Deliverables no.: D5.2c & D5.2d

District heating flexibility – short term heat storage in buildings

Photo: By & Havn / Ole Malling

HOFOR
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Public deliverable ☒
Confidential deliverable ☐

Preface

EnergyLab Nordhavn – New Urban Energy Infrastructures is an exciting project, which will continue until the year of 2019. The project uses Copenhagen's Nordhavn as a full-scale smart city energy lab, which main purpose is 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 DKK 143 m (€ 19 m), of this DKK84 m (€ 11 m) funded in two rounds by the Danish Energy Technology Development and Demonstration Programme (EUDP).

Forord

EnergyLab Nordhavn er et spændende projekt der løber til og med 2019. Projektet foregår i Københavns Nordhavn, og fungerer som et fuldskala storbylaboratorium, der skal undersøge, udvikle og demonstrerer løsninger for fremtidens energisystem.
Målet er at finde fremtidens mest omkostningseffektive energisystem, der desuden kan bidrage til 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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Executive Summary

Because renewable energy sources such as solar and wind are less predictable, and therefore not suitable to cover peak loads, oil and natural gas fueled boilers are started up to cover the peak loads that occur in a district heating network.

However, due to the economic and environmental challenges associated with the use of fossil fuels such as oil, the Danish Government have decided that the share of renewable energy sources in the district heating production must be increased by 33% by 2020 from 19% in 2009, and thus the production will have to cope with the penetration of renewables now and in the future.

To ensure an environmentally friendly and safe energy production for the future, part of the solution to make the district heating production in Copenhagen CO_2 neutral might be to manage the heating demand at the consumer side to allow for a more flexible energy production. A more flexible district heating consumption will make it possible to remove the CO_2 emitting peak load production, and increase the share of renewables. Furthermore, the flexibility of district heating in the future heating system, where heat pumps play an important role, could also benefit the electrical system.

In this project the peak consumption in both residential and office buildings was relocated by reducing the heating supply for shorter periods (3-5 hours) when shorter peak loads typically occur. By exploiting the short term heat storage in the buildings` thermal mass, the thermal comfort of the occupants was not deteriorated when the heating supply was reduced.

The investigations of short term heat storage in buildings were conducted through field measurements in 23 buildings in the Copenhagen district during the heating season of 2017/2018.

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3	20.04.2018	Kristian Honoré	2. draft
4	26.04.2018	Christine Sandersen	3. draft
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1. Introduction

Greater Copenhagen Utility Company (HOFOR), supplies heat to approximately 500.000 inhabitants, which is equal to 99% of the total heat consumption in Copenhagen. Today the largest proportion of heat distributed through the district heating system owned by HOFOR is produced on a natural gas heating plant, and 6 combined heat and power plants (CHP) - three waste incineration plants, and three plants that primarily burn biomass, natural gas and coal, but also a small proportion of oil.

1.1 Heat production in Greater Copenhagen

In the context of heat production, a distinction is made between the two types of loads that occur in a district heating (DH) network - base loads and peak loads.

1.1.1 Incineration plants and base load boilers

The base load can be defined as the continuous heat demand throughout a day, and is in the Greater Copenhagen area covered by incineration plants and CHPs. Waste incineration plants utilizes waste from households to heat up the DH water, while the base load production at the CHPs in Copenhagen is based on biomass (wood pellet and wood chips). As base loads are continuous loads on the DH system, the waste incineration plants and the base load boilers are constantly producing energy.

1.1.2 Peak load boilers

Whereas base loads are continuous, peak loads are larger, fluctuating loads. E.g. when the technical systems in an office building start up, or when several people shower in a residential building simultaneously. Shorter peak loads normally occur between 06-09.00 in the morning and 17-20.00 in the afternoon. These peak loads are typically covered by natural gas.

Longer lasting peak loads (days, or weeks) can also occur during periods with very low outdoor temperatures in the winter, when the heating demand is at its highest. When these longer lasting peak loads occur, the waste incineration plants and other base load boilers are unable to supply enough heat, and the oil fueled peak load boilers are started up. Oil fueled peak load boilers might also be started up in the event of a breakdown in one of the production plants. Oil is easy accessible in comparison to other fuels, but it is categorized as a fossil fuel with amounts of carbon dioxide (CO_2), Sulphur (S), nitrogen (N) and particle emissions it causes.

CO_2-neutral district heating by 2025

Today, about 60 % of the DH production in the Copenhagen area is CO_2-neutral (see figure 1), and when the new sustainable biomass CHP plant AMV4 will be in operation in 2020, this share will equal to about 80 % as coal will be replaced by biomass. The goal is however that the heat production in Copenhagen will be 100 % CO_2-neutral by 2025 [11].

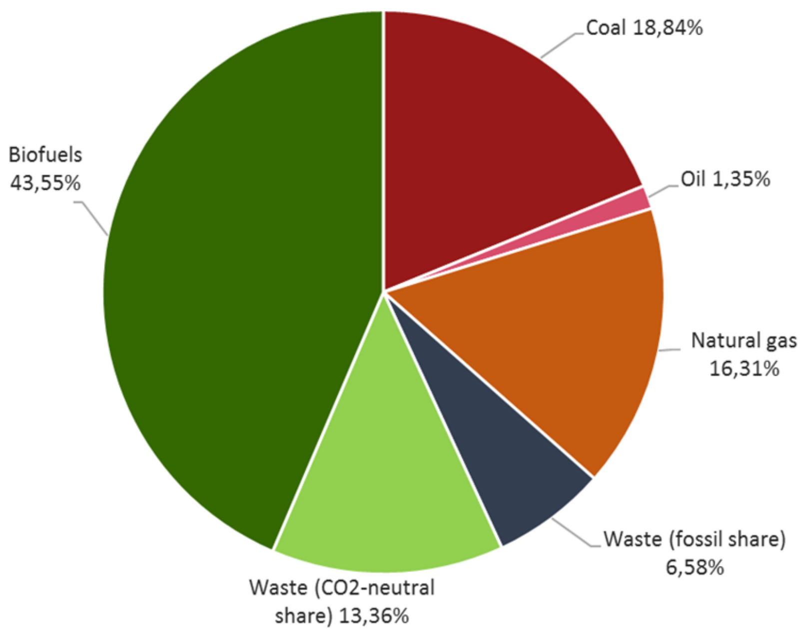

Figure 1 CO_2-neutral share of the district heating production in the Capital area, 2016

If these goals are to be achieved, the fossil fueled peak load boilers have to be substituted. One solution would be to manage the heat consumption at a building level – making the customers (buildings) flexible heat consumers. This would offer more flexibility to the heat production, and the start-up of oil- and natural gas fueled peak load boilers can be avoided, and so the fossil fuels can be phased out from the DH production in Copenhagen.

Flexible heat customers, and operation and maintenance contracts

The purpose of *Deliverable 5.2 c Short term heat storage in buildings* was to recruit 10 buildings to investigate the concept of flexible heat consumption. To demonstrate and prove the concept of flexible heat customers it is essential that the customers` heating centrals and heating systems are operated in an optimum manner. As the purpose of *deliverable 5.2 d Operation and maintenance contracts* was to take responsibility over 5 customers` heating system for optimum operation, the reporting of deliverables 5.2 c and d have been merged into one report.

In the investigations conducted in deliverable 5.2 c the heating supply is reduced for shorter periods to move peak consumption to periods when the heat production is under less pressure. The building mass is used as a short-term heat storage unit, and thus the thermal comfort is unaffected, when the heating supply is changed. Customers with flexible heating supply are called *flexible heat customers*, and are considered active participants and an instrument in the challenge of making the DH production in the Greater Copenhagen more flexible, and to reduce and eventually remove the use of fossil fuels.

As an integrated part of the customer recruiting process for the above described activity on flexible heat customers, *operation and maintenance contracts* was made with the customers according to deliverable 5.2 d. And so, the heating centrals of all the 23 recruited buildings are optimized and operated by HOFOR.

2. Background

As waste incineration is very environmentally friendly and cheap to operate, waste incineration plants are favoured for base load production all year around in Copenhagen. Waste cannot be stored for longer periods, and thus it must be utilized immediately. Because of this they are designed for a very stable energy production with little flexibility, making them less suitable to cover peak demands.

Renewable energy sources such as wind, and solar are too fluctuating, and cannot be stored sufficiently for later use in e.g. heat pumps to cover peak demands. Large heat accumulators is another option, but they are quite costly and space consuming. This is among other things the reason why the majority of peak load boilers today run on natural gas or oil.

Nevertheless, as the costs of fossil fuels are high and there is significant concerns regarding the emissions they cause, the Danish government have decided to increase the use of renewables in the energy production by 33% by 2020. Thus, to secure stability of energy supply, the DH production will have to be able to handle the penetration of renewables in the future.

2.1 Load shifting

One solution on how to make the energy system more flexible, and thus to phase out the use of fossil fuels could be to install thermal energy storage units, e.g. huge water-based heat storage tanks, to cover the energy demand during peak hours. This is however a very expensive and time consuming option to carry out in practice, and it requires a lot of space. Another more feasible, and less costly option may be to manage the heat consumption at building level in order to avoid the start-up of peak load boilers, and thereby the use of fossil fuels in the DH energy production.

In this investigation the aim was to use what is called a *load shifting* strategy to shift the peak consumption in a few selected buildings to others periods, by reducing the heating supply for shorter periods when peak loads typically occur between 06-09.00, and 17-20.00 as shown in figure 2. Depending on how many flexible heat consumers there is in an area, i.e. how much of the heat consumption is being moved, the heat consumption curve will become flatter and relieve the pressure on the production during peak hours. See figure 3.

Figure 2 Illustration of load shifting

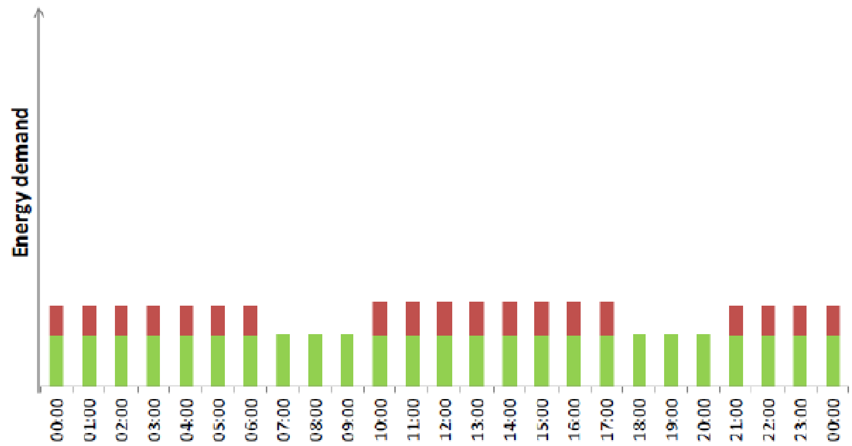

Figure 3 Illustration of flattened energy consumption curve due to load shifting

2.1.1 Short-term heat storage

To ensure a satisfactory thermal environment when the heating supply is reduced the *sensible heat storage* potential in buildings is exploited. Sensible heat storage occurs, when the temperature of a storage medium such as oil, water, sand, brick or concrete is changed, e.g. when the room temperature in a building is increased and heat is stored in the walls, floors and ceiling of the building. Later, when the room temperature is lowered, the process can be reversed and the heat can be released and used to heat up the room.

The heat storage capacity (kWh) depends on the specific heat capacity (J/kgK) of the storage medium, the density- (kg/m^3) and amount of thermal mass (m^3), and temperature change (ΔT) and increase almost proportionally. Thus, different types of buildings are expected to have various reactions to flexible heating supply.

2.2 Flexible heat customers

In Copenhagen there is a great variety of buildings from different building eras, however, there is often a concentration of similar building types in certain geographic areas in Copenhagen. E.g. in the Nordhavn district, there are primarily new buildings (built after 2000). These building are however not representative of the majority of buildings in the Copenhagen district. Because of this it was decided to recruit both old- and new buildings to participate in the investigations.

Figure 4 Flexible heat customers recruited in Nordhavn

In total 32 buildings in Copenhagen was recruited to participate in the project, see figure 4, and 5 respectively. Agreements was made with the building owner/building administrator about participating in the investigations on short term heat storage in buildings, thus allowing us to control their district heating substations for the duration of the project. An agreement was also made with the residents of the apartments, where the room sensors were placed, allowing us to collect and use the measurements for research purposes. Please find examples of agreements enclosed in appendix A, and B respectively.

Various technical difficulties have unfortunately delayed the start-up of the investigations in some of the recruited buildings, but at the present short term heat storage have been tested in 19 residential buildings, and 4 office buildings.

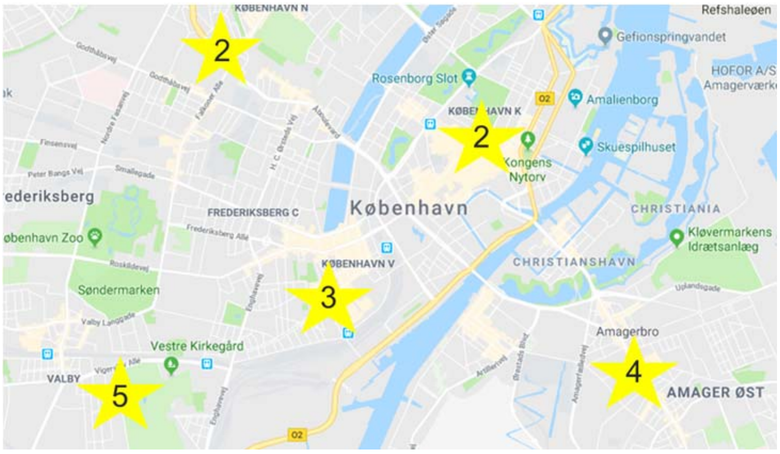

Figure 5 Flexible heat customers recruited in outside in other areas in Copenhagen

2.2.1 Grouping of buildings

To increase the validity of the test, similar buildings were grouped accordingly to give a better assessment basis in an analysis phase. They were grouped according to the criteria described in the following sections.

Construction type

The types of construction can give an indication of the heat storage capacity of a building. Concrete and brick buildings (see figure 6, left) , which are described as *heavy buildings*, have a higher thermal storage potential due to the high density and specific heat capacity of the material. Wooden constructions, and buildings with large glass facades (see figure 6 right) typically have a smaller thermal energy storage potential, and thus they are described as *light buildings*.


Figure 6 Left: Heavy brick building. Right: Light building with large glass facades

Building age

The age of the building can give an indication of the quality and level of insulation in a building, and thus the heat loss through the building envelope which is a contributing factor to the heat storage potential in a building. New buildings will typically have a high level of insulation of great quality, while in older buildings there is less, and often degraded insulation.

District heating substation

A district heating substation transmits the heat from the DH system to the buildings through a plate heat exchanger, and through a heating coil to the heating- and domestic hot water system respectively as shown in figure 7.

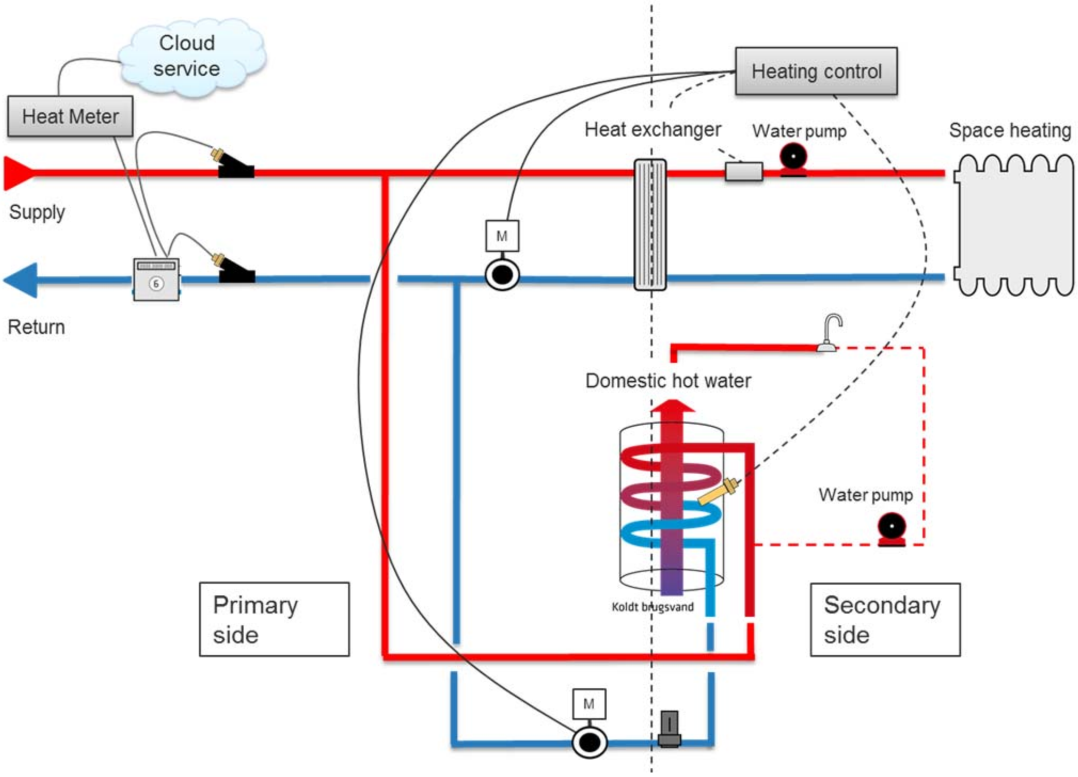

Figure 7 Typical district heating substation **with a central heating-, and a domestic hot water system**

Heating system

A building`s type of heating system can affect the energy savings potential during peak load hours significantly. E.g. 1-string radiator systems (only one pipeline, see figure 8 left) with very high supply temperatures have a poor cooling of the DH water as the return temperature very much follows the supply temperature. Thus, by reducing the supply temperature in a 1-string radiator circuit for a short period, the cooling (ΔT) of the DH water is immediately improved.

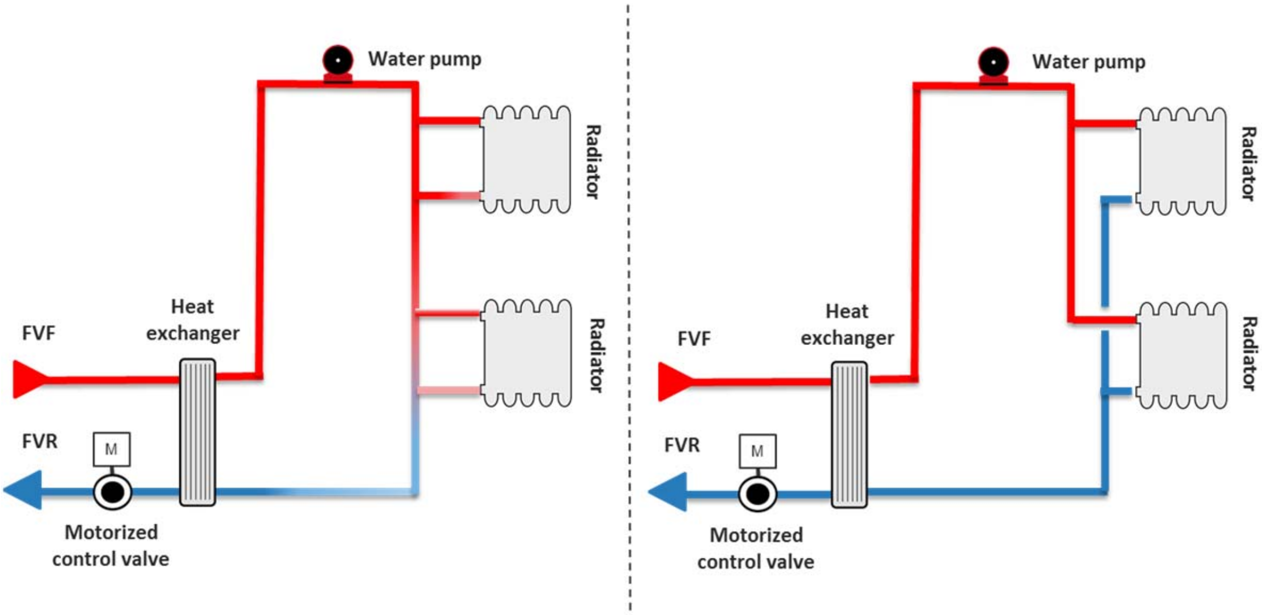

Figure 8 Left: Simplified principle diagram of a 1-string radiator circuit. Right: Simplified principle diagram of a 2-string radiator circuit

In a 2-string radiator system (see figure 8 right) the cooling is, if operated correctly, very well. However, in 2-string systems a reduction of the supply temperature, will not give an equally large reduction of the return temperature as the supply- and return pipeline is not directly connected. Thus, the cooling is not improved as much as in a 1-string system.

The energy consumption in a building is determined by how much water that passes through the system, and the difference in supply- and return temperature. See eq. 1 below.

$$((\boldsymbol{m}\char`^\mathbf{3}/\boldsymbol{h}) \times \mathbf{0,86})/\Delta \boldsymbol{T} \qquad \textbf{Equation 1.}$$

Therefore, greater energy savings may be gained by reducing the supply temperature of a 1-string radiator system because they are less energy efficient to begin with. However, a 1-string system will have difficulties with emitting enough heat at a lower temperature level in comparison to a 2-string system. Because of this the supply temperature can only be reduced for short periods in these types of systems.

Domestic hot water system

Peak demand is primarily caused by DHW consumption, so naturally the type of DHW system will have an impact on the size, and length of the peak. E.g. an instantaneous water heater (IWH), which heats up the domestic water, whenever there is a demand (see figure 6 left), typically creates larger, shorter peaks during demand hours. This type of system guarantees high comfort for the building residents, but offers quite little flexibility in terms of load shifting as there is no storage capacity, when compared to a correctly operated DHW tank (see figure 9 right).

Figure 9 Left - IWH unit for single family households from Metrotherm. Right - DHW tank for single family households from Metrotherm.

In Copenhagen, the household water has very high levels of calcium. IWH are very sensitive to lime deposits, and they can be quite difficult to clean. Thus, due to previous experiences with IWH in Copenhagen they are typically not recommended by HOFOR.

Overview of building groupings

Based on the type of construction, building age, and district heating substation components the 23 buildings investigated were sorted into 3 main categories, and 9 subcategories as presented in table 1. The floor area is used to calculate the weighted energy consumption (W/m^2). The number of apartments show whether the building is residential or public, or a mix of both.

	DH substation components	Building	m^2	Apartments
Old heavy buildings	DHW tank + 1-string radiatorsyst.	1	3267	15
		2	4748	65
		3	634	0
	DHW tank + 2-string radiatorsyst.	4	3664	20
		5	457	5
		6	1321	15
		7	4756	12+20
		8	1262	17
		9	1690	19
	DHW tank+1-string radiatorsyst.+vent.	10	309	0
		11	4467	46
		12	4468	46
		13	8367	84
		14	8367	84
		15	6186	13 + office
	IWH+1-string radiatorsyst.	16	17788	119
	IWH+2-string radiatorsyst.	17	1430	18
New heavy buildings	DHW tank+floorheating+2-string radiatorsyst.	18	2679	23 + office
	DHW tank+floorheating+2-string radiatorsyst.+vent.	19	12090	102
		20	4252	29 + office
New light buildings	DHW tank+2-string radiatorsyst.	21	660	0
		22	1000	0
	DHW tank+2-string radiatorsyst.+vent.	23	970	0

Table 1 Building overview sorted according to age, construction type and heating system

3. Method

When describing a district heating central, two terms are commonly used – primary, and secondary side. The term primary side is used on the DH system and the secondary side describes the building's central heating- and domestic hot water system as shown in figure 10.

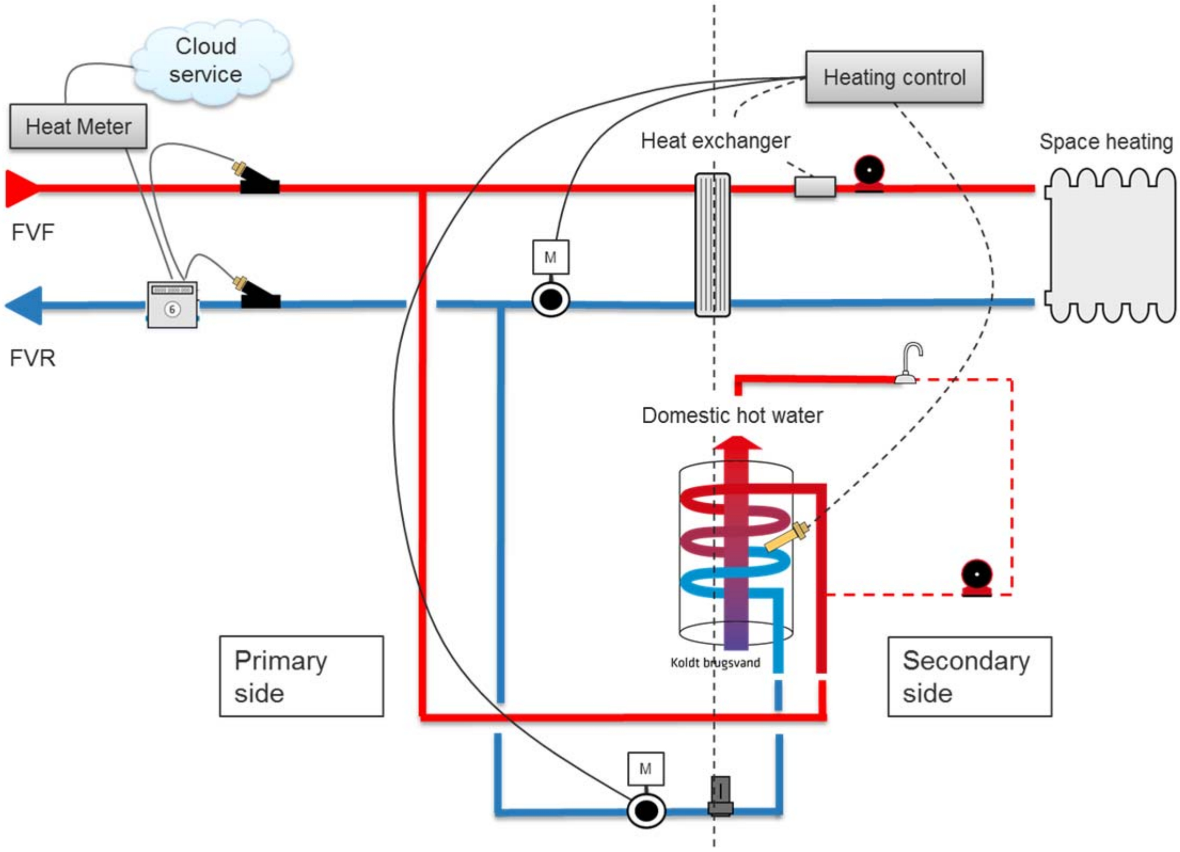

Figure 10 Typical heating central, with heat meter on the primary side of the system, and a heating control on the secondary side of the system

The heating control is owned by the building administrators, but the control valves are typically located on the primary side of the heating central. Thus, changes in the heating control will affect the DH system. Flexible heating supply in a building requires an intelligent heating control, which is able to supply heat at different temperature levels, at given time periods.

3.1 Heating control

In the majority of the buildings in this project, a Danfoss ECL310 heating control with a wireless connection to the Danfoss ECL310 Portal was used, meaning that the heat supply could be remotely controlled. In the few remaining buildings any changes in the heating supply had to be made manually in the building`s heating central.

The heating supply in a building is determined by a supply temperature compensation curve (see figure 11), which means that it changes depending on the outdoor temperature, and a calculated indoor temperature (comfort temperature).

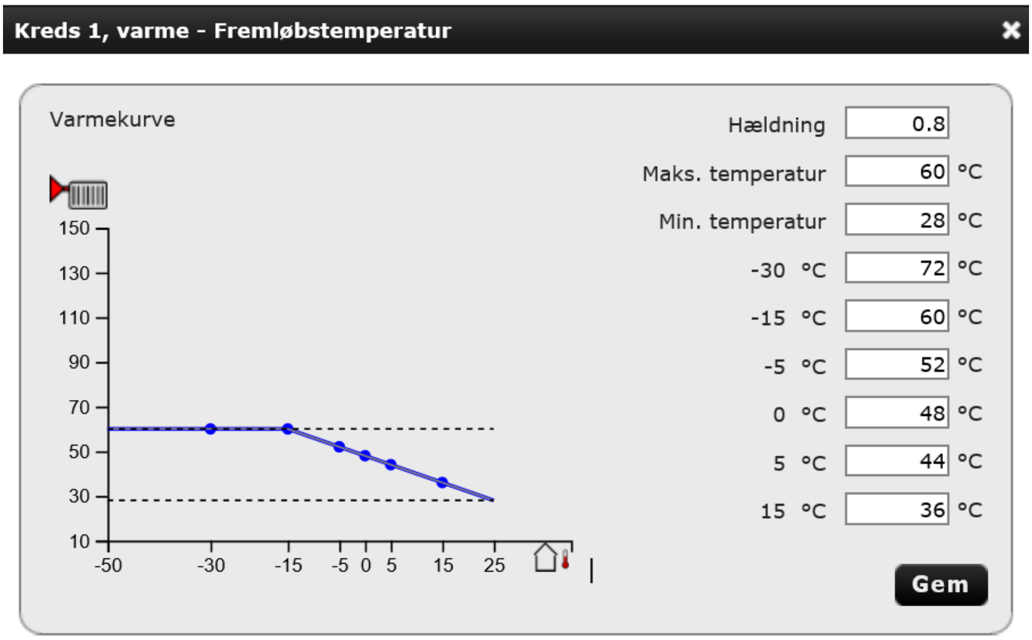

Figure 11 Temperature compensation curve as presented in the remote control application of the Danfoss ECL310

With the Danfoss heating control the calculated indoor temperature can be changed for shorter periods to reduce, or increase, the heating supply. For each degree (°C) the indoor temperature is changed from the neutral set point (20°C) the heating supply is changed by about ±4°C from the temperature compensation curve. However, depending on the outdoor temperature the size of the reduction will fluctuate as shown in figure 12, due to an auto-conserve function in the Danfoss heating control which limits the reduction when it is very cold outside.

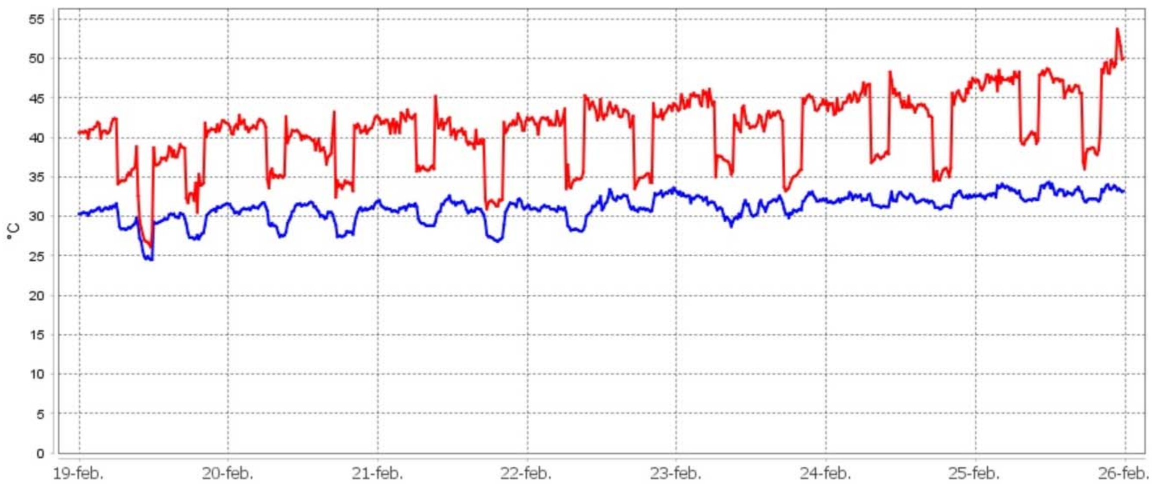

Figure 12 Supply (red) and return (blue) temperatures of a central heating system a week in February.

The heating supply temperature in the 23 buildings was reduced gradually by approximately 4-10°C from the middle December 2017 and until the end of March 2018. The purpose was to increase the size of the reduction as much as possible to determine each building`s limit without compromising the indoor comfort (see section 3.3.3 Thermal comfort). When the limit was met, the heating supply would be reduced no further.

3.1.1 Heating schedule

The initial heating supply reductions were in general performed in the periods 06-09.00 in the morning and 17-20.00 in the afternoon. To investigate how long different building types can be used as short-term storage units, and thus provide flexibility to the district heating production, some changes were made to the start, stop and duration of the reduction interval. The different reduction schedules are presented in table 2.

	Monday - Friday		Saturday - Sunday	
	1st period	2nd period	1st period	2nd period
A	06-09.00	17-20.00	06-09.00	17-20.00
Ax	06-09.00	17-20.00	07-10.00	17-20.00
B	06-10.00	17-21.00	06-10.00	17-21.00
Bx	06-10.00	17-21.00	-	-
C	06-10.00	17-20.00	07-10.00	17-21.00
D	06-09.00	17-20.00	-	-
E	06-11.00	17-22.00	-	-

Table 2 Time schedules for heating supply reductions

A building would only be subjected to schedules with longer duration if it was believed that it would not deteriorate the thermal comfort of the residents. This means that not all buildings were subjected to the same heating supply schedules.

3.2 Indoor temperature monitoring

While the demonstration was conducted in the 23 buildings, potential changes in the room temperature in a building were monitored by measuring the air temperature in a few selected apartments, or rooms in each building. Two types of wireless room sensors was used – *Enless*, which is integrated with our own remote metering system, and *IC-meter* (indoor climate meter), which is an external solution, see figure 13 left and right respectively. The IC-meter also measures relative humidity, decibel level, and CO_2 level in the apartment. However, the extra parameters measured by IC-meter was not recorded.

Figure 13 Left - IC-meter. Right - Enless room sensor

3.3 Processing and evaluation of data

The energy consumption during the demonstration period was measured by an energy measurement system, and collected by a data retrieval system used by HOFOR called Energy Key. Two types of indoor climate sensors were used – one solution integrated in HOFOR`s remote metering system, and another independent solution called IC-meter. All data was collected, and managed in Excel. The evaluation process is explained in the following sections.

3.3.1 Energy consumption

The total energy consumption in a building is made up of what is called *degree-day* dependent consumption (DDC) and degree-day independent consumption (DIC). Degree-day is a measure of how cold it has been, and how much energy is used for heating. Thus, DDC describes the heat consumption for heating, whereas DIC accounts for the heat consumption for domestic hot water (DHW) and heat losses from the piping. Both parameters are considered not to be influenced by the outdoor temperature regardless of the heat losses from the piping being slightly larger in the heating season.

Peak consumption

When evaluating a building`s energy performance a *degree-day correction* is usually performed on the daily heat consumption over a period to take account for the influence of external factors (e.g. outdoor temperature). In this project we wish to evaluate the energy performance on an hourly basis to determine how much of the consumption that can be shifted i.e. *the load shifting potential* in relation to a reference. Unfortunately, this kind of correction cannot be conducted on an hourly basis, and so the influence of external factors had to be accounted for in a different way.

Peak consumption in residential buildings is primarily caused by DHW. The calculated daily average consumption follows the base consumption that changes according to the outdoor temperature as show in figure 14. Thus, by calculating how much the consumption changes according to the daily average, it is possible to isolate the peak consumption (W/m^2) from the base consumption, as shown in figure 15.

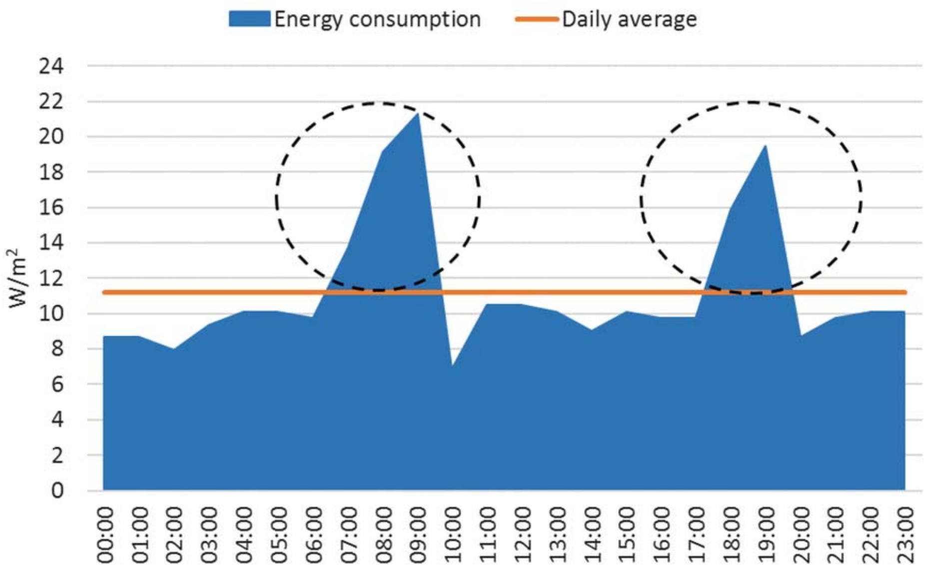

Figure 14 Hourly energy consumption in a new residential building on a Thursday in February 2017. Peak loads circled in black

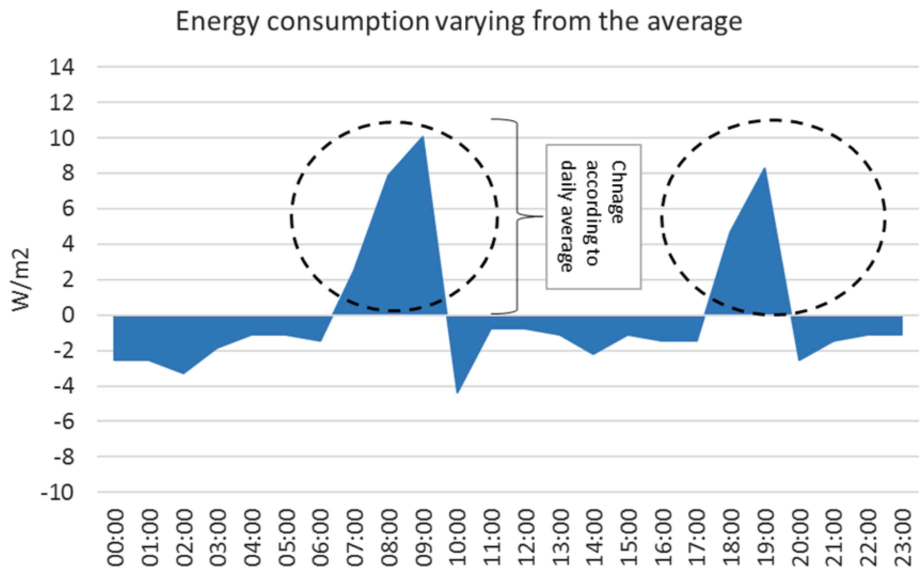

Figure 15 Peak consumption in a new residential building on a Thursday in February 2017. presented as the change in energy consumption according to the daily average.

Load shifting potential

Peak hour consumption (PHC) is defined as the heat consumption that occurs between 06-09.00, and 17-20.00. The load shifting potential of a building was determined by evaluating how much the PHC (W/m^2) was reduced from a reference period as shown in figure 16.

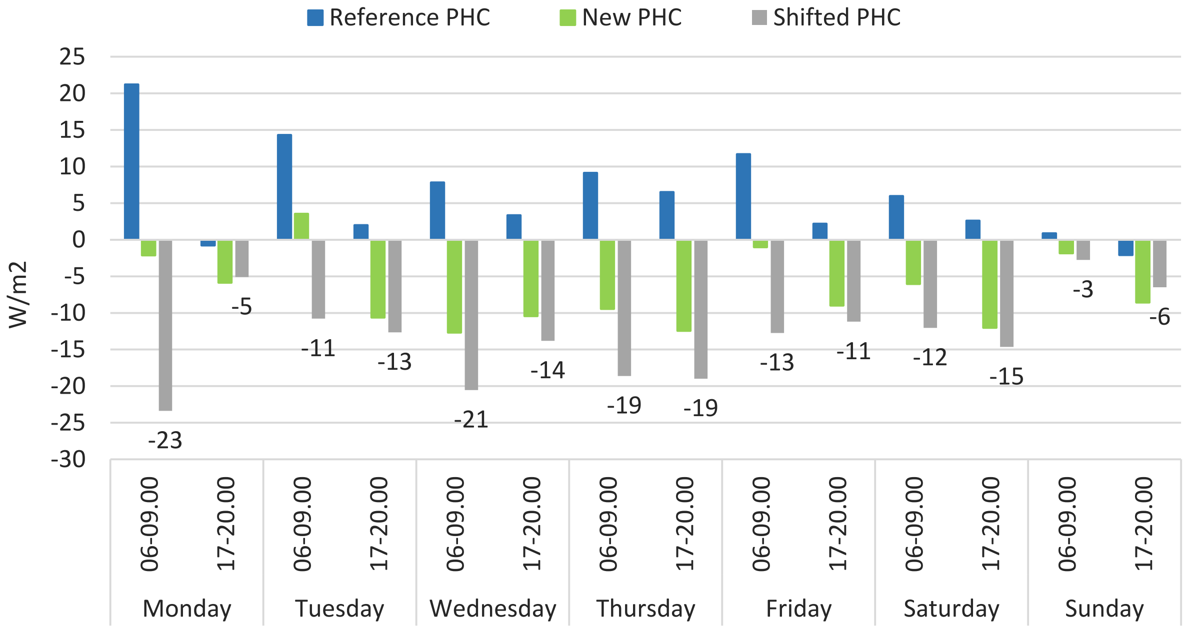

Figure 16 PHC during reference from a week in February 2017 and test period during a week in February 2018, and shifted PHC in a new residential building.

Based on the overview presented in figure 16 the overall potential is determined as the average reduction of the PHC Monday to Friday, and Saturday to Sunday as shown in table 3. A negative number indicates a reduction of the PHC in W/m2.

		Monday - Friday		Saturday - Sunday	
	DH substation components	06-09.00	17-20.00	06-09.00	17-20.00
Building type	Example	-5	-2	5	-4

Table 3 Example of how average change in PHC is presented in the results section

3.3.2 Thermal comfort

To ensure that the thermal comfort of occupants was not compromised, it was decided that temperature drops less than 1°C during a 3 hour reduction in heating supply is acceptable as such a small change is believed not to be noticed by residents. However, if very unusual large temperature drops occurred over a very short period, the temperature drop was anyway approved, assuming that it was due to manual ventilation (opening of a window or door). Any complaints from residents were reported, and the demonstration in the current building would be terminated immediately.

4. Results

The results section is divided into 3 main categories, representing each of the three building categories and. The results presented are for an 8°C reduction of the heating supply in the periods of 06-09.00 (07-10.00 weekends), and 17-20.00 for comparison. Average shifted peak hour consumption (W/m^2), and the evaluated flexibility length is presented for each group.

4.1 Old heavy buildings

The group *old heavy buildings* are sorted into 5 subcategories, and the average load shifting potential for each subgroup is presented in table 4.

	DH substation components	Monday - Friday 06-09.00	Monday - Friday 17-20.00	Saturday - Sunday 06-09.00	Saturday - Sunday 17-20.00
Old heavy buildings	DHW tank + 1-string radiatorsyst.	-24	-21	-13	-21
	DHW tank + 2-string radiatorsyst.	-10	-10	-2	-9
	DHW tank+1-string radiatorsyst.+vent.	-11	-10	-6	-11
	IWH+1-string radiatorsyst.	-6	-12	-8	-7
	IWH+2-string radiatorsyst.	-16	-8	-2	-9

Table 4 Average peak hour consumption shifted, W/m^2 in old heavy buildings

None of the measurements showed temperature drops larger than the set limit of 1°C during the tested time periods, however complaints were made in 2 buildings with 1-string radiator systems, when the heating supply was reduced for 4 hours. The evaluated flexibility length for old heavy buildings is thus set to 2-4 hours, where buildings with 1-string radiator systems and ventilation systems has the lowest flexibility of 2 hours, and buildings with 2-string radiator systems has the highest flexibility of 4 hours.

4.2 New heavy buildings

The group *new heavy buildings* are sorted into 2 subcategories, and the average load shifting potential for both subcategories is presented in table 5.

	DH substation components	Monday - Friday 06-09.00	Monday - Friday 17-20.00	Saturday - Sunday 06-09.00	Saturday - Sunday 17-20.00
New heavy buildings	DHW tank+floorheating+2-string radiatorsyst.	-15	-11	-4	-9
	DHW tank+floorheating+2-string radiatorsyst.+vent.	-9	-10	-2	-9

Table 5 Average peak hour consumption shifted, W/m^2 in new heavy buildings

None of the indoor temperature measurements showed consistent temperature falls larger than the set limit of 1°C during the tested time periods. The evaluated flexibility length for new heavy buildings is 5-7 hours.

4.3 New light buildings

The group *new light buildings* are sorted into 2 subcategories, and the average load shifting potential for both subcategories is presented in table 6.

		Monday - Friday		Saturday - Sunday	
	DH substation components	06-09.00	17-20.00	06-09.00	17-20.00
New light buildings	DHW tank+2-string radiatorsyst.	-5	-1	-2	-4
	DHW tank+2-string radiatorsyst.+vent.	6	-2	9	0

Table 6 Average peak hour consumption shifted, W/m^2 in new light buildings

Due to technical difficulties, in of the three buildings within this subcategory only one test was performed. None of the indoor temperature measurements showed consistent temperature falls larger than the set limit of 1°C, but repeated complaints from occupants in two of the tested buildings was made when conducting flexible heating supply test, thus for the tested time schedules the flexibility is set to 0 hours for this building category. Please be noted that all buildings tested of this type have been office buildings.

5. Discussion

To give a better overview, the discussion section is divided into subsections, which distinguish the evaluation of the indoor temperature monitoring from the evaluation of the potential for short term heat storage and load shifting in buildings.

5.1 Short term heat storage in buildings

When evaluating to what extent the different types of buildings can be used as a short-term heat storage units to manage the heat demand, a balance is made between flexibility length (for how long the heating supply can be reduced without affecting the thermal comfort of the residents), and the load shifting potential within peak load hours. A common finding for all the buildings is that the load shifting potential is largest during weekdays between 06.00 and 09.00, and smaller and quite fluctuating during the weekend. However, the span of the amount of consumption shifted within peak hours is relatively large between the different building categories.

Old heavy buildings

Within peak load hours the load shifting potential is largest in old heavy buildings with DHW tanks, and 1-string radiator system, when compared to the other buildings tested. This is because of the initially poor cooling of the DH water in 1-string radiator systems. The flexibility length in these buildings is however evaluated to only 3 hours as 1-string systems have difficulties heating a room at low supply temperatures. The load shifting potential is smaller in buildings with DHW tanks and 2-string radiator systems, but in comparison these buildings have a flexibility length of 4 hours.

In buildings with DHW tanks, and heating by ventilation and 1-string radiator system, there is a considerable load shifting potential. However, ventilation systems are very sensitive to changes in the room temperature (short reaction time), so when the indoor temperature dropped slightly, the ventilation system in the tested building interrupted the heating reduction. This heating reduction was typically interrupted after 2-2.5 hours on very cold days (around 0°C). Thus, the flexibility is set to only 2 hours. This combination of components in a DH substation is not very common in the Copenhagen area, and as they have a very low flexibility length these buildings should not be in focus in the succeeding work.

Buildings with IWH and 1- and/or 2-string radiator systems are very rare in Copenhagen as DHW tanks is the recommended solution for DHW systems. There is however a significant load shifting potential in these buildings (large peak loads), and the flexibility length is evaluated to 3 and 4 hours, for 1- and 2-string radiator systems respectively. Thus, these buildings should not be excluded from the further work with flexible heating supply, but they should not be a main point of focus.

New heavy buildings

The load shifting potential is second largest in new heavy buildings with DHW tanks, and 2-string radiator systems. These types of buildings are evaluated as the most suited for flexible heating supply with a flexibility length of 5-7 hours. The load shifting potential is not larger in these types of buildings when only managing the heating demand, because it is equivalent to a much smaller share of the total heat consumption when compared to older buildings. Thus, an equally large reduction of the heating supply in a new and an old brick/concrete building, will give a smaller reduction of the total heat consumption in the new (very well insulated) building.

The majority of new buildings have large DHW tanks installed, which essentially are small thermal energy storage units. Unfortunately, the heat storage capacity in DHW tanks is not fully utilized at the present. This is in many cases due to the control valves of the DHW tank being over-dimensioned, or due to a too short integration time (reaction time) of the heating of the DHW water, essentially causing the DHW tank to operate as a very ineffective instantaneous water heater.

New light buildings

New glass/wooden buildings have for now been excluded from further evaluation due to the repeated complaints on the thermal environment during the flexible heating supply. It should however be noted that all buildings within this category have been office buildings, meaning that they are only in use for certain periods throughout the day (approximately 07-17.00), and many office buildings have night-setbacks, making them less suitable for flexible heating supply especially in the morning hours (06-09.00).

Regardless, they might be of interest in the future as flexible heat customers during the day e.g. in the period 09-15.00 when the internal gains from the occupants reduce the heating demand. To carry this out in reality, one must change the general conditions made by HOFOR regarding night-setbacks, and perhaps instead introduce flexible heating as a day-setback.

5.2 Indoor temperature monitoring

None of the indoor temperature measurements showed consistent patterns in temperature falls larger than the set limit of 1°C, however complaints wa still made in a few buildings. Whether it is because the set limit is too high, or if it is because the indoor temperature is only measured in a few apartments/rooms and because of this critical temperature falls might have been overlooked, the reliability of the indoor temperature monitoring is reduced.

6. Conclusion

The conclusion of the work conducted in deliverable 5.2 (c) is that there is a significant potential for increasing the flexibility of the DH production by reducing the heating supply for shorter periods in new heavy buildings, and in older heavy buildings without ventilation systems as shown in table 7.

	Old heavy buildings	New heavy buildings
DH substation components	IWH or DHW tank + 1 or 2-string radiatorsystems	DHW tank+ floorheating+ 2-string radiatorsystem (+ heating by ventilation)

Table 7 Buildings to be used as short term heat storage units

When reducing the heating supply by about 8°C from 06-09.00 in the morning, the load shifting potential is on average largest in older brick/concrete buildings with 1-string radiator systems, and second largest in new heavy buildings with 2-string radiator systems and floor heating. However, old heavy buildings with 1 or 2-string radiator systems can only be used as short term heat storage units for about 3-4 hours without affecting the thermal comfort of the occupants, whereas new heavy buildings (regardless of the heating system) can sustain a satisfying thermal environment for up to 7 hours with a reduced heating supply.

During the entire demonstration period, the room temperature in the buildings was measured to monitor major changes in room temperature that could potentially bother users. Unfortunately, on a few occasions, the measurements proved useless for this purpose because the users complained despite the fact that no drastic temperature changes were measured.

From the findings in this report, it is assumed that the heat storage capacity in buildings can be used as an instrument in HOFOR`s peak load strategy by reducing the heating supply in 3 and 7 hour sequences in old buildings without ventilation systems, and in new buildings respectively.

Furthermore it is evident that there is huge potential for better operation and maintenance of the customers heating centrals, as this seems to be a low interest and high complexity area for them. In addition to the fact that newly installed heating central units are not adequately adjusted by the suppliers or contractors, the more advanced heating systems make it even more difficult for building owners to operate their district heating substation. This is a big challenge when working on realizing energy savings and optimizing the comfort of these new buildings.

7. Prospective work

The concept of flexible heating customers will be further examined at building level. In addition, the effect of simultaneously reducing the heat supply of the main heat exchanger in the associated distribution area will be investigated through static simulations of temperature levels and hydraulic conditions in Termis, and field studies.

Furthermore, the effect of preheating buildings will be examined as it is believed that this might increase the flexibility length of especially old heavy buildings with 1 string radiator systems based on findings made by Gothenburg Energy in Sweden.

So far, HOFOR have only investigated short-term heat storage and load shifting in residential- and office buildings. Because of this, buildings with other areas of use, e.g. schools, sport facilities and nursing homes, will be included in the proceeding investigations.

An analysis of ways to automate the control of the heating supply in several buildings simultaneously will be conducted. For this analysis an agreement has been made with the Finnish company *Leanheat*, and a report on this case will follow later. Implementation on a distribution area will be examined through static simulations of selected distribution networks and field studies.

In the proceeding work with short term heat storage in buildings a way of utilizing the heat storage capacity in DHW tanks, especially in new buildings, will be investigated. The work will focus on optimizing the control of the DHW system, and the possibility of lowering the temperature set point within the DHW tank for the duration of a peak load period. It is believed that it is possible to reduce the DHW consumption without affecting the comfort of the residents, by allowing the temperature within the DHW tank to drop to about 45°C for the duration a peak load period, and then to gradually heat up the DHW water again over the next 2-3 hours. A tank temperature of 45°C is acceptable according to the Danish standard DS439 for water installations in short term peak load situations.

HOFOR has also started an internal project to analyze and investigate the possibilities for improving the operation and maintenance of buildings heating centrals and internal heating systems as this is an important tool for HOFOR to reach its energy savings objectives and to optimize the operation of the district heating system to support Copenhagen in becoming CO_2 neutral by 2025.

Furthermore, the flexibility of district heating in the future heating system, where heat pumps play an important role, could also benefit the electrical system.

Appendix A

Example of an agreement made with a building owner or administrator allowing HOFOR to take responsibility over their district heating substation for the duration of the project, and following to use the collected data for scientific purposes.

KONTAKTPERSON
Att.:

Tillæg til fjernvarmeforsyningsaftale - Fleksibel kunder pilot projekt
Kære ___________,

I henhold til aftale modtager I hermed, et tillæg til jeres eksisterende fjernvarmeaftale, som fleksibel kunde.

HOFOR´s demonstration påfører ikke kunden ekstra omkostninger, og efter demonstrationsperioden vil fjernvarmeforsyningen fungere helt som normalt.

Demonstrationsperioden løber fra 1 december 2017 – 31 marts 2018, og aftalen som fleksibel kunde kan gensidigt opsiges med 1 måneds varsel.

Kunden accepterer med sin underskrift deltagelsen i HOFOR´s demonstration af fleksibel fjernvarmeforsyning, hvor HOFOR kortvarigt og uden varsel har mulighed for at øge, reducere og/eller afbryde fjernvarmeforsyningen i demonstrationsperioden (Kunden kan som nævnt ovenfor til enhver tid afbryde demonstrationen).

Desuden indvilliger kunden i at energidata fra bygningens fjernvarmeforsyning anvendes til forskningsbrug, samt efter nærmere aftale at data kan anvendes i forbindelse med offentlige visualiseringer af bygningers energiforbrug.

Kunden vil til gengæld, blive tilbudt følgende:

- ForsynOmeter (intelligent energistyring) frem til og med december 2018, så varmeforbrug og afkøling kan følges løbende via PC/SmartPhone (se folder for yderligere information), værdi kr. 2.500,- årligt.
- Drifts- og vedligeholdelsesaftale af varmeanlæg frem til og med slutningen af marts 2018.
- Drifts- og vedligeholdelsesaftalen indeholder en årlig fysisk gennemgang af varmeanlægget samt overvågning af varmeanlægget via ovennævnte ForsynOmeter løsning. Aftalen indgås med en af kunden og HOFOR udvalgt VVS-installatør.
- Annullering af evt. dårlig afkølingstarif som følge af demonstrationen i demonstrationsperioden frem til og med slutningen af marts 2018. Evt. bonus for god afkøling vil fortsat blive udbetalt.

HOFOR ved Christine Sandersen kan kontaktes på tlf.nr. 27 95 43 35 eller på e-mail: ceps@hofor.dk.

Kunden ved navn _______ kan kontaktes på tlf.nr _______ eller e-mail: _________

Denne aftale er et tillæg til den eksisterende fjernvarmeforsyningsaftale mellem Kunden og HOFOR og kundenummeret er angivet ovenfor:

____
Dato:

____

____
Dato:

____
Christine Sandersen
HOFOR

Appendix B

Example of an agreement made with a building resident allowing HOFOR to measure and monitor their indoor environment, and following to use the collected data for scientific purposes.

ATT:
NAVN PÅ BEBOER
ADRESSE

Fleksible Kunder Pilotprojekt i HOFOR
Kære beboer

I samarbejde med HOFOR har _______________valgt at deltage i et
projekt hvor det arbejdes med at udvikle nye løsninger og afprøve teknologier, der kan give os alle et grønnere energisystem i fremtiden.

Forsøg med fleksibel varmeforsyning

I HOFOR vil vi gerne finde ud af, hvor stort potentialet er for at spare energi ved at lagre varme i bygningsmassen. Hvis vi ved, hvor meget varme en vis bygning er i stand til at holde på i et bestemt tidsrum, vil vi have bedre mulighed for at reducere vores oliefyrede spidslastproduktion – spidslastproduktion er den ekstra varme, vi er nødt til at producere, når der f.eks. er stor efterspørgsel til varmt brugsvand om morgenen når mange går i bad. Spidslastproduktionen koster mange penge og er særlig tung, hvad gælder CO_2. Udfasning af den oliefyrede spidslastproduktionen er derfor en meget vigtig faktor for at kunne opnå målet om en CO_2-neutral fjernvarme produktion i København inden 2025.For at sikre at beboerenes komforttemperatur ikke bliver påvirket vil det være behov for at placere temperaturfølere i et par udvalgte lejligheder. Skulle det alligevel ske at komforttemperature bliver påvirket, kan forsøgene altid afbrydes med kort varsel.

Aftalespecifikationer

Projektet løber fra 1 december 2017 til 31 marts 2018. Deltagelse i demonstrationen kan til enhver tid afbrydes af kunden. HOFOR´s demonstration påfører ikke kunderne ekstra omkostninger.

Kunden accepterer med sin underskrift at HOFOR kan placere en rumføler i jeres lejlighed, samt nedhente data vedrørende jeres indendørstemperature under hele projektets forløbsperiode. Rumføleren kræver ingen montering da den kan placeres på en reol, eller et skab.

Desuden indvilliger kunden i at nedhentede data anvendes til forskningsbrug, samt efter nærmere aftale at data kan anvendes i forbindelse med offentlige visualiseringer af bygningers energiforbrug.

Hvis I har nogle spørgsmål vedrørende projektet er i meget velkomne til at kontakte HOFOR.

__________	__________
Dato:	Dato:
_______________	_______________
Underskrift Kunden	Underskrift HOFOR

Med venlig hilsen

Christine Sandersen, Energiplanlægger, HOFOR