# Delivery no. 5.2 b:

# Analysis of the potential for storing heat in district heating pipelines


*Photo: By &Havn / Ole Malling*


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**Public deliverable** ☒

**Confidential deliverable** ☐

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# Preface

*EnergyLab Nordhavn – New Urban Energy Infrastructures* is an extensive project, which will continue until the year of 2019. The project will use Copenhagen's Nordhavn as a full-scale smart city energy lab, with the main purpose to do research and to develop and demonstrate future energy solutions of renewable energy.

The goal is to identify the most cost-effective smart energy system, which can contribute to the major climate challenges the world are facing.

Budget: The project has a total budget of MDKK 143 (M€ 19), of this MDKK 84 (M€ 11) funded in two rounds by the Danish Energy Technology Development and Demonstration Programme (EUDP).

# Forord

*EnergyLab Nordhavn* er et omfattende projekt, der løber til og med marts 2019. Projektet udføres i Københavns Nordhavn, der fungerer som et fuldskala storbylaboratorium, der skal undersøge, udvikle og demonstrere løsninger for fremtidens energisystem.

Målet er at finde fremtidens mest omkostningseffektive energisystem, der desuden kan bidrage til at finde en løsning på de store klimaudfordringer, verden står overfor nu og i fremtiden.

Budget: Projektets totale budget er DKK 143 mio. (EUR 19 mio.), hvoraf DKK 84 mio. (EUR 11 mio.) er blevet finansieret af Energiteknologisk Udviklings- og Demonstrationsprogram, EUDP.

## Project Information

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|---|---|
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# 1 Introduction and background

## 1.1 Introduction

Energy flexibility and the possibility of decoupling energy use from energy generation become increasingly important in energy systems relying on fluctuating renewable energy sources. Energy storage in the district heating system can absorb large amounts of energy, also transformed from electrical energy, over several days or even weeks. This is in contrast to e.g. electric vehicles and flexible consumption of electric appliances (refrigerators, freezers, etc.). Heat may be stored in dedicated heat storages or in the pipelines by temporarily increasing the forward temperature. Another option related to heat storage in the context of district heating systems is the heat storage in building mass. This possibility is currently intensively researched due to its high potential, but not commonly applied in practice. There are already dedicated energy storages in Copenhagen, but they are expected to be substantially expanded. In that context, also the possibility of storing heat in the grid itself also becomes of interest. The obvious benefit of such solution is that it does not require additional investment in the storage capacity and is readily available already now.

## 1.2 Aim

The report presents the result of a study that was performed to test the heat storage potential of the district heating network. The economic potential of such solution and technical barriers and limitations (e.g. in heat transfer capacity) are also discussed.

# 2 Description of the case study Installations, tools, data and data quality

## 2.1 Geographical location of the case study

The area where the case study was performed is located around Århusgade in Nordhavn, Copenhagen. The part of a larger development project, transforming former industrial district into a residential one and all the buildings in the case study area are either newly built or extensively renovated. The distribution grid, where the case study was made is a part of the Greater Copenhagen district heating system.

The map shown in Figure 1 presents the district heating network in Nordhavn and Østerbro. The map shown in Figure 2 presents the layout of the local distribution grid in Århusgade area in Nordhavn.

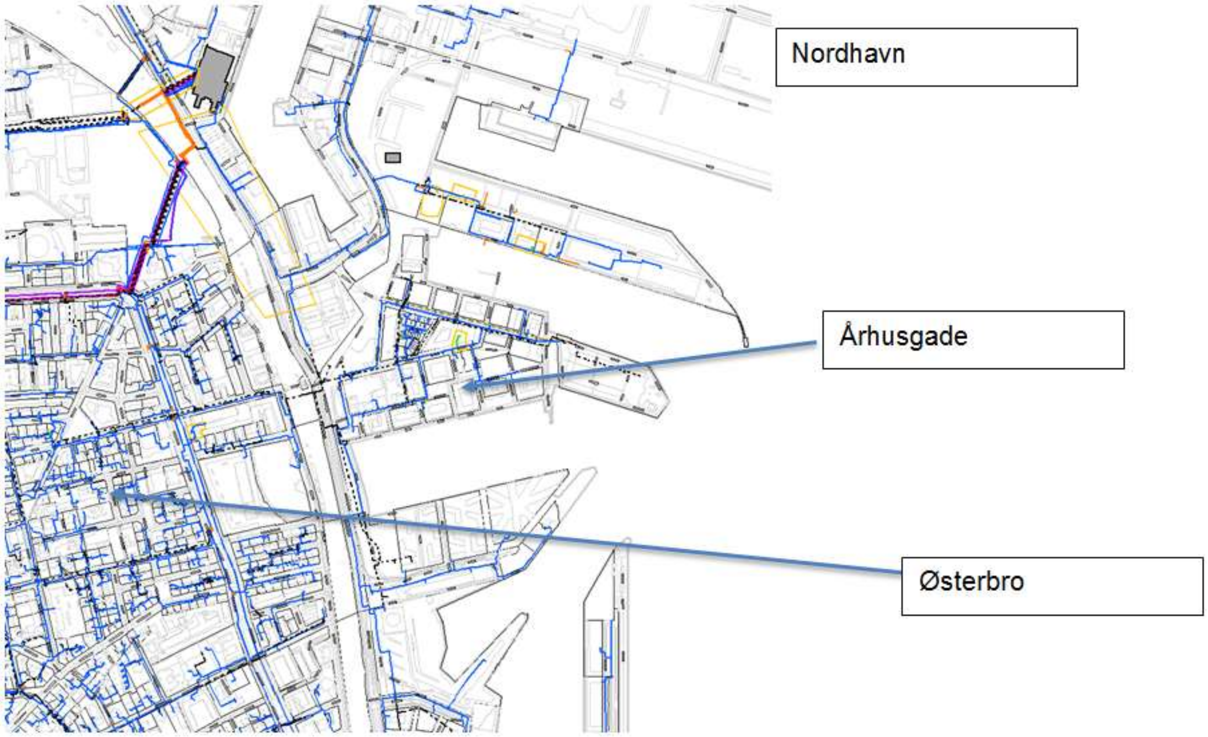


Figure 1. District heating network in and around Nordhavn, Copenhagen

## 2.2 Data collection

Data used in the investigation was collected for three consecutive days (Sunday, Monday, Tuesday) both in the experiment and in the reference period. The data collection occurred every hour, both in the heat meter and in the building substations. Figure 2 shows where in the grid the measurements were taken. The plant in the figure represents the location of the area heat meter. Blue circles represent buildings substations, where the measurements were made. Red circles represent building substations that were connected to the grid at the time of the experiment, but there was no data being collected there yet. Yellow circles represent heat meters located in the row house area. At the time of the experiments no measurements from this area were available yet. Moreover, the estimated energy use there was aggregated and represented as located at the first heat meter in the area.

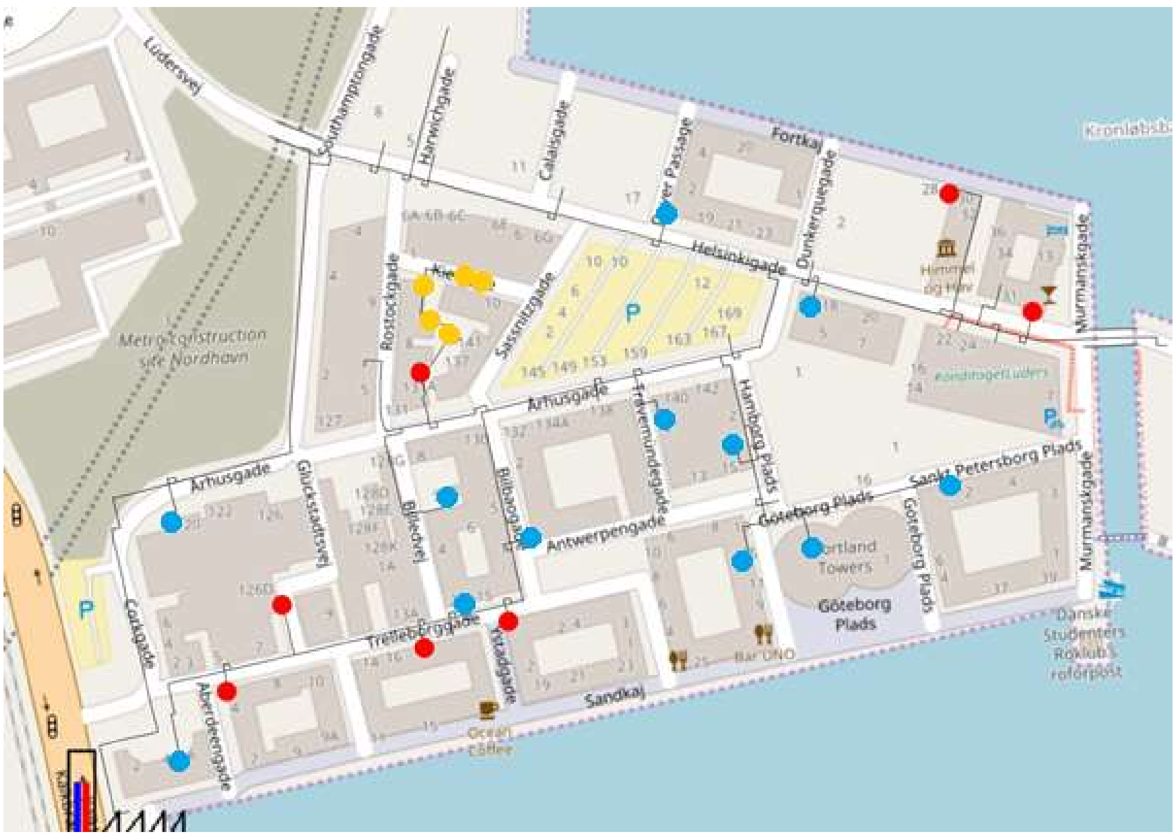


Figure 2. Map of Århusgade area with heat meters marked with coloured circles. Blue circles represent heat meters, where the measurements were made. Red circles represent building substations that were connected to the grid at the time of the experiment, but there was no data being collected there yet. Yellow circles represent heat meters installed in the row house area, where the data was aggregated.

Figure 3 shows the area heat meter mentioned above. The heat meter measures water flow, temperature and pressure in supply and return pipe. The nominal flow that can be measured by the meter is 400 $m^3/h$. The temperature is measured with the precision of ± 0.1 °C. The data is measured continuously and stored in a SQL database on hourly basis.

Figure 4 presents one of the building heat meters. All customers in the area and their heating substations are equipped with electronic heat meters for remote metering of flow, energy and temperatures. The nominal flow that can be measured by the heat meters in Nordhavn is variable depending on the expected demand, but until now the maximal value is 25 $m^3/h$. The measurements from the customer heat meters are also collected every hour and stored in a SQL database.

Additionally, measurements were made also at Langelinie heat exchanger connecting the local distribution network and transmission network that supplies both Nordhavn and Østerbro areas.

Figure 3. Main area heat meter at the entrance of Århusdage area, Nordhavn

Figure 4. Example of building heat meter in Århusgade area, Nordhavn

## 2.3 Data quality and limitations

For the case study, the measurements taken over the period of 72 hours from Sunday 12:00 AM to Tuesday 12:00 PM in two consecutive weeks were used. During the period in question there was no interruption in data collection neither in any of the buildings, nor in the area heat meter, nor in the substation supplying the area further upstream in the network. The measurements in the substations were made in 12 buildings in the area. Because of it, the heat use in the rest of the buildings and the return temperature from the substations had to be estimated in the simulation, using the measurement data from the area heat meter.

The exact explanation how missing data was estimated for the simulation purposes is presented in section 5.2 “Assumptions regarding building energy use data”.

## 2.4 Simulation software "Termis"

Simulations were performed in Termis. Termis is a commercial software originally developed by 7 Technologies and now owned and sold by Schneider Electric. Termis can be used for design, operation and energy planning of district heating networks. It can simulate both the thermal and hydraulic conditions in a district heating network and is capable of performing both steady state and dynamic simulations.

In the investigation performed in the case study Termis was used in an offline-mode with historical measurement data used as input.

## 3 Description of the performed tests

### 3.1 Supply temperature increase tests

The case study is based on the measurements taken during two tests.

In the first test, the measurements analysed were made over the period of 72 hours from Sunday 12:00 AM to Tuesday 12:00 PM in two consecutive weeks (12-14.03.2017 and 19-21.03.2017). In the period between 19th and 21st of March (experiment period), supply temperature was increased about 15 K over usual supply temperature that would be used at that outdoor air temperature. It was done to store heat in the pipes. The increase occurred around 3 a.m. on Monday and lasted until 6 a.m. on Tuesday. Then on Tuesday the normal supply temperature setpoint was restored to release the stored heat and decrease the morning peak. The supply temperatures measured both in the Langelinie heat exchanger and at the entrance to Århusgde area during the test period and in the reference period in March are shown in Figure 5. The increase was introduced through changing the setpoint of the supply temperature in Langelinie heat exchanger that connects the district heating transmission network with the local heat distribution network in Østerbro and Nordhavn. As the transmission network operates on higher temperatures than the distribution network, introducing that change did not require an increase in temperature in transmission network. Between 12th and 14th of March, described in the study as reference period in March, the network operation was as usual.

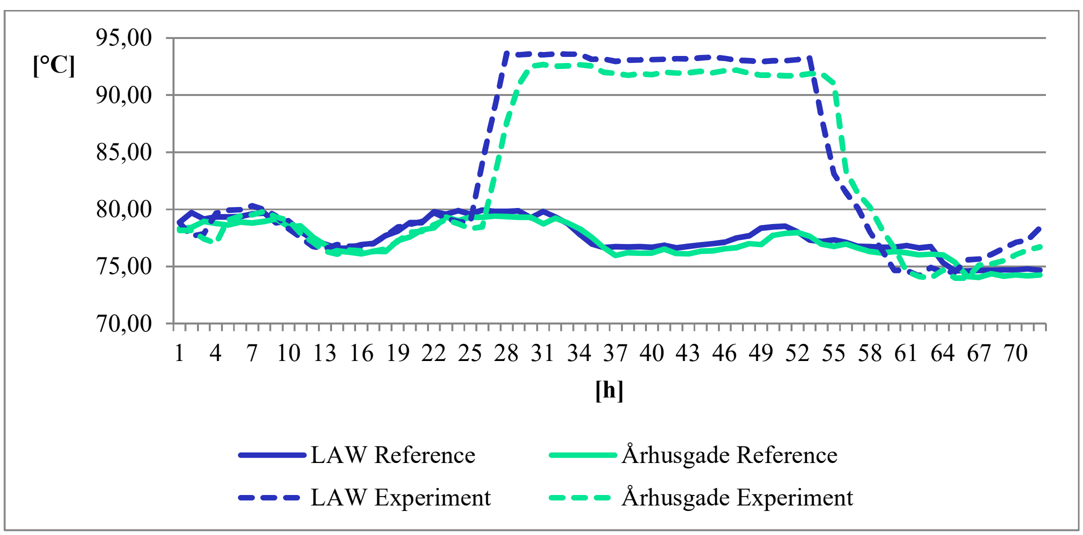


Figure 5. Supply temperatures measured in Langelinie heat exchanger and at the entrance to Århusgade area in reference and experiment periods in the test in March

In the second test performed in October the measurements analysed were also made over the period of 72 hours from Sunday 12:00 AM to Tuesday 12:00 PM. However, in the case of this experiment, specifying a direct reference period is more difficult. The beginning of the week after the experiment was characterized by clearly lower air temperatures than the experiment period, as can be seen in Figure 8 and the measurements from the week before were not recorded. It was decided to use the available measurements from the period 8-10.10.2017 as a point of reference. In the experiment period in October the supply temperature was also increased by about 15 K over normal supply temperature that would be used at that outdoor air temperature. The increase occurred around 12 p.m. on Sunday and the increased temperature at the entrance to Århusgade area was measured until 10 a.m. on Monday. Then, the normal supply temperature setpoint was restored to release the stored heat and decrease the morning peak. Between 8th and 10th of October, described in the study as reference period in October, the network operation was as usual. The supply temperatures measured at the entrance to Århusgde area during the test period and in the reference period in October are shown in Figure 6.

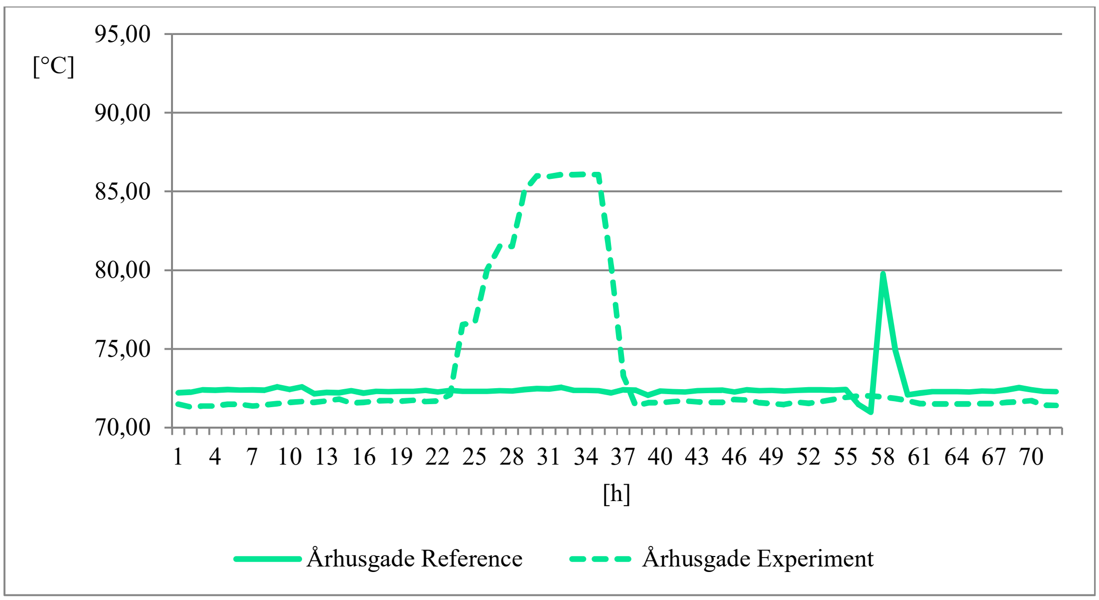


Figure 6. Supply temperatures measured and at the entrance to Århusgade area in reference and experiment periods in the test in October

### 3.2 Outdoor temperatures in the investigated periods

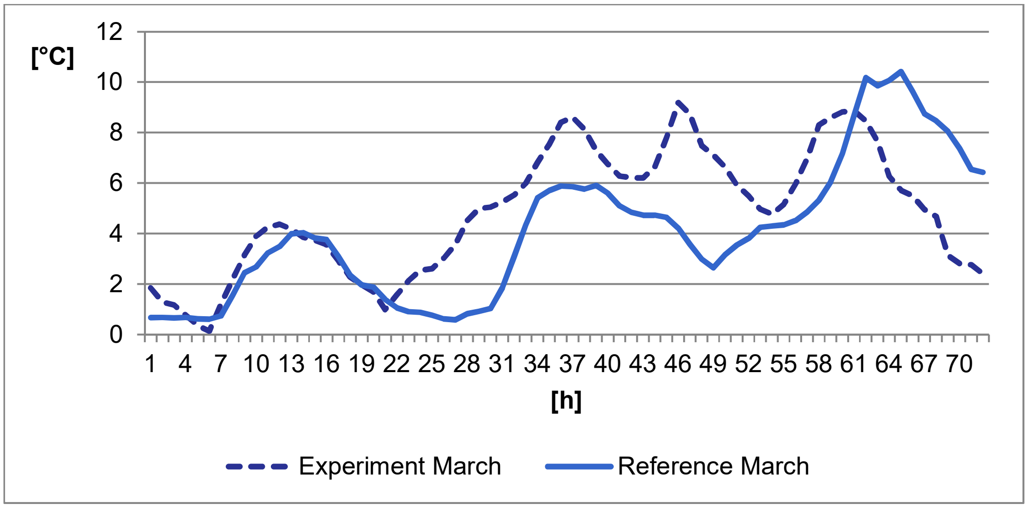


Figure 7. Ambient air temperature in Copenhagen in the reference and experiment periods in March

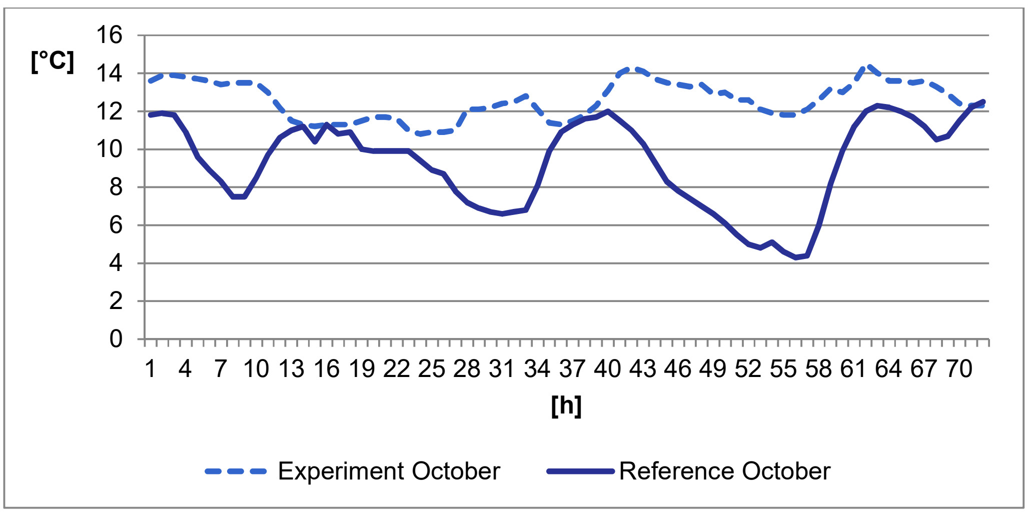


Figure 8. Ambient air temperature in Copenhagen in the reference and experiment periods in October

In the context of discussing energy use in the district heating system, it is also important to analyse weather conditions during the investigated periods. Figures 7 and 8 show the ambient temperatures in Copenhagen both during the reference and experiment period in March and October, respectively. The weather data was downloaded from the weather station located at DTU in Lyngby. Unfortunately, exact measurements from a weather station in Nordhavn were not available.

Based on the analysis of the measurement data, it can be seen that the peak energy supply in the experiment period in the March test, during the time of storage discharge, was lower than measured on other weekdays. In the test in October, the peak was at the same level as for two other weekdays and significantly lower than one day in the reference period. The weather conditions in the reference and experiment periods did not fully match and the experiment period was on average warmer than the reference period both in March and in October. Because of it, it is difficult to estimate the effect of the heat storage and to separate the effect of the heat storage from the influence of outdoor temperature (and possible changes in energy use that may be caused by other factors).

# 4 Measurement data analysis

The measurements were initially analysed to investigate, if there is a clearly visible effect of applying the heat storage in the district heating grid.

## 4.1 Estimation of the heat storage potential

The theoretical potential of the heat storage in the local grid was investigated. To do so, first the volume of pipes in the analysed area was calculated. Branches, where there was no flow were excluded. Only the supply pipes were accounted for, as the return pipes are not used for heat storage. The result of the calculation is shown in Table 1. The total calculated supply pipe volume is 45 $m^3$.

Then, the theoretical number of hours of storage was calculated for different levels of temperature increase. This is the maximum theoretically possible amount of heat that can be stored in the grid under assumed conditions in a case. Under real operating conditions, the energy stored will be usually less than value shown in Table 2 and Table 3. The energy stored was calculated using the equation below:

$$E = V \cdot \rho \cdot c_p \cdot \Delta T$$

$$t = \frac{E}{P} \cdot \frac{1}{3600}$$

where E is the additional thermal energy stored in the pipes [kJ], V is the total volume of the pipes in $m^3$, $\rho$ is the water density (assumed to be 980 $kg/m^3$), $c_p$ is the specific heat of water (assumed to be 4.18 kJ/kg·K), the $\Delta T$ is the temperature increase, t is the number of hours of storage in h and P is the averaged thermal power supplied to the area in kW. As the heat losses in the local network are low, it was assumed that all the power supplied to the area is supplied to the buildings.

Table 1. Volume of pipes in the Århusgade area, Nordhavn.

| Diameter | Heat transfer coefficient | Pipe lenght | Pipe volume |
|---|---|---|---|
| [m] | [W/(m·K)] | [m] | [m$^3$] |
| 0,0160 | 0,152 | 142,6 | 0,03 |
| 0,0200 | 0,179 | 64,3 | 0,02 |
| 0,0256 | 0,192 | 29,5 | 0,02 |
| 0,0320 | 0,157 | 14,4 | 0,01 |
| 0,0372 | 0,166 | 11,6 | 0,01 |
| 0,0390 | 0,185 | 10,8 | 0,01 |
| 0,0503 | 0,265 | 26,8 | 0,05 |
| 0,0510 | 0,210 | 103,9 | 0,21 |
| 0,0545 | 0,211 | 96,2 | 0,22 |
| 0,0660 | 0,253 | 49,7 | 0,17 |
| 0,0703 | 0,237 | 308,9 | 1,20 |
| 0,0799 | 0,302 | 3,4 | 0,02 |
| 0,0825 | 0,219 | 319,4 | 1,71 |
| 0,0839 | 0,294 | 32,5 | 0,18 |
| 0,1071 | 0,260 | 210,5 | 1,90 |
| 0,1325 | 0,300 | 584,9 | 8,06 |
| 0,1603 | 0,341 | 64,4 | 1,30 |
| 0,2101 | 0,363 | 629,5 | 21,83 |
| 0,2630 | 0,354 | 154,9 | 8,41 |
| | | **SUM:** | 45,36 |

For the test in March, the theoretical number of hours of storage was calculated for average power supplied in the reference period, in the experiment period, between 4 and 7 a.m. each day in the reference period and between 4 and 7 a.m. each day in the experiment period. Identical procedure was applied for the test in October, but the peak hours chosen there were between 6 and 9 a.m. each day.

The results of the calculation for the test period in March are shown in Table 2. The results of the test of the calculation for the test period in October are shown in Table 3.

Table 2. Theoretical hours of storage at different levels of temperature increase and average thermal power under the reference and experiment conditions for the test period in March

| Temperature difference ($\Delta$T) | Heat stored in full volume (E) | Average power delivered in the reference period (P) | Number of h of storage - reference period (t) | Average power delivered in the experiment period (P) | Number of h of storage - experiment period (t) |
|---|---|---|---|---|---|
| [K] | [MJ] | [MW] | [h of storage] | [MW] | [h of storage] |
| 5 | 929 | 1.73 | 0.15 | 1.66 | 0.16 |

| | | | | | |
|---|---|---|---|---|---|
| 10 | 1858 | | 0.30 | | 0.31 |
| 15 | 2787 | | 0.45 | | 0.47 |

| Temperature difference (ΔT) | Heat stored in full volume (E) | Average morning peak power in the reference period (P) | Number of h of storage - reference period (t) | Average morning peak power in the experiment period (P) | Number of h of storage - experiment period (t) |
|---|---|---|---|---|---|
| [K] | [MJ] | [MW] | [h of storage] | [MW] | [h of storage] |
| 5 | 929 | 1.96 | 0.13 | 1.92 | 0.13 |
| 10 | 1858 | | 0.26 | | 0.27 |
| 15 | 2787 | | 0.39 | | 0.40 |

Table 3. Theoretical hours of storage at different levels of temperature increase and average thermal power under the reference and experiment conditions for the test period in October

| Temperature difference (ΔT) | Heat stored in full volume (E) | Average power delivered in the reference period (P) | Number of h of storage - reference period (t) | Average power delivered in the experiment period (P) | Number of h of storage - experiment period (t) |
|---|---|---|---|---|---|
| [K] | [MJ] | [MW] | [h of storage] | [MW] | [h of storage] |
| 5 | 929 | 0.89 | 0.29 | 0.66 | 0.39 |
| 10 | 1858 | | 0.58 | | 0.78 |
| 15 | 2787 | | 0.87 | | 1.17 |

| Temperature difference (ΔT) | Heat stored in full volume (E) | Average morning peak power in the reference period (P) | Number of h of storage - reference period (t) | Average morning peak power in the experiment period (P) | Number of h of storage - experiment period (t) |
|---|---|---|---|---|---|
| [K] | [MJ] | [MW] | [h of storage] | [MW] | [h of storage] |
| 5 | 929 | 1.17 | 0.22 | 0.80 | 0.32 |
| 10 | 1858 | | 0.44 | | 0.64 |
| 15 | 2787 | | 0.66 | | 0.96 |

## 4.2 Analysis of thermal power delivered

Figure 9 shows the thermal power delivered to the Århusgade area in the reference and experiment periods in March. It can be seen that the peak on Tuesday, during the experiment period when the storage discharge occurs is clearly lower than the corresponding peak in the reference period (1.88 MW compared to 2.17 MW).

Figure 10 shows the thermal power delivered to the whole area of Østerbro and Nordhavn in the reference and experiment periods in March. It can be seen that the shape of the curves corresponds to the curves in Figure 7 and the peak on Tuesday, during the experiment period when the storage discharge occurs is clearly lower than the corresponding peak in the reference period (76.40 MW compared to 83.02 MW).

The daily peaks demand peaks registered in LAW and in the area heat meter in Århusgade are described more in detail in sections 4.5 and 4.6. The weather conditions and their possible influence are discussed in detail in section 3.2.

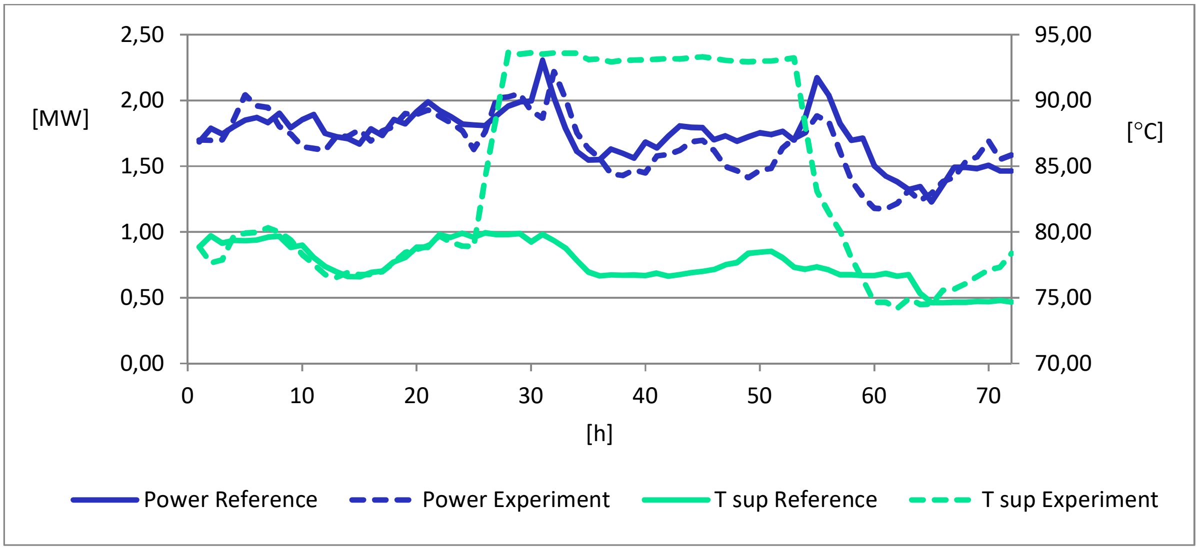


Figure 9. Power delivered to the Århusgade area in reference and experiment periods in March

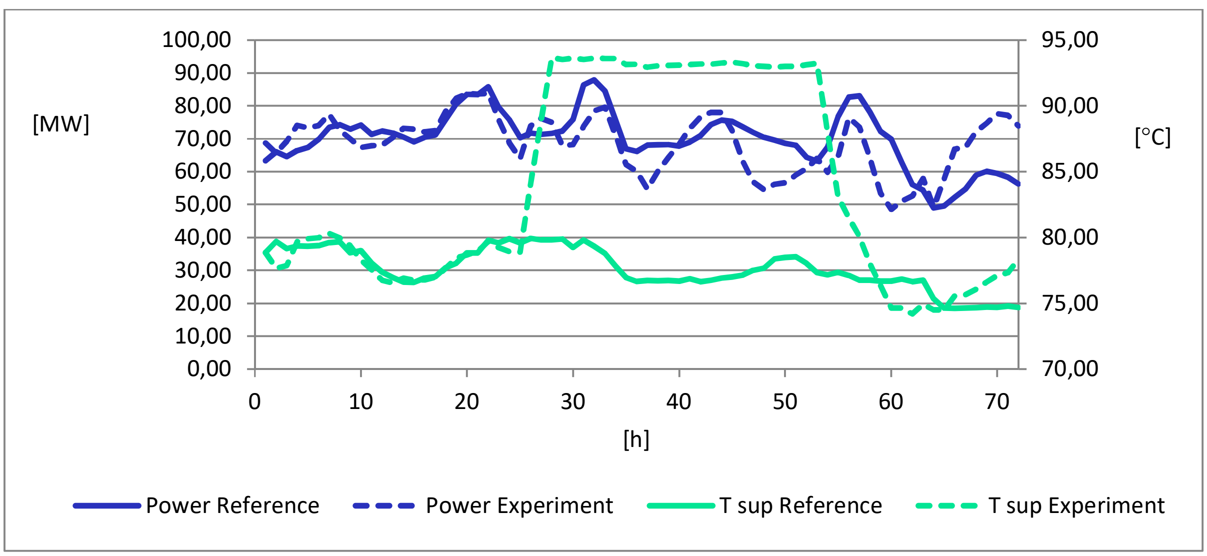


Figure 10. Power delivered through LAW to the Østerbro and Nordhavn area in reference and experiment periods in March

### 4.3 Analysis of water flow

It can clearly be seen that the flow in the network decreases significantly during the temperature increase period. This effect can be seen clearly both in LAW and in the Århusgade area, as shown in Figure 11 and 12, and is in agreement with the expectations. The average flow in the area heat exchanger (LAW) during normal operation is 2341 $m^3/h$ and during the period of increased temperature it decreased to 1379 $m^3/h$ (59% of the reference value). The decrease in case of Århusgade was not that significant – the average flow decreased from 58 $m^3/h$ to 50 m3/h (86% of the reference value).

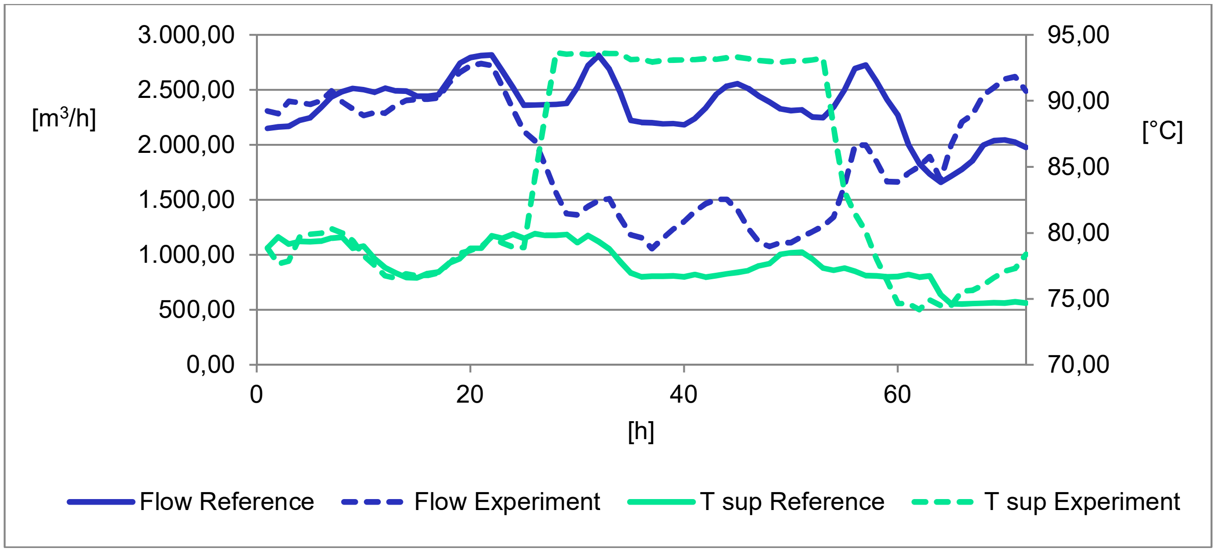


Figure 11. Water flow in Langelinie heat exchanger in the reference and experiment periods in March

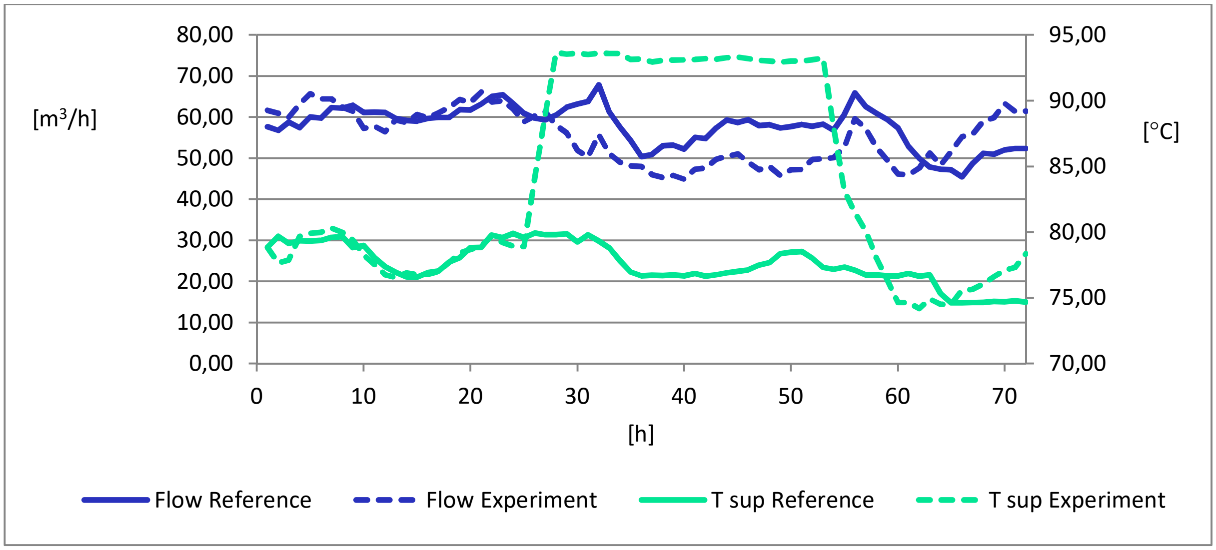


Figure 12. Water flow in measured in the heat meter at the entrance to Århusgade area in the reference and experiment periods in March

## 4.4 Analysis of return temperature

Another investigated factor was possible change in the return temperature from the building substations. Figure 13 presents the return temperature measured in the Langelinie heat exchanger (LAW) (so return temperature from both Østerbro and Nordhavn area) in both the experiment and reference period in March, as well as the return temperature from Århusgade area in Nordhavn also both for the experiment and reference period in March.

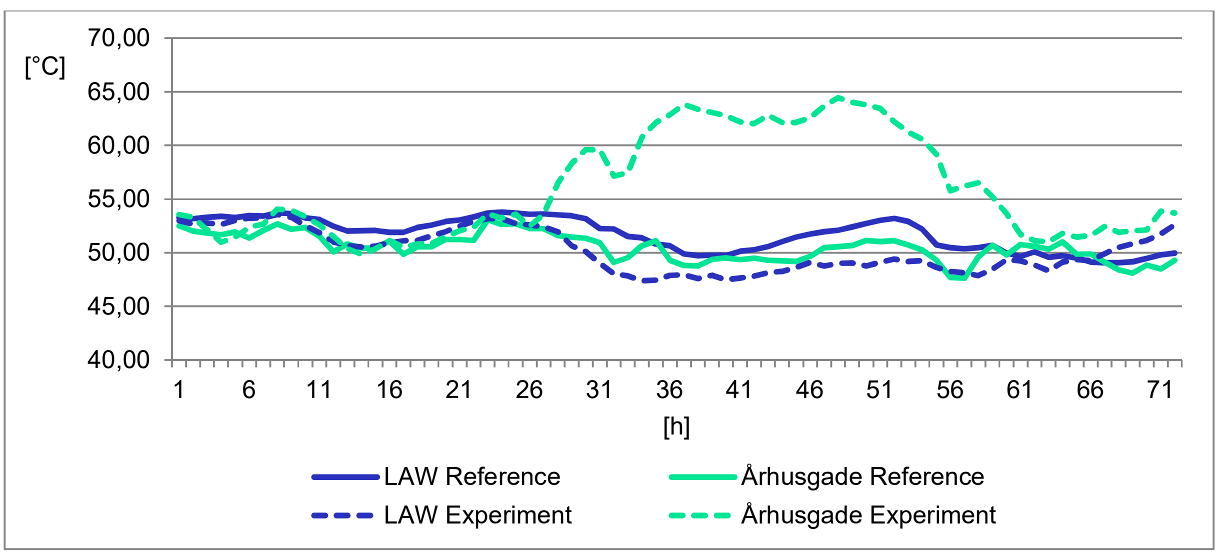


Figure 13. Return temperature in Langelinie heat exchanger and in Århusgade area heat meter in reference and experiment period in March

It can be seen from the figure that in the reference period the return temperatures measured in Langelinie heat exchanger (LAW) and in the Århusgade heat meter are very similar, but the return temperature from Århusgade area in Nordhavn is slightly lower than the overall return temperature to LAW. This is also the case during the first part of the experiment period before the supply temperature is raised. In the experiment period the overall return temperature to LAW decreases slightly, as expected, due to the higher heat exchanger efficiency. However, the return temperature from Århusgade area (measured in the area heat meter) is increased by about 10°C from the reference level. This might be due to a malfunction in one of the buildings` district heating substations.

Figure 14 presents the return temperature from Århusgade area in Nordhavn both for the experiment and reference period in October. It can be seen that the previously visible malfunction does not occur anymore and there is no increase in measured return temperature visible during the period of increased supply temperature. The return temperature in the experiment period does not differ significantly from the return temperature in the reference period and remains relatively stable over the whole analysed period.

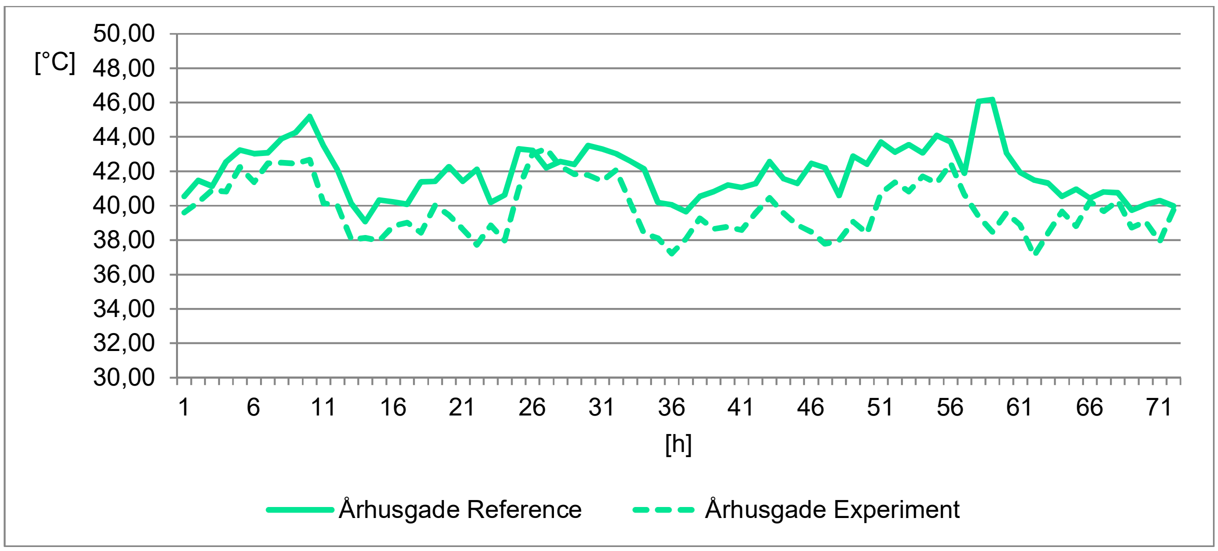


Figure 14. Return temperature in Århusgade area heat meter in reference and experiment period in October

Figures 15 and 16 presents return temperatures from building substations measured in 12 buildings in Århusgade area during the test in March. Measurements from the reference period are shown in Figure 13, measurements from the experiment period – in Figure 14. It can be seen, that in Building 10, the return temperature from the building substation increases with the increase in supply temperature. This combined with a very high return temperature in general and high flow, indicates a malfunction of the substation that was present during the measurements. The average heat demand in Building 10 in the reference period was 93 kW and the mass flow 13.0 m$^3$/h, compared to e.g. 101 kW and 2.0 m$^3$/h, respectively, in Building 8.

Figures 17 and 18 show the return temperatures from building substations measured in the same 12 buildings in the Århusgade area during the test in October. Measurements from the reference period are shown in Figure 15, measurements from the experiment period – in Figure 16.

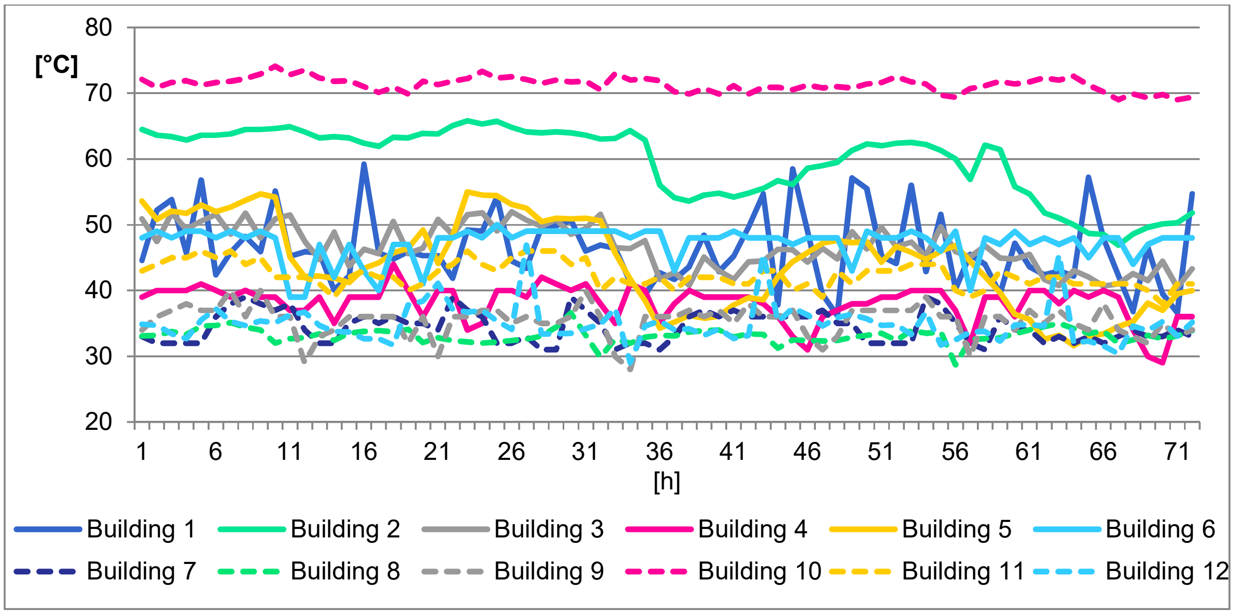


Figure 15. Return temperature from building substations in the reference period in March

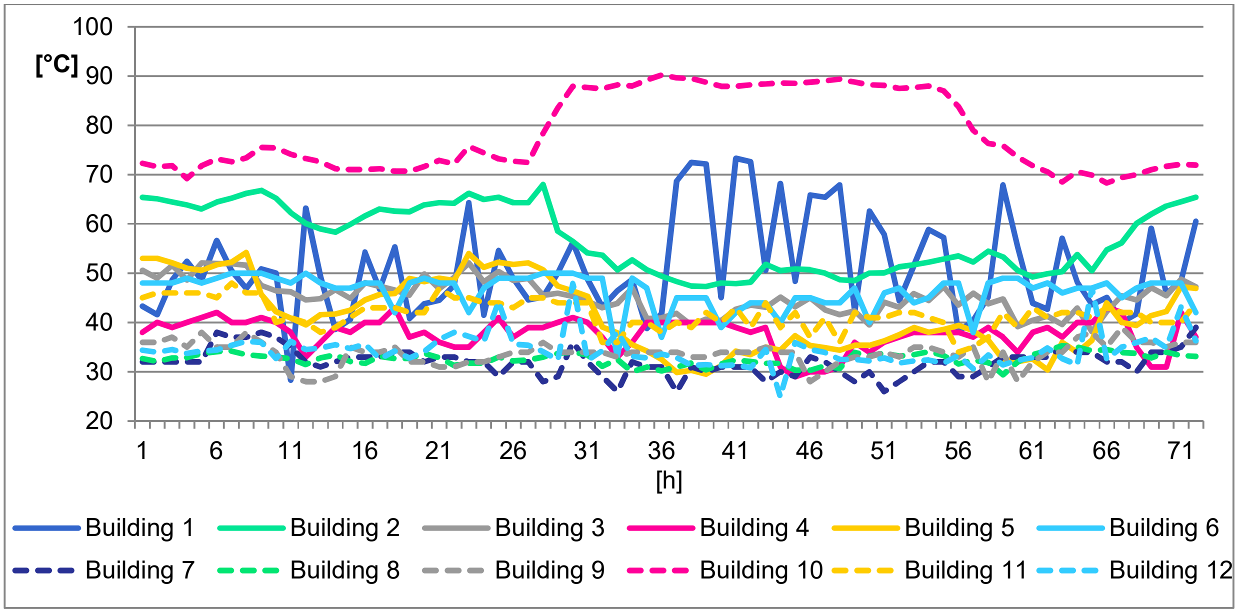


Figure 16. Return temperatures from building susbtations in the experiment period in March

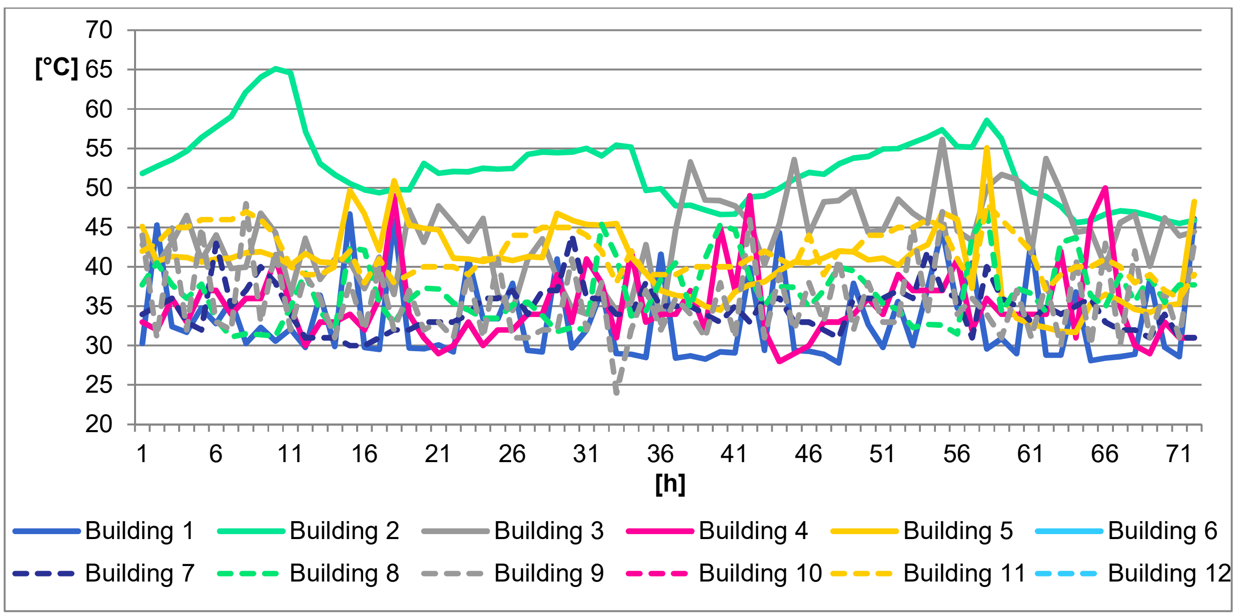


Figure 17. Return temperatures from building susbtations in the reference period in October

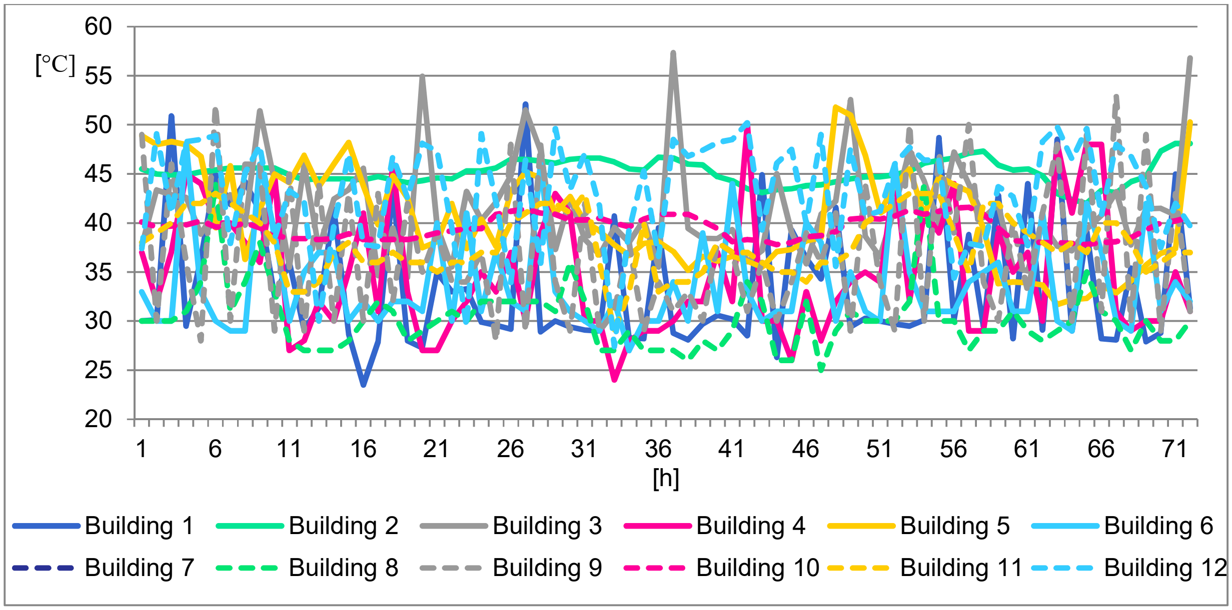


Figure 18. Return temperatures from building substations in the experiment period in October

The measurements of return temperature from individual substations for the experiment period were analysed in detail. The return temperature during the period of normal operation was compared with the return temperature during the temperature increase. It was expected, that the temperature increase will result in a slight decrease of the return temperature. Paired t-test was used, to check, whether the return temperature from building substations decreases significantly during the period with increased supply temperature compared to the period of normal operation. The data for each building was aggregated, so that the analysis was made for the mean cooling values in each building over the investigated periods. The comparison was made for the measurements made between 26th and 62nd hour for both periods, to exclude the period not affected by experiment and to see the results more clearly.

During the measurement analysis it was discovered that one of the substations had a control valve malfunction. For this reason, the measurements from that substation were excluded from the analysis. For the return temperature from building substations, the calculated p-value equals 0.069 and the mean of the differences is 3.65. It shows that in the properly functioning substations the decrease of return temperature was observed during the period of increased supply temperature. It corresponds also to the results of the measurements made in the Langelinie heat exchanger in the March test, where a decrease of about 2.3 K was observed (48.9 compared to 51.2 °C).

## 4.5 Daily peaks registered by the area heat meter

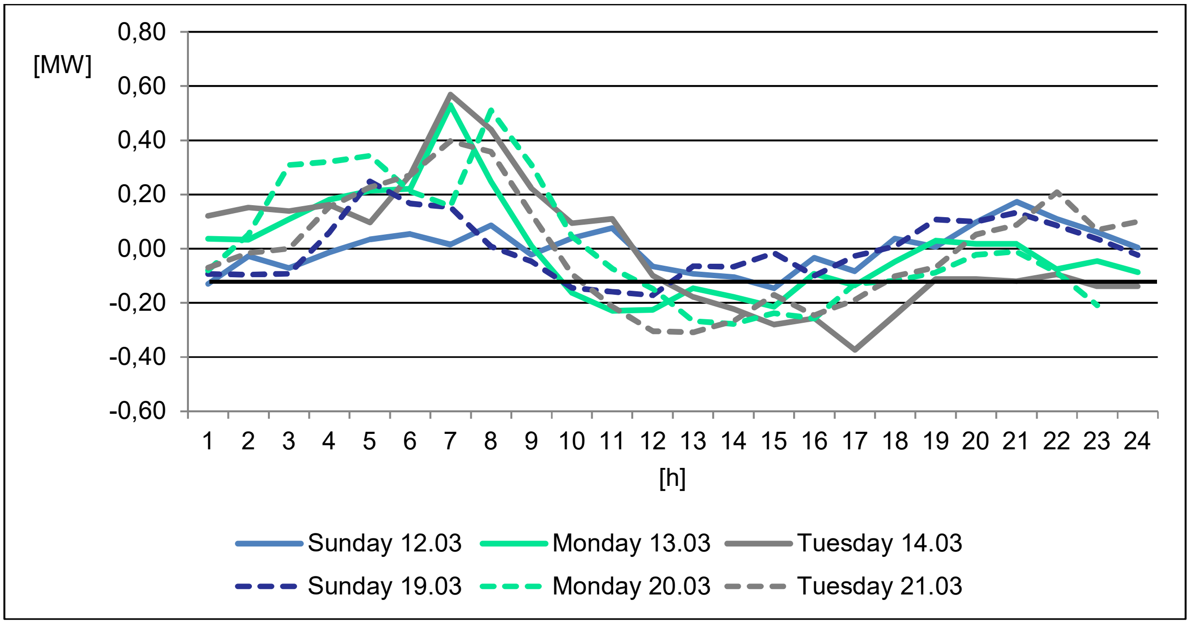


Figure 19. Difference between daily average power and hourly power as measured in the area heat meter in March. Dashed lines represent measurements from the experiment period, continuous lines - measurements from the reference period.

Figure 19 shows the plotted differences between daily average power supplied to the area of Århusgade and the hourly measurements of the supplied power for all 6 days in the investigated period in March. Both morning and afternoon can be clearly seen for all 6 days represented. It can also be noticed, that while afternoon peaks were similar for all days, the morning peak on Sundays was less pronounced than on Mondays and Tuesdays. On Monday in the experiment period there is also visible an additional peak starting about 2 a.m. and finishing about 6 a.m., representing charging the network in the experiment period.

It can be seen that the peak on Tuesday morning in the experiment period is lower than the three other weekday morning peaks (maximum 0.40 MW increase from the daily average, compared to 0.51 MW, 0.53 MW and 0.57 MW).

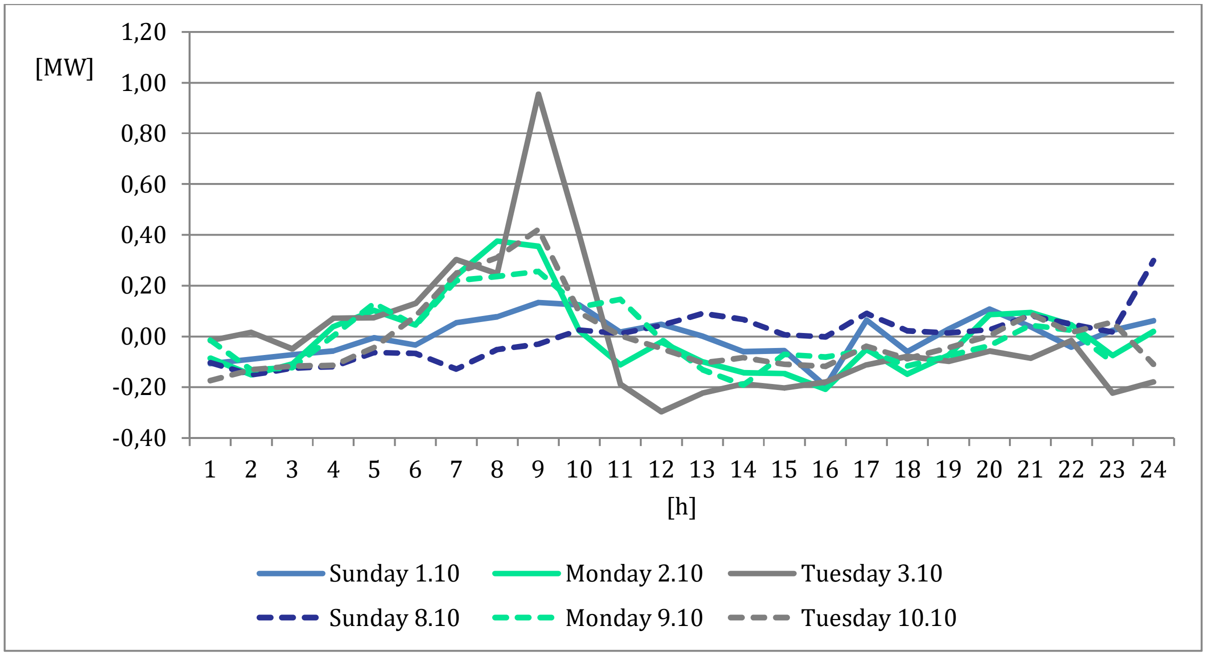


Figure 20. Difference between daily average power and hourly power as measured in the area heat meter in October. Dashed lines represent measurements from the experiment period, continuous lines - measurements from the reference period.

Figure 20 shows the plotted differences between daily average power supplied to the area of Århusgade and the hourly measurements of the supplied power for all 6 days in the investigated period in October. While the morning peaks are visible, the afternoon peaks cannot be clearly observed. The charging period on Monday is not clearly visible either. The morning peaks are less pronounced on Sundays than during the weekdays, same as during the experiment period in March. The largest morning peak occurred on Tuesday in the reference period - it corresponds to the period of lower temperatures that occurred on Tuesday, as can be seen in Figure 7.

## 4.6 Daily peaks registered in the Langelinie heat exchanger

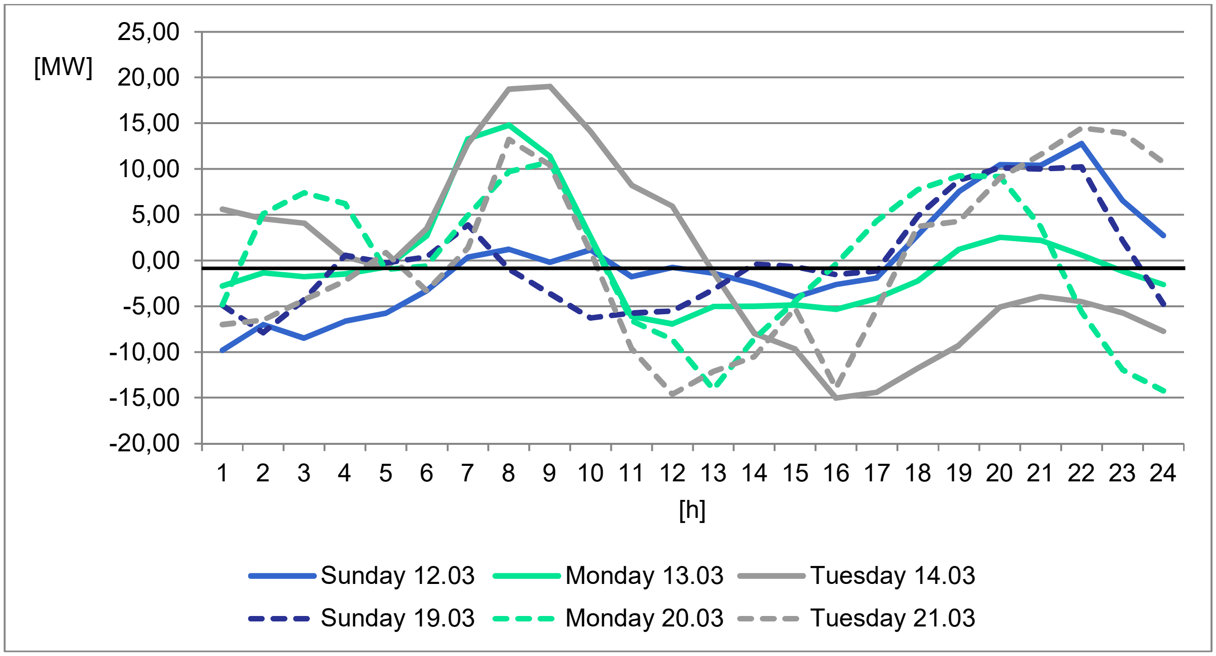


Figure 21. Difference between daily average power and hourly power as measured in the Langelinie heat exchanger. Dashed lines represent measurements from the experiment period, continuous lines - measurements from the reference period.

Figure 21 shows the plotted differences between daily average power supplied to the area of Østerbro and Nordhavn and the hourly measurements of the supplied power for all 6 days in the investigated period. The pattern with morning and afternoon peaks can be seen in the plots for all 6 days, but there are greater differences between the days than in the case of measurements from Nordhavn. On Monday in the experiment period there is also visible an additional peak starting about 1 a.m. and finishing about 5 a.m., representing charging the network in the experiment period. The peak appears here earlier than in the area heat meter due to the transport time required for the temperature increase to reach Århusgade area.

It can be seen that the peak on Tuesday morning in the experiment period is lower than the peak on Monday and Tuesday in the reference period (13.24 MW increase from the daily average, compared to 14.80 and 19.03 MW). However, it is higher than the morning peak on Monday during the experiment period (13.24 MW increase from the daily average, compared to 10.75 MW).

No measurements from the Langelinie heat exchanger were available for the second experiment.

# 5 Simulation setup and investigated scenarios

## 5.1 Simulation setup

The model of the local district heating network was built in Termis. Main area heat meter was substituted with a district heating plant, as could be seen in Figure 1. This was done to satisfy software requirements, as there has to be plant included in the model.

Measurement data was then used where possible as an input to the model. Supply temperature measured at the entrance to the area was used as an input for supply temperature from the plant in the model. Due to the software constraints, pressure at the entrance to the area was assumed to be constant and equal to the average measured supply pressure. In buildings where the hourly measurements were made, average hourly heating power and return temperature from the building were used as input. The procedure used to estimate the input data for the buildings where no measurements were available is described in section “Assumptions regarding building energy use data”.

Subsequently, the model was validated using the measurements done in the existing system at the consumer nodes and the measurement point at the entrance to the area. To validate the models, simulated heating power, return temperature from the system and flow in the network were compared with measured values.

After the model was validated, different scenarios regarding the exact parameters of the supply temperature increase were investigated.

## 5.2 Assumptions regarding building energy use data

Measurements from part of the buildings were not available during the period when the experiment in March was performed (the situation during the test is shown in the map in Figure 2). Because of it, assumptions have been made regarding the heat demand and the return temperature in remaining buildings.

### Heat load

Heat load in the remaining buildings was distributed proportionally to the heat use in a normal year expected in each of the buildings. Heat losses of 10% from pipelines were taken into account, so the heat used in the buildings is 90% of the heat supplied to the area. The losses were divided between supply and return based on the average supply and return temperatures. The average supply temperature was 77.5 °C and the average return temperature 52.5 °C, so with the ambient temperature of 8 °C, 61% of the losses were attributed to supply and 39% to the return. So, 6.1% of heat is lost from the supply pipes and 3.9% from the return pipes. For the three buildings, where the expected heat use in a normal year was not known, the value was assumed based on their design heat load and averaged relation between design heat load and heat use during a normal year for other buildings of similar size in the area. Moreover, heat demand for all the row houses was aggregated to simplify the model. For the row houses where the heat use during a normal year was not known, the heat use in a normal year was estimated using the same method as for the large buildings. Formulas used in the calculation are shown below. Index a denotes the group of buildings where the measurements were made and index b the buildings where measurements were not available.

$$P_b = P_{tot} - P_a$$

$$P_i = n_i \cdot P_b(1 - 0.1 \cdot 0.61)$$

where:

$P_{tot}$ - total heat load of the buildings in Århusgade area, including heat loss from the grid

$P_a$ - heat load of the buildings where measurements were available, including heat loss from the grid

$P_b$ - heat load of the buildings where measurements were not available, including heat loss from the grid

$P_i$ - heat load of building i

$n_i$ - share of the design heat load of building i in the total design heat load of buildings where no measurements were made

**Return temperature**

Return temperature was assumed to be the same in all remaining buildings. Return temperature was also calculated based on the measurements from area heat meter. As it was stated before, the losses in the network during the normal operation period were assumed to be 10%. The ambient temperature was assumed to be constantly 8 °C. The heat loss during the experiment period was calculated to be 12% based on the increase in supply and return temperature compared to the normal operation (91.8 °C and 61.6 °C, respectively). Formulas used in the calculation are shown below:

$$\mathrm{T}_{\mathrm{ret\ avg\ a}} = \frac{\sum_1^{12} \mathrm{T}_{\mathrm{ret\ i}} \cdot \dot{\mathrm{m}}_{\mathrm{i}}}{\sum_1^{12} \dot{\mathrm{m}}_{\mathrm{i}}}$$

$$\mathrm{T}_{\mathrm{ret\ a\ hm}} = \mathrm{T}_{\mathrm{ret\ avg\ a}} \cdot (1 - 0.1 \cdot 0.39)$$

$$\dot{\mathrm{m}}_{\mathrm{b}} = \dot{\mathrm{m}}_{\mathrm{tot}} - \dot{\mathrm{m}}_{\mathrm{a}}$$

$$T_{ret\ b\ hm} = \frac{\dot{m}_{tot} T_{ret\ tot\ hm} - T_{ret\ a\ hm} \dot{m}_a}{\dot{m}_b (1 - 0.1 \cdot 0.39)}$$

where:

| | |
|---|---|
| $T_{ret\ avg\ a}$ | - average return temperature from the buildings where the measurements were made |
| $T_{ret\ i}$ | - return temperature from building i |
| $m_i$ | - mass flow through the substation in building i |
| $T_{ret\ a\ hm}$ | - return temperature from the buildings where measurements were made when the flow reaches area heat meter heat |
| $m_a$ | - mass flow through the substations in buildings where the measurements were made |
| $m_b$ | - mass flow through the substations in buildings where the measurements were not made |
| $m_{tot}$ | - total mass flow in the grid |
| $T_{ret\ b\ hm}$ | - return temperature from the buildings where measurements were not made when the flow reaches area heat meter heat |
| $T_{ret\ tot\ hm}$ | - total return temperature from the area measured in the area heat meter heat |

## 5.3 Scenarios investigated in the simulation

After the network model was validated against the measurements, different scenarios regarding the heat storage setup were investigated.

### 5.3.1 Influence of different levels of temperature increase

The first parameter investigated was influence of different levels of temperature increase in the storage charging period. Three levels of temperature increase were investigated: 5, 10 and 15 K. Figure 12 shows the supply temperature profiles for the three cases. Actual measured supply temperatures during the reference periods were used as the reference case.

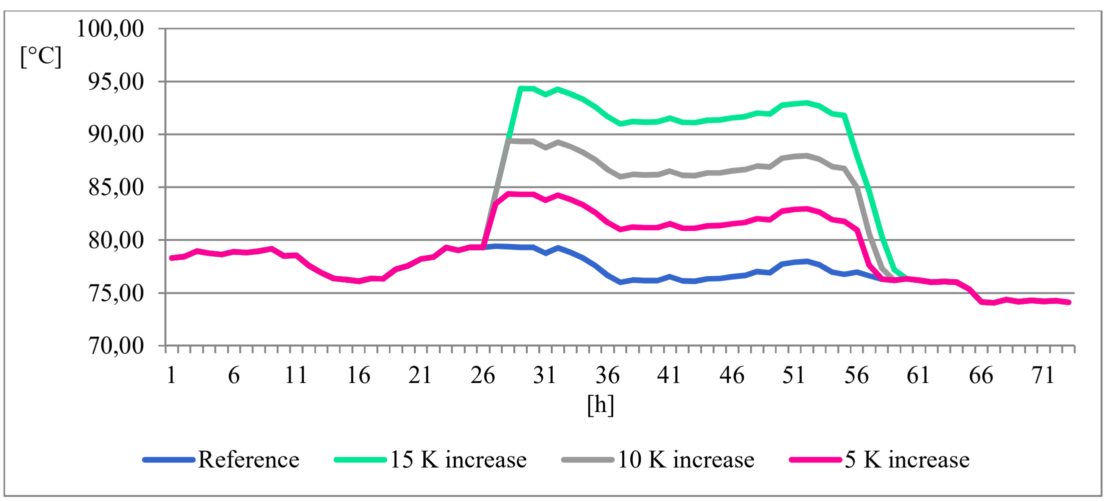


Figure 22. Supply temperature in different scenarios regarding temperature increase for heat storage in the grid

### 5.3.2 Influence of different duration times of temperature increase

The second parameter investigated was the duration of the temperature increase. Here again three scenarios were analysed and compared with the reference case. In all of the cases the supply temperature was raised by 15 K. In the first case, the temperature increase lasted as long as in the actual experiment from 2 a.m. on Monday to 7 a.m. on Tuesday (for 29 h). Then, also the increase for 6, 5, and 4 h (starting at 1 a.m., 2 a.m. and 3 a.m. on Tuesday, respectively) were investigated. In each of these cases the grid discharge occurred at the same time.  Figure 13 shows supply temperature profiles for the cases analysed.

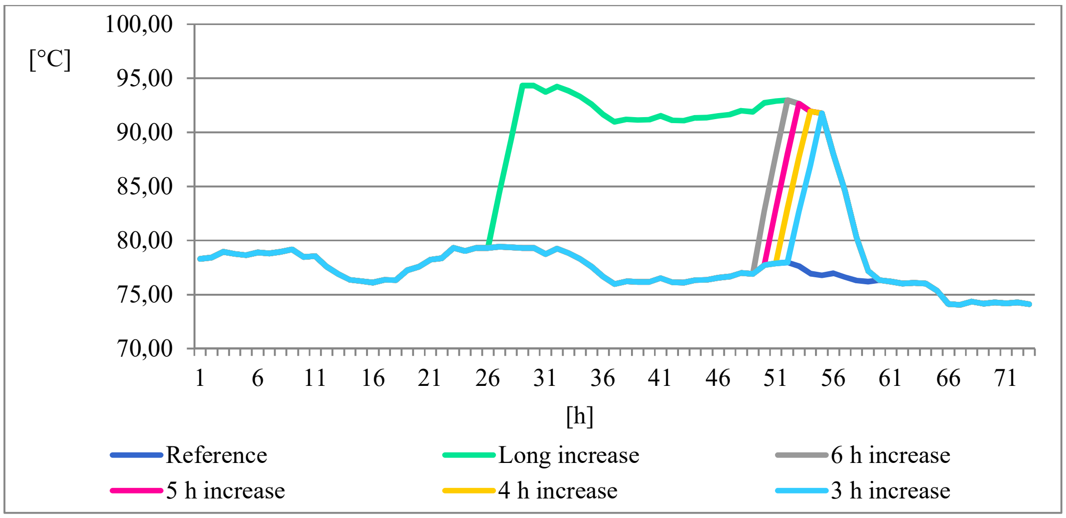


Figure 23. Supply temperature in different scenarios regarding the duration of temperature increase for heat storage in the grid

### 5.3.3 Adjustment of return temperature in the building with malfunction

The third parameter investigated was the influence of return temperature from the buildings. Initially, only the known malfunction in one of the buildings (Building 10) was corrected and the return temperature there was lowered to 40 °C. The value was chosen based on the requirements set for buildings built or extensively renovated in and after 2016 in HOFOR's "Technical Regulations".

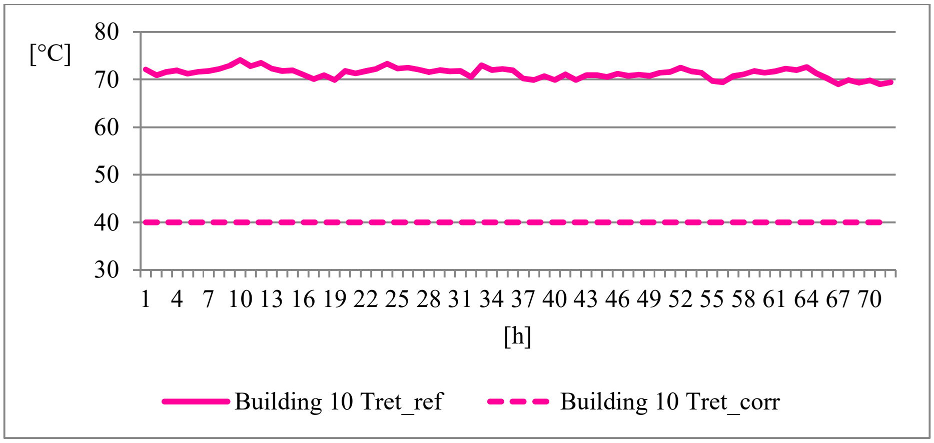


Figure 24. Return temperature from the substation in Building 10 in the reference case and in the investigated scenario

### 5.3.4 Adjustment of the return temperature in all the buildings

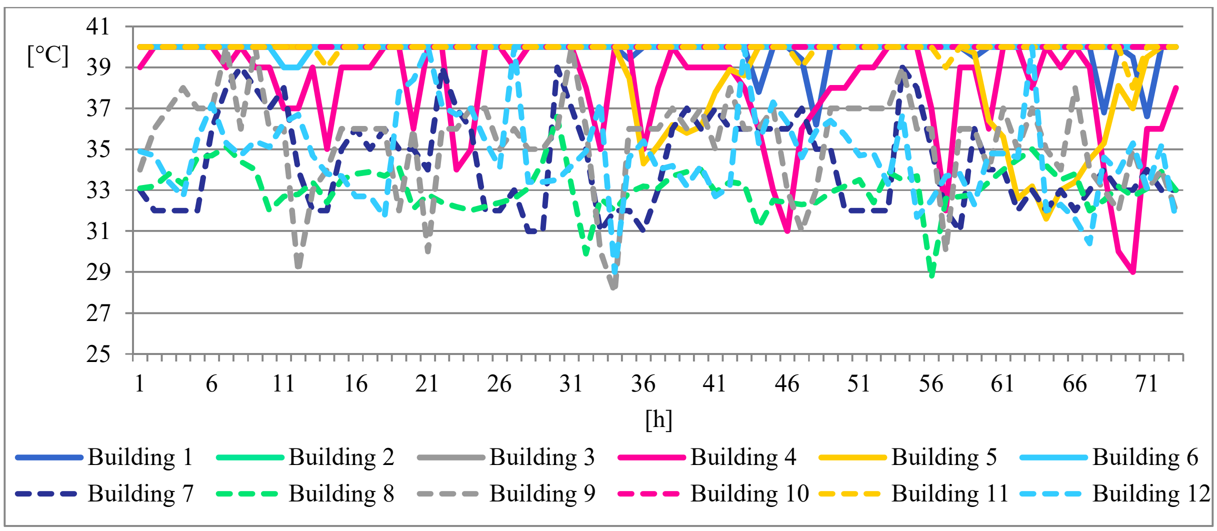


Figure 25. Return temperatures from all of the building substations in the investigated scenario with all of the return temperatures adjusted to maximum 40 °C

As the next step, return temperature from all buildings was adjusted so that it does not exceed 40 °C. Figure 25 shows the modified return temperatures used as input in the 12 buildings, where the measurements were available.

### 5.3.5 Network with lower heat density

The last factor which influence on the potential of heat storage in the grid was investigated was the heat density of the area. As the area analysed in the case study is characterized by high heat density, also the scenarios with lower heat density were investigated. To do so, scenarios with 150%, 75%, 50% and 25% of reference heat demand were simulated. The shape of the heat demand profiles in individual buildings was kept identical and no buildings were disconnected from the network. In all the cases the temperature was periodically increased by 15 K.

# 6 Analysis of the simulation results

## 6.1 Model validation

As the first step, the grid model and the methodology used to assumptions regarding buildings' energy use and return temperatures were validated. To do so, the simulation results were compared with the measurement data. Figures 26, 27 and 28 show the validation results for the reference case, where simulated heating power, mass flow and return temperature were compared with the measurements.

In Figure 26 it can be seen, that the simulated power of the heat source in the model matches the measured values well.

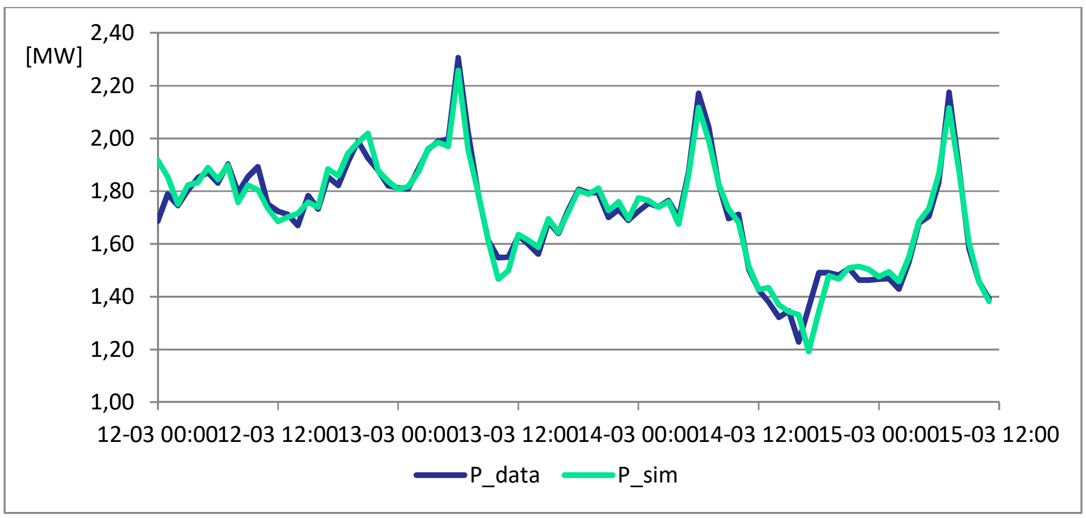


Figure 26. Measured and simulated thermal power at the entrance to the area in the reference case

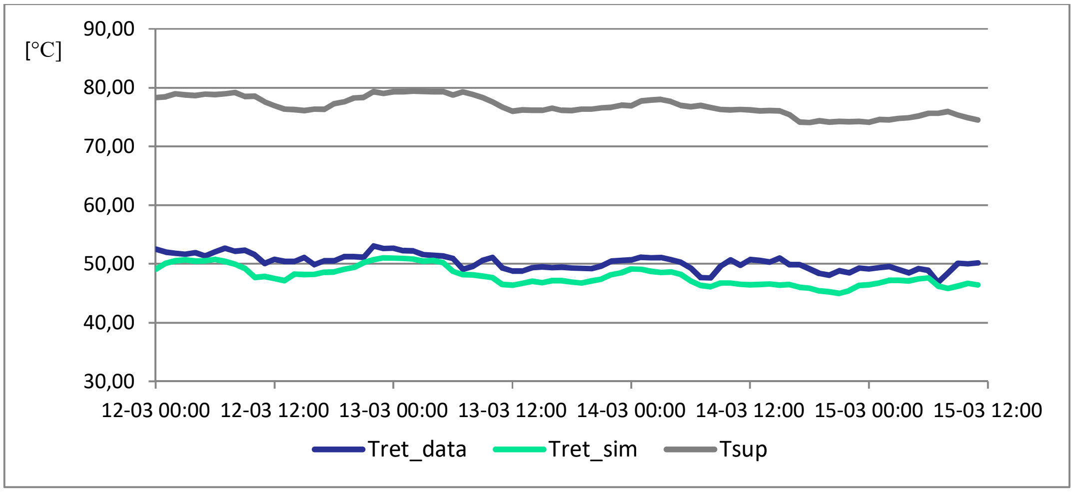


Figure 27. Supply temperature and measured and simulated return temperatures at the entrance to the area in the reference case

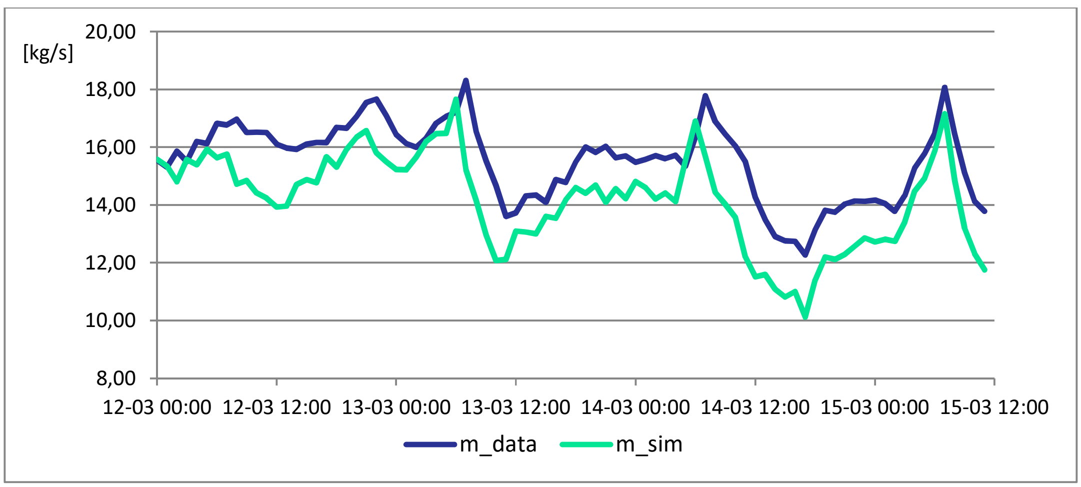


Figure 28. Measured and simulated mass flow at the entrance to the area for the reference case

Similar validation was performed also for the model with the data from the experiment period. The validation results can be seen in Figures 29, 30 and 31.

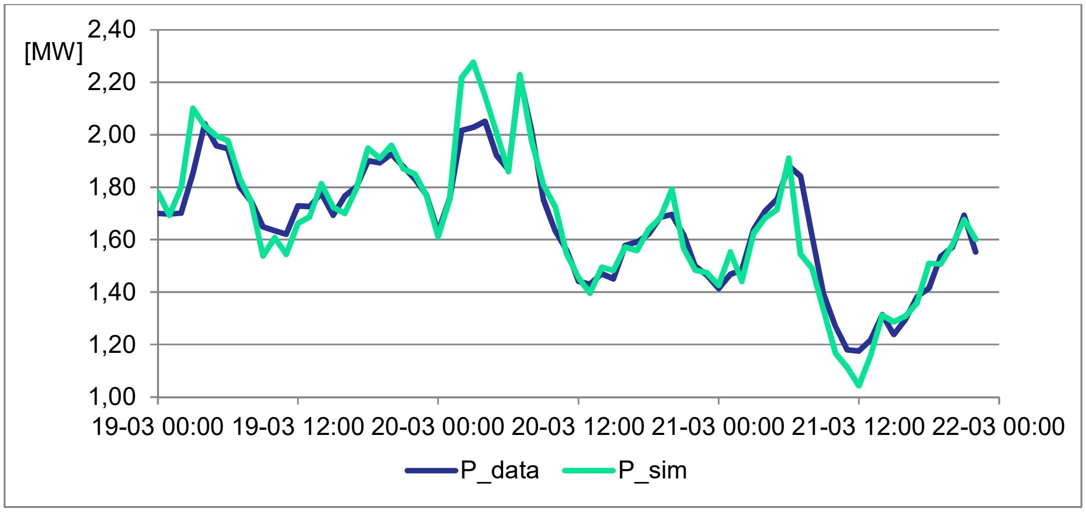


Figure 29. Initial comparison of measured and simulated thermal power at the entrance to the area in the experiment case based on the data from March

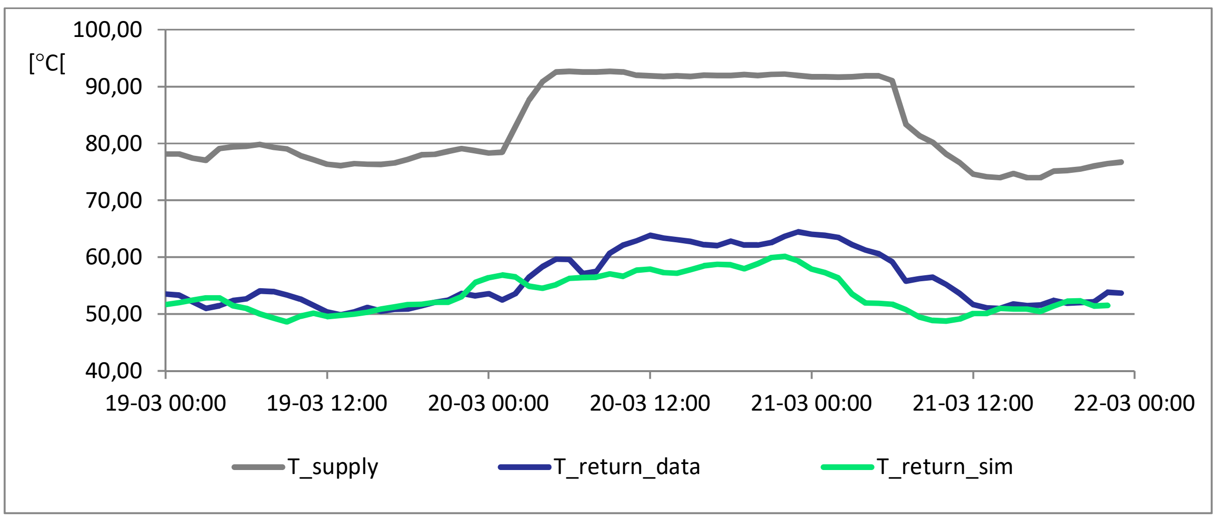


Figure 30. Supply temperature and measured and simulated return temperatures at the entrance to the area in the experiment case

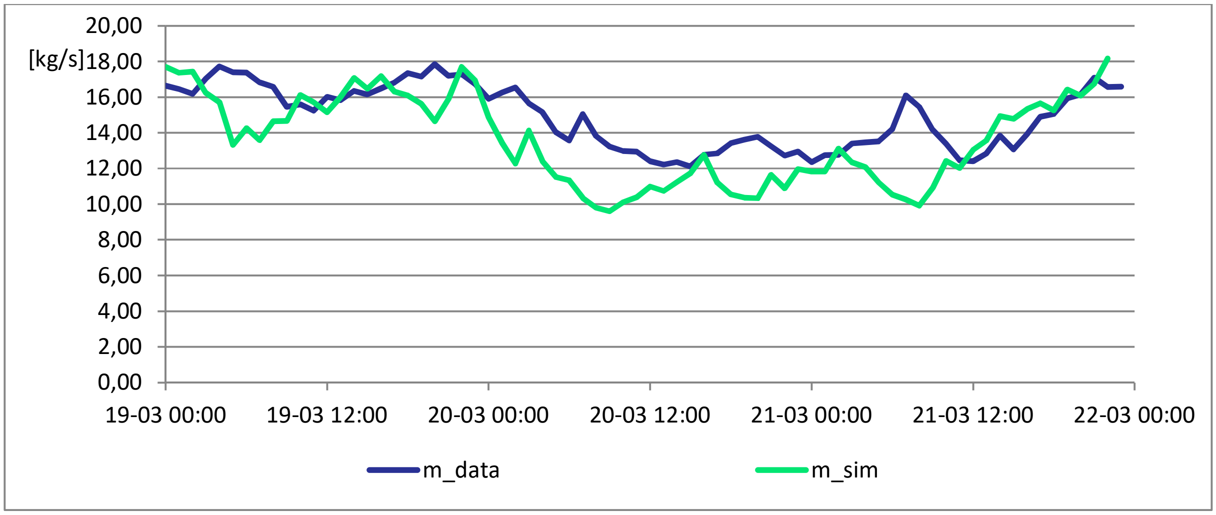


Figure 31. Measured and simulated mass flow at the entrance to the area for the experiment case

Moreover, to check the model performance more in detail, the simulated and measured supply temperatures over time in a node at the beginning of the grid (Building 10) and two nodes further down in the network (Building 2 and Building 8) were investigated. The results of the comparison are shown in Figure 32, 33 and 34. This was done for the data from the experiment scenario in March, where the increase and the time it reaches individual nodes can be clearly observed. The simulated and measured supply temperatures to individual nodes are in acceptable agreement.

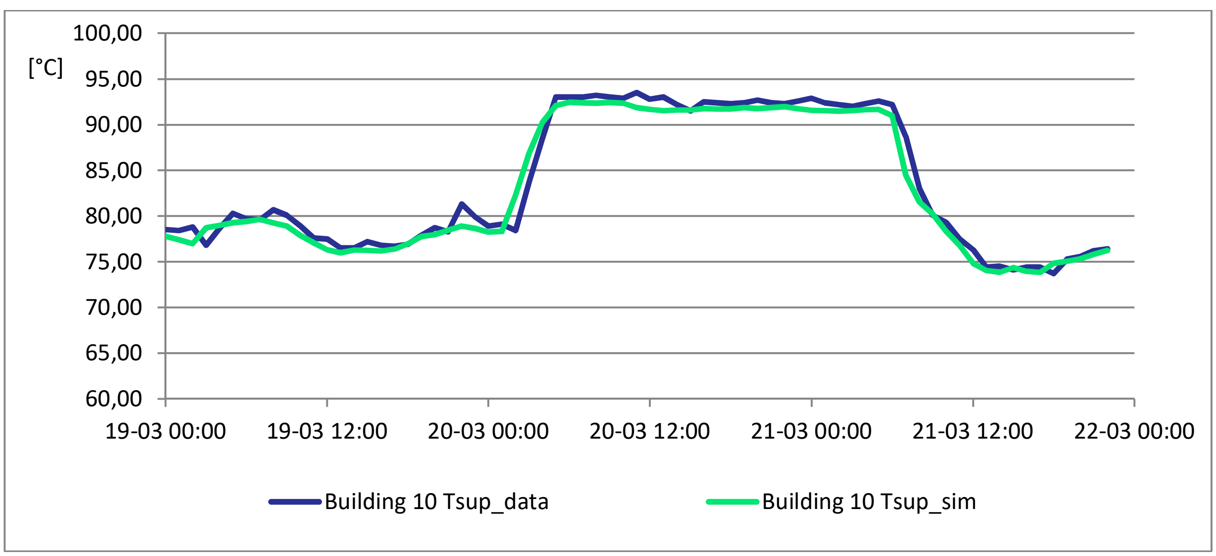


Figure 32. Measured and simulated temperature to Building 10 based on the data from the March test

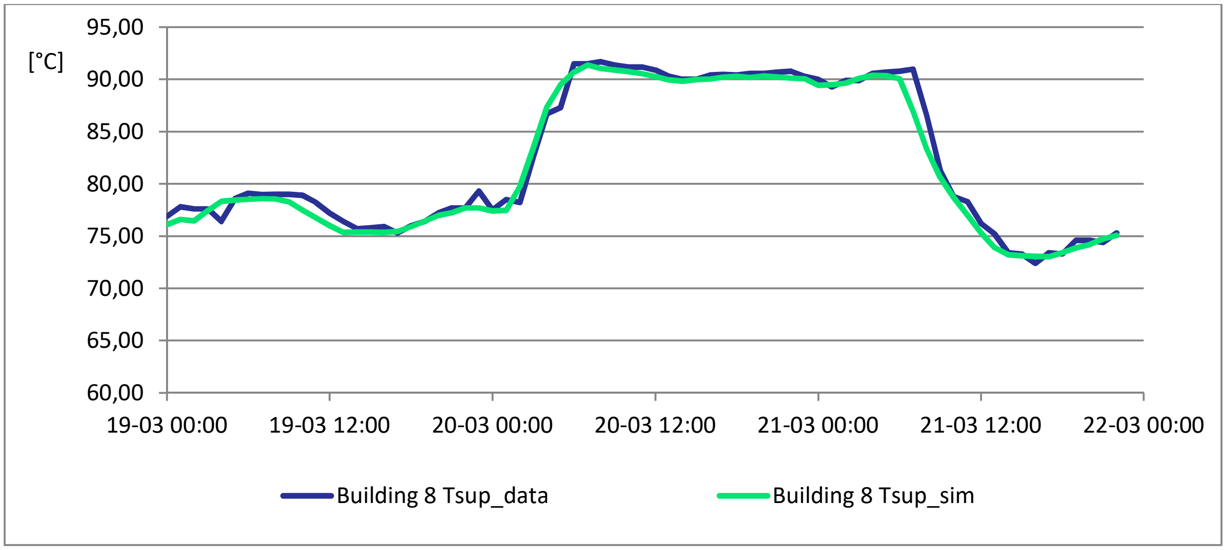


Figure 33. Measured and simulated temperature to Building 8 based on the data from the March test

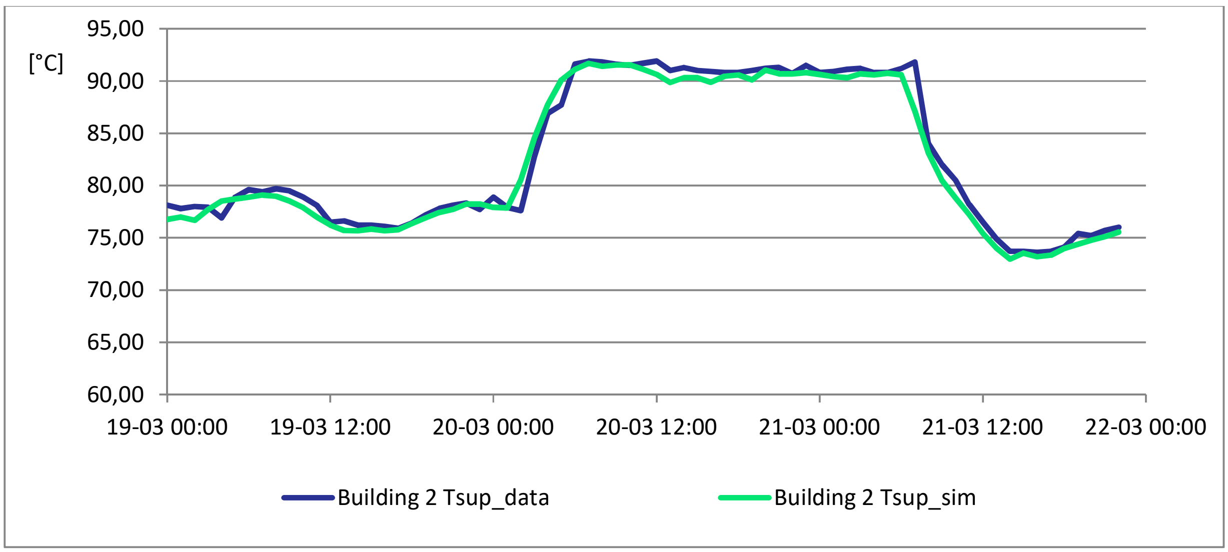


Figure 34. Measured and simulated temperature to Building 2 based on the data from the March test

## 6.2 Influence of different levels of temperature increase

The influence of different levels of temperature increase on the subsequent peak demand was also investigated. The scenarios included were described in section 5.3.1 “Influence of different levels of temperature increase” and the profiles used can be seen there in Figure 22.

Figure 35 and Table 4 show the results of the simulations performed for three different temperature increase levels. The second column contains the values of simulated peak thermal power. The values in the third column represent heat delivered to the area during the grid discharge period. Heat delivered to the area in the whole investigated period is in fourth column. Fifth, sixth and seventh column show the relative comparison between the values from different scenarios and the reference case. It can be seen that applying the heat storage strategy leads to a slight decrease in the peak demand. The decrease is the greater the higher was the temperature increase, as shown in Table 4. Similar decrease in the heat delivered in the discharge period is also observed. However, applying the heat storage strategy with the temperature increase over such a long period resulted also in increased energy use in all the cases considered.

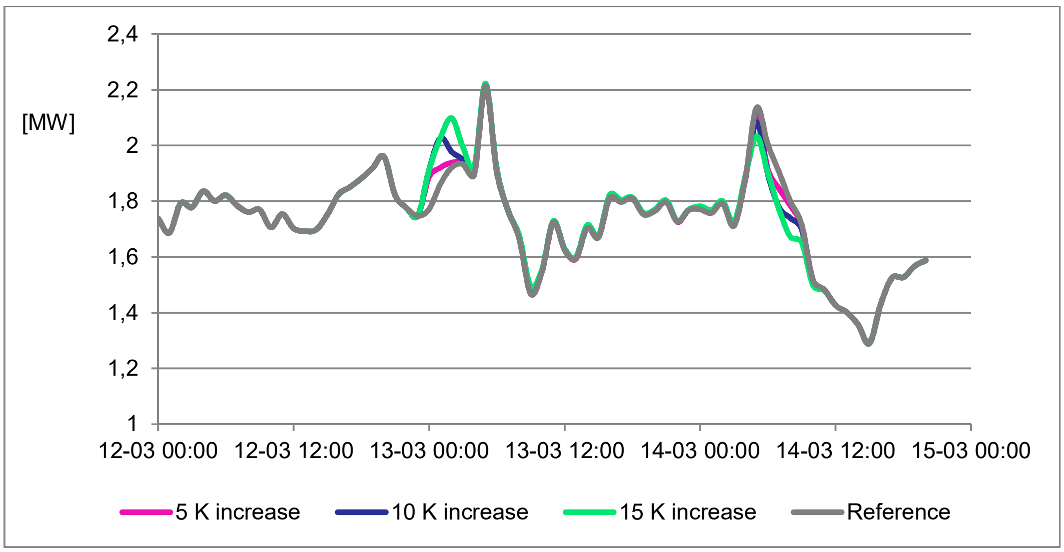


Figure 35. Simulated thermal power in the reference case, as well as with the temperature increase by 15, 10 and 5 K in the same period as in the experiment case

Table 4 Simulation results for different levels of temperature increase (simulation with 1 h time step)

| Scenario | Simulated peak [MW] | Heat delivered in discharge period [MJ] | Total heat delivered [MJ] | Simulated peak [%] | Heat delivered in discharge period [%] | Total heat delivered [%] |
|---|---|---|---|---|---|---|
| Reference | 2.135 | 41574 | 425751 | 100% | 100% | 100.00% |
| Long increase by 5 K | 2.107 | 41134 | 426028 | 98.7% | 98.9% | 100.07% |
| Long increase by 10 K | 2.083 | 40640 | 426324 | 97.6% | 97.8% | 100.13% |
| Long increase by 15 K | 2.033 | 40146 | 426564 | 95.2% | 96.6% | 100.19% |

## 6.3 Influence of different duration times of temperature increase

The second analysed factor was the duration of temperature increase. The scenarios included were described in section 5.3.2 “Influence of different duration times of temperature increase” and the profiles used can be seen there in Figure 23.

Figure 36 shows the results of the simulations performed for three selected scenarios regarding duration of the temperature increase, while all of the obtained results are presented in Table 5. It can be seen that the simulated peak and the heat delivered in the discharge period remain the same for the increase that lasted 29 h and the increase that lasted 6 h, and the 5-hour increase had the same heat delivered in the discharge period, lower total heat delivered and only slightly higher simulated peak demand (95.4% compared to 95.2% for 29 and 6 h increases). This corresponds to the results of measurement analysis discussed in section 4.3. As expected, shorter temperature increases resulted in general in lower total energy use.

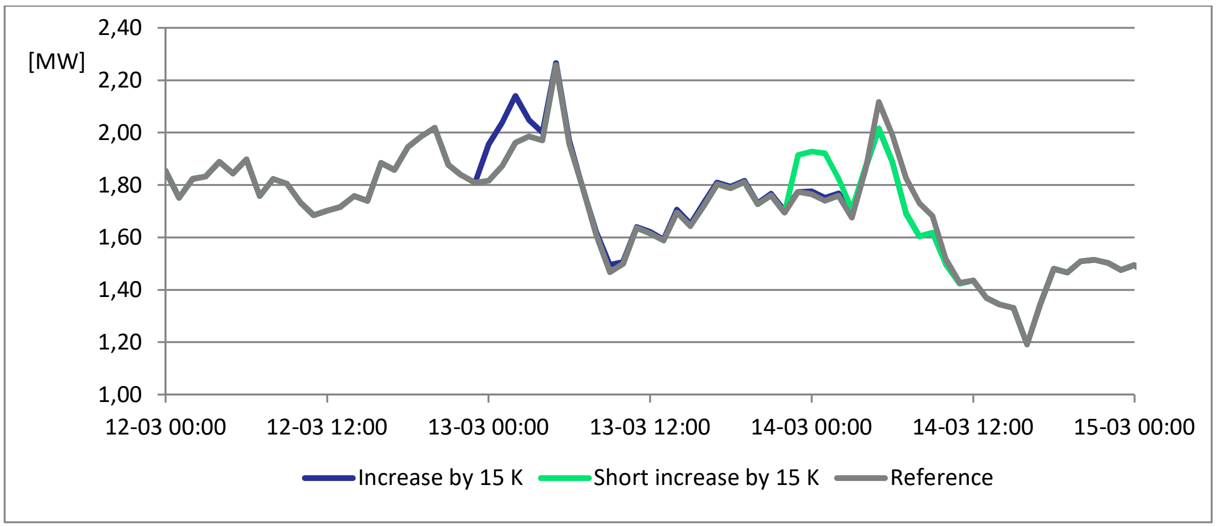


Figure 36. Simulated thermal power in the reference case, as well as for the long increase by 15 K and short increase by 15 K

Table 5. Simulation results for different durations of the increase (simulation with 1 h time step)

| Scenario | Simulated peak [MW] | Heat delivered in discharge period [MJ] | Total heat delivered [MJ] | Simulated peak [MW] | Heat delivered in discharge period [%] | Total heat delivered [%] |
|---|---|---|---|---|---|---|
| Reference | 2.135 | 41574 | 425751 | 100% | 100% | 100.00% |
| Long increase by 15 K | 2.033 | 40146 | 426564 | 95.2% | 96.6% | 100.19% |
| 6 h increase by 15 K | 2.034 | 40146 | 425910 | 95.2% | 96.6% | 100.04% |
| 5 h increase by 15 K | 2.037 | 40147 | 425890 | 95.4% | 96.6% | 100.03% |
| 4 h increase by 15 K | 2.051 | 40154 | 425868 | 96.1% | 96.6% | 100.03% |

| | | | | | | |
|---|---|---|---|---|---|---|
| 3 h increase by 15 K | 2.099 | 40183 | 425890 | 98.3% | 96.7% | 100.03% |

## 6.4 Influence of the adjustment of return temperature

The third factor investigated was the influence of possible changes in return temperature from the building substations on the effectiveness of the heat storage in the grid. The scenarios investigated are described in sections 5.3.3 "Adjustment of return temperature in the building with malfunction" and 5.3.4 "Adjustment of the return temperature in all the buildings". In both of the cases a slight increase of the peak demand was observed under the assumed conditions. However, as expected, flow in the network decreased visibly, as shown in Figure 38.

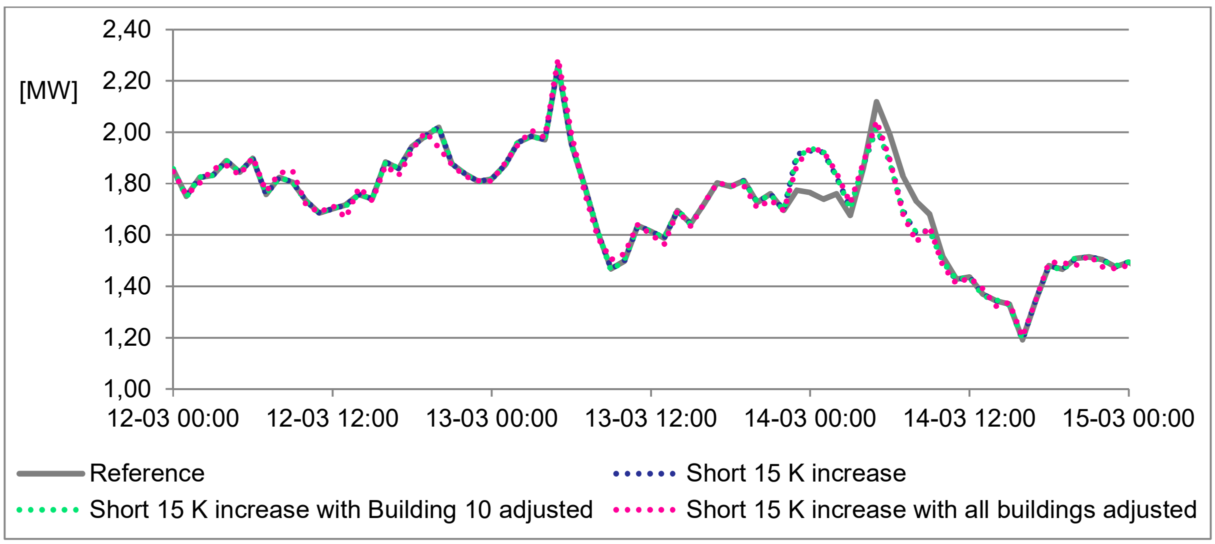


Figure 37. Simulated thermal power in the reference case and in the cases with short 15 K increase for different building return temperature scenarios

Table 6. Simulated values of the peak demand on 14.03 in the reference case and in the scenarios with short 15 K supply temperature increase

| **Scenario** | **Value of the simulated peak demand on 14.03 [MW]** |
|---|---|
| Reference scenario | 2.118 |
| No change in $T_{ret}$ | 2.016 |
| $T_{ret}$ from Building 10 adjusted | 2.018 |
| $T_{ret}$ from all buildings adjusted | 2.045 |

The reasons for it are further discussed in detail in the Discussion section.

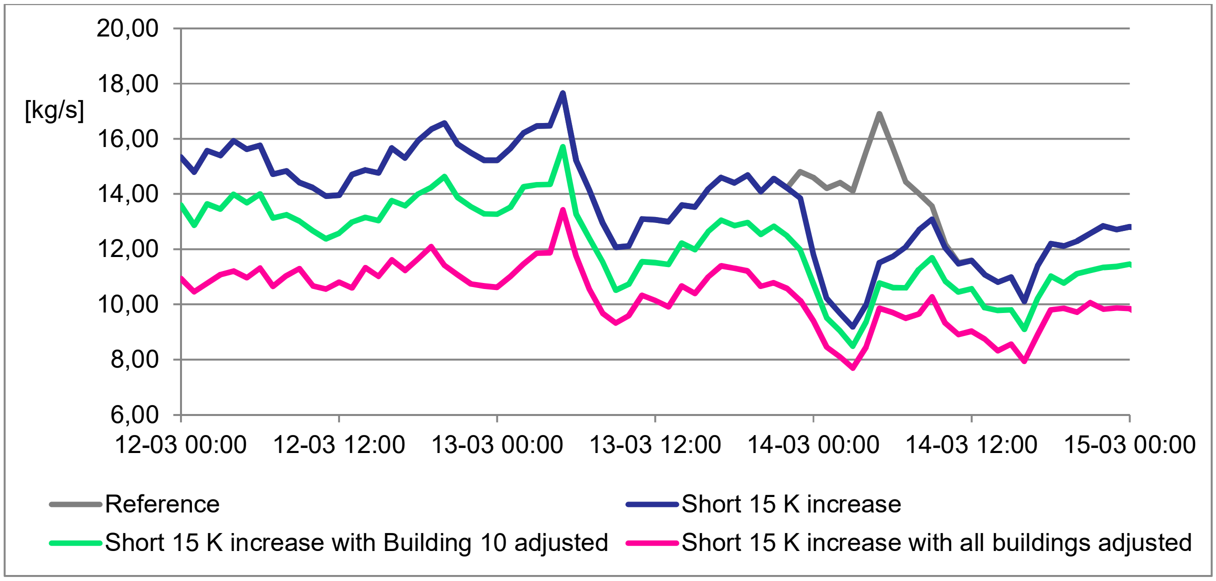


Figure 38. Simulated mass flows in the network in the reference case and with short temperature increase by 15 K and different levels of return temperature from the buildings

## 6.5 Network with lower heat density

The last scenario investigated included the analysis focused on the impact of the heat density of the area on the viability of heat storage in the grid. The scenario was described in section 5.3.5 “Network with lower heat density”. The last factor which influence on the potential of heat storage in the grid was investigated was the heat density of the area. To do so, scenarios with 150%, 75%, 50% and 25% of reference heat demand were simulated. The shape of the heat demand profiles in individual buildings was kept identical and no buildings were disconnected from the network. In all the cases the temperature was periodically increased by 15 K. The pipe dimensions were identical in all the cases.

The results for the cases analysed are shown in Table 7. Simulations were made for a longer period than in cases presented in Table 4 and 5, what resulted in greater total heat delivered in the cases with the demand left unchanged. It can be seen, that both the decrease in simulated peak and the decrease in heat delivered in the discharge period are greater for the case with lower heat demand. The exception here is the case with 25% of the original heat demand, where simulated peak decreased proportionally less than for the case with 50% of the original heat demand. However, as expected, the decrease in heat delivered in the discharge period was still relatively greater than in cases with higher heat demand.

Table 7. Simulation results for different levels of temperature increase and different durations of the increase (simulation with 1 h time step)

| Scenario | Simulated peak [MW] | Heat delivered in discharge period [MJ] | Total heat delivered [MJ] | Simulated peak [%] | Heat delivered in discharge period [%] | Total heat delivered [%] |
|---|---|---|---|---|---|---|
| 150% heat demand ref | 3.297 | 60196 | 747747 | 100.0% | 100.0% | 100.00% |
| 150% heat demand sim | 3.185 | 58847 | 748623 | 96.6% | 97.8% | 100.12% |
| 100% heat demand ref | 2.135 | 41574 | 503601 | 100.0% | 100.0% | 100.00% |
| 100% heat demand sim | 2.033 | 40146 | 504489 | 95.2% | 96.6% | 100.18% |
| 75% heat demand ref | 1.662 | 30951 | 384836 | 100.0% | 100.0% | 100.00% |
| 75% heat demand sim | 1.573 | 29467 | 385658 | 94.7% | 95.2% | 100.21% |
| 50% heat demand ref | 1.113 | 21049 | 262280 | 100.0% | 100.0% | 100.00% |
| 50% heat demand sim | 1.005 | 19524 | 263083 | 90.3% | 92.8% | 100.31% |
| 25% heat demand ref | 0.568 | 11085 | 139590 | 100.0% | 100.0% | 100.00% |
| 25% heat demand sim | 0.537 | 9549 | 140385 | 94.4% | 86.1% | 100.57% |

# 7 Technical limitations and legal regulations

In the context of commercial agreements and regulations, no potential obstacles were identified. The supply temperature in the distribution grid cannot exceed 110 °C according to the regulations in "Tekniske bestemmelser for fjernvarme, varmt vand". The increase is relatively simple to perform technically, as the supply temperature in the transmission grid is higher than in the distribution grids and the setpoint change requires only a change in the control of a heat exchanger between the transmission grid and distribution grid(s). It is important, however, that the consumer substations operate correctly to avoid problems with increased return temperature. Additionally, the speed of temperature increase should not exceed 4 K/h.

Increasing the frequency of temperature changes in the network leads to increased fatigue of pipes caused by their thermal expansion. This was investigated by the authors of the "SGMS –

SmartHeatNet. SmartHeatNetworks - Intelligente Fernwärmenetze (FFG-Nr. 825549). Ein Projekt im Rahmen der Smart Grids Modellregion Salzburg" report and the increase in fatigue was found to be insignificant. However, the authors suggested the need for a more detailed analysis, as the calculations performed were valid only for the straight pipes and it is the compensators that are impacted by the stress from the thermal expansion of pipes the most.

# 8 Discussion

The measurements from both tests indicate a decrease in power delivered to the area during the period of storage discharge compared to the reference period. In case of the test in March, the relative peak on Tuesday morning in the experiment period is lower than the three other weekday morning peaks. Still, this effect is not clear in the data from the October test, where the difference between daily average power and hourly power during discharge period was very similar to the values on two other weekdays. However, the air temperatures and solar radiation during the storage discharge period in the experiment period were higher than the temperatures in the corresponding reference period and the exact impact of different weather conditions on the measurement results is difficult to estimate. The variability of weather conditions is one of the reasons for the difficulties with using the measurement data to identify the effectiveness of heat storage in district heating pipes in reducing peak demand.

In case of the simulation results, supply temperature increase by 5, 10 and 15 K resulted in the peak decrease of 0.028 MW, 0.052 MW and 0.102 MW, respectively (1.3%, 2.4% and 4.8% of the reference peak demand). At the same time, as expected, the greater the temperature increase, the grater was total heat delivered during the simulation period.

No benefits related to longer charging period were observed. In the simulation study, the peak demand was practically identical in case of the 29 h increase and in case of the 6 h increase, with the 5 h increase resulting in only slightly lower decrease (2.033 MW, 2.034 MW and 2.037 MW, respectively). At the same time, the total energy delivered was the greater the longer was the temperature increase. However, the results from the field test in October indicate the importance of proper timing of the supply temperature increase. In case of storing heat in a district heating grid with the aim of lowering future peak heat demand (when the grid is not charged using surplus energy), it is also important to optimize charging duration. In an ideal scenario, setpoint would be raised only long enough to charge the available capacity, but not longer, to avoid increased heat loss. All of it requires accurate estimation of flows in the network.

However, the results from the field test in October indicate the importance of proper timing of the supply temperature increase. In case of storing heat in a district heating grid with the aim of lowering future peak heat demand (when the grid is not charged using surplus energy), it is also important to optimize charging duration. In an ideal scenario, setpoint would be raised only long enough to charge the available capacity, but not longer, to avoid increased heat loss.  All of it requires accurate estimation of flows in the network.

The results of the test performed in October show the importance of timing the temperature increase correctly if the aim is to use it as heat storage to decrease peak heat demand. It requires both scheduling the temperature increase early enough that it reaches most of the pipes that are supposed to be used as the storage, as well as decreasing the temperature to the previous setpoint at the right time for the storage discharge to occur during the peak demand period. All of it requires accurate estimation of flows in the network.

No improvement in the effectiveness of applying heat storage in the grid as a peak demand reduction strategy was observed at reduced return temperatures. In fact, the decreased return temperature lead to slight increase in the peak demand. This is related to the slight increase in heat losses from the grid that can occur due to the low flow speed in the network. The increase in the peak is related only to the increase in heat demand and does not take into account a decrease in pumping energy. T accounts neither for a potential increase in plant efficiency that would occur in plants using condensing boilers, nor for an increased possibility of integrating renewable energy sources that exists in systems operating at lower temperatures.

Due to the fact that the experiment in October did not work as expected due to the too short temperature increase, it was decided to use data from March experiment as a the input for the performed simulations. There is a mismatch between the simulation results and the measurements made in the district heating grid in Nordhavn during the investigated periods. The reason for it is that measurements from 7 larger buildings and all the row houses were not available at the time of the test and the assumptions made do not fully match the actual behaviour of the buildings. Part of the problem is most likely caused by another substation malfunction similar to the one that occurred in Building 10 that was discovered in one of the buildings where no measurements were available later during the year. This lead to increased return temperature from the substation during the period of temperature increase, as the control equipment did not function properly and the mass flow through the substation was most likely not decreased. It could explain the increased mismatch between simulated and measured return temperature in the experiment period compared to the reference period, as can be seen in Figure 30.

Another problem related to the assumptions regarding the building energy use during the test period was how to include the energy needed to charge the network in the input data. The results for the simulation where this factor was not accounted for can be seen in Figure 29. It can be seen that in the period, when charging of the grid is expected, the simulation results exceed the measured values. Then, during the period when a storage discharge occurs, the simulated power is lower than the measured one. It is most likely caused by including charging and discharging the storage in the simulation twice (once by dividing it between the buildings, where the measurements were not available and then by simulating the storage charging).

Another factor that was not included in the analysis was the expected decrease in return temperature from the buildings that should occur at increased supply temperature, as described in section “Analysis of measurement data”. This effect can be seen in the measurements from Langelinie heat exchanger shown in Figure 10, where in the period of increased supply temperature average return temperature was 2.3 degrees lower than in the surrounding period (48.9 compared to 51.2 °C). However, in case of a smaller network, such as the one in Århusgade area, the influence of individual buildings is much more pronounced and in case of a control system malfunction in some of them such a decrease may not occur. This can be seen in the measurements made in Århusgade area, where the return temperature from the area increased during the experiment (61.0 compared to 52.5 °C on average). Additionally, the effect of lowered return temperature should not be used as an argument for increasing design temperatures in district heating systems.

The usability of the strategy in cold winter periods in dense urban area appears to be limited due to a limited storage capacity of the grid. Already in the March test the total available storage capacity at 15 K increase of the grid was calculated to be about 0.45 h of average heat demand and during the actual operation not all of the gird capacity will be used as storage. The number of hours of storage will be even lower in the cold winter periods, but even then this strategy can be introduced without additional investment costs. To increase the energy production savings from heat storage in the grid, the strategy should be implemented simultaneously with flexible district heating customers, as described in deliverable 5.2.C "Short term heat storage in buildings".

Heat storage in the grid may be useful as a supplementary method of energy storage in the periods when cheap, surplus energy is available, e.g. in case of surplus electricity production from renewable sources. This could be done e.g. in combination with heat pumps. Heat storage in the grid can act also as additional heat storage for heat pumps, both facilitating their operation and making it possible to optimize the operation based on the electricity prices. It can be used also in case of capacity problems and when part of the system requires repair or maintenance.

Moreover, this strategy does not require any additional investment costs and can be applied in the existing district heating systems.

# 9 Conclusions

The aim of the report was to investigate the potential of using the district heating network as a heat storage. It has been previously shown that district heating systems can absorb large amounts of energy coming e.g. from electricity generation from fluctuating renewable energy sources.

The measurements made during two tests run in March and October 2016 were analysed. Calculated storage potential of the grid at the heat demand that occurred during the two tests is not significant. At 15 K increase, the additional energy stored in the grid could cover the average heat demand in the reference period for ca. 30 min and in reality not all of the network volume will be used. The measurements indicate a decrease in peak demand during the period of storage discharge. However, while the relative hourly heat demand during the discharge periods is either lower or on a similar level as during other weekdays, it is difficult to differentiate between the influence of weather conditions and the storage discharge on the demand profile. Significant decrease in the flow was measured for the whole area of Østerbro and Nordhavn. This effect is visible also in Århusgade area, but is less pronounced there due to malfunctions in some of the buildings. The measurements results confirm also that in correctly functioning substations return temperature from the building decreases at increased supply temperatures. This effect is also seen in large networks - in case of the whole Østerbro district heating network, the average return temperature from the grid during the temperature increase was 2.3 K lower than under normal operation. The results of the test performed in October indicate also the importance of timing the increase properly, taking into account flows in the network and time it takes for the increase to reach different buildings, while using this strategy to decrease peak demand.

To further investigate the potential of the district heating network, a model based on the real network was built in Termis and different scenarios concerning strategies of charging the grid were analysed. The results of the analysis show limited potential of using heat storage in the district heating pipes to decrease peak demand – in the base scenario, where the temperature was increased by 15 K compared to the reference setpoint, the simulated peak demand decreased by 0.102 MW (4.8% of the reference peak demand). Such a decrease may be sufficient to avoid or postpone the start-up of smaller peak-load boilers in the district heating system. It was also determined that extending the time of charging the grid over what is needed for the increase to reach to its end does not result in additional benefits – on the contrary, it leads to greater energy use due to increased heat loss. For the cases with changed heat demand, both the decrease in simulated peak and the decrease in heat delivered in the discharge period are the greater, the lower the heat demand.

Still, the strategy can still be potentially useful as a supplementary method of energy storage in the periods when cheap, surplus energy is available. It can also be applied in combination with flexible district heating customers to further increase the flexibility potential that can be provided by a district heating system.

Finally, the technical limitations and legal obstacles for applying this strategy were analysed. No legal obstacles for using heat storage in the grid were identified. Technical limitations that have to be taken into account include the maximum speed of temperature increase and, in cold periods when the supply temperature is already high, maximum allowed supply temperature in the distribution network.

# 10 Prospective work

The prospective work should focus on investigating the possible applicability of this strategy in combination with other technologies, to see if there are additional benefits to be obtained. The two main options here would be combining it with electricity-based heat sources such as heat pumps and applying it in combination with flexible customers' operation.

Heat storage in the network could be used in combination with heat pumps to store heat produced from surplus electricity generated from fluctuating energy sources. Moreover, the grid could be used as additional heat storage with the aim of optimizing heat pump operation.

The second area that should be investigated is utilizing this strategy together with flexible customers' operation to further reduce the peak load demand. Here, heat storage in the grid would fulfil supplementary role, increasing even more flexibility potential of district heating networks.

Also the influence of network heat density on effectiveness of the heat storage in the grid should be investigated more in detail.

# 11 Executive Summary

The report describes the results of a case study performed in the Nordhavn and Østerbro area, Copenhagen. The aim of the case study was to investigate the possibility of reducing peak heat demand in the district heating system by using district heating pipes as short-term heat storage. It was achieved by temporarily increasing the supply temperature in the distribution network by changing the temperature setpoint in the heat exchanger connecting the distribution grid with the transmission grid. First part of the report describes the case study area and the measurement infrastructure, as well as the performed tests. The second part of the report focuses on the analysis of measurement data collected during two tests. Thermal power delivered, changes in the mass flow and return temperature in the network, daily demand peaks were all analysed. The relative hourly heat demand during the discharge periods is either lower or on a similar level as during other weekdays, however, it is difficult to differentiate between the influence of weather conditions and the storage discharge on the demand profile. The measurements results confirm also that in correctly functioning substations return temperature from the building decreases at increased supply temperatures. As expected, the flow in the network during the periods of increased temperature decreases significantly. The third part of the report focuses on a simulation study that was performed using the model of the case study area. In the simulation study, different scenarios regarding temperature increase level and its duration, as well as different heat demand in the area were investigated. The impact of the changes in return temperatures from building substations was also investigated. The simulation results also show potential of using heat storage in the district heating pipes to decrease peak demand – in the base scenario, where the temperature was increased by 15 K compared to the reference setpoint, the simulated peak demand decreased by 4.8% of the reference peak demand. The temperature increase should not last longer than needed to charge the network, as it leads to increased heat losses and consequently energy use, without any added benefits. Finally, conclusions from the performed analysis and recommendations for prospective work were presented. The strategy can be potentially useful as a supplementary method of energy storage – in particular during the periods when cheap, surplus energy is available.

## Quality Assurance

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