH would be a promising heat technology in 2050. It should also be noted that in Fig. 5, increase of the building numbers was not counted, which could increase the total heat demand.

## 5. Conclusion

The results show that a typical terraced home built before 1980, without any oversizing of the SpH system, could be heated to 21°C approximately 80 % of the year by LTDH at 50°C. If the SpH system is oversized by 30 %, this share increases to 94 %. To cover the heating demand for the rest of the year, the DH supply temperature should be raised to nearly 80°C and 60°C for the cases of no and 30 % oversizing, respectively. Further, increase in mass flow rate would also allow achieving desired indoor temperature over the year. This might be achieved by adjustment at the radiator valve. Many buildings have already been renovated, the most common measures being replacement of windows. This means that the actual heating demand in many existing buildings should be lower than that of the reference building. In this case, the non-oversized SpH system was able to cover the heating demand 89.5 % of the year, and the DH supply temperature should be raised above 60°C only in the coldest periods. For buildings built by TEK10 or passive house standards, the transition to LTDH is easily possible without any additional measure.

Before LTDH can be implemented in the Norwegian DH networks, some challenges should be addressed. The most important is to ensure a safe production of DHW even at low supply temperatures. This may require installation of additional water treatment equipment and, if necessary, replacement of heat exchangers to cover the high momentary loads for direct DHW production. It is shown that the transition of existing buildings to LTDH is possible, but that it may require extra investments in substations or building renovation. This means that the DH supply temperature could already be lowered outside the coldest periods. A reduction of the peak heating demand in existing buildings would ease the transition to LTDH, and reduce the need to increase the supply temperature periodically. Finally, it might be concluded that the LTDH would be a necessary technology for building heating in the future and enable transition to the renewable energy society.

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