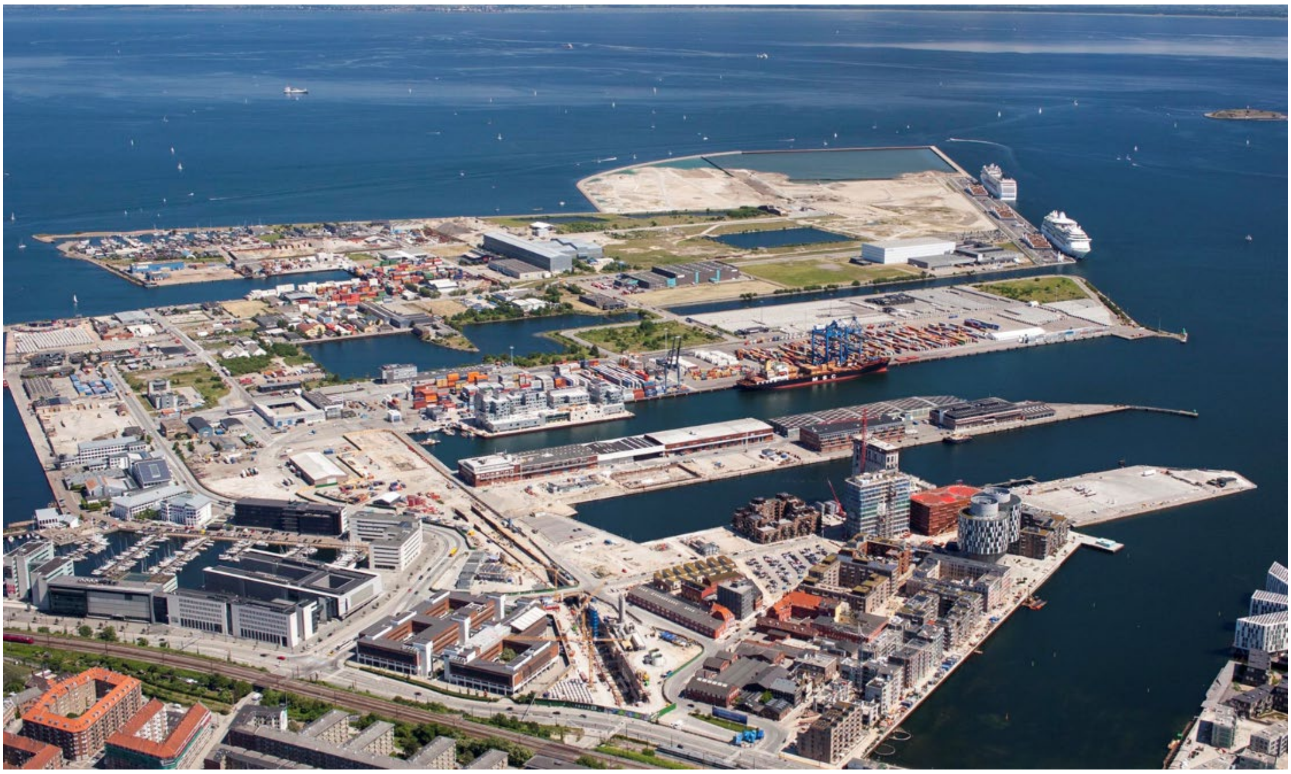
Deliverable no.: D5.4b

Installation and demonstration of domestic hot water circulation booster for reducing district heating return temperature



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Jan Eric Thorsen, Danfoss

Morten Skov & Kristian Honoré, HOFOR

22-11-2019

Public deliverable	■
Confidential deliverable	☐

Preface

EnergyLab Nordhavn – New Urban Energy Infrastructures is a project that has been using Copenhagen's Nordhavn district as a full-scale smart city energy lab, with the main purpose to do research, development and demonstration of possible energy solutions for the future with maximum use of renewable energy. The goal is to identify the most cost-effective smart energy system, which can contribute to solving the major climate challenges the world is 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 – New Urban Energy Infrastructures er et projekt, der foregår i den Københavnske bydel, Nordhavn, der fungerer som et fuldskala storbylaboratorium, hvor der skal undersøges, udvikles og demonstreres mulige løsninger til fremtidens energisystem med et maksimalt brug af energi fra vedvarende kilder. Målet er at finde fremtidens mest omkostningseffektive energisystem, der samtidigt 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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Deliverable title:	**Installation and demonstration of domestic hot water circulation booster for reducing district heating return temperature**
WP title:	**WP5 – District Heating Infrastructure**
Task Leader:	**Morten Skov**
WP Leader:	**Kristian Honoré**
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Executive Summary

Together with DTU-BYG, DTU-MEK and Danfoss a new and innovative solution for reducing district heating (DH) return temperatures was designed, developed and produced to address the domestic hot water (DHW) circuit and specifically the DHW circulation system continuously operating with a high DH return temperature in stand-by mode, being most of the time 24/7 all year around.

The high return temperatures from the DHW system is typically a phenomena seen in older buildings with large DHW circulation pipes and poorly insulated pipes, and thus high DHW circulation heat losses resulting in high DH return temperatures.

Therefore, the concept of a Circulation Booster for DHW (CB) was developed, produced and installed in an older multi-family building with 15 spacious apartments on Strandboulevarden in Copenhagen to reduce the overall DH return temperature.

The aim was to secure a low DH return temperature from the DHW system, where especially the DHW circulation caused a high DH return temperature, due to the relative high heat loss of the DHW circulation system. The new solution is heating the DHW circulation water from 50°C to 55°C in two steps, by means of a direct heat exchange and a booster using DH at normal supply temperatures between 65 – 90°C as the energy source.

Based on 10 months of operation, it was concluded that the CB is successfully installed and demonstrated.

The share of electric energy consumption for the CB concept is 10% for the total DHW production over the year. The share of DHW circulation energy loss was 70% of the total needed DHW production energy, meaning heating up the cold water to DHW temperature at tapping and continuously heating the DHW circulation temperature from 50-55C.

The DH return temperature from the DHW system, was reduced by appx. 25°C from 47°C to 22°C comparing the old DHW tank and DHW circulation solution, with the new CB solution including the DHW tank.

A number of economic scenarios have been analyzed, and with the current HOFOR DH tariff structure and the electricity prices, the CB concept does however not give a feasible economic case.

But considering future scenarios with lower electricity prices and/or a more progressive cooling bonus for providing a low DH return temperature there could be site specific installation and buildings where this concept could be relevant and feasible.

Further it provides HOFOR with a quite simple retrofit solution for solving problematic customer installations with high DH return temperatures to increase efficiency of the Combined Heat & Power (CHP) production as well the possibility for lowering the DH supply temperature in the DH system of Copenhagen.

Version Control

Version	Date	Author	Description of Changes
1.0	10.07.2019	Jan Eric Thorsen & Kristian Honoré	Draft
2.0	26.09.2019	Morten Skov	Applications and calculations
3.0	02.10.2019	Kristian Honoré	Update and comments
4.0	08.11.2019	Morten Skov & Kristian Honoré	Update for external review
5.0	17.11.2019	Jan Eric Thorsen	Comments
6.0	17.11.2019	Torben S. Ommen	External review
7.0	22.11.2019	Morten Skov & Kristian Honoré	Final version and sent for WPL approval

Quality Assurance

Author	Reviewer	Approver
Jan Eric Thorsen / Danfoss, Morten Skov & Kristian Honoré / HOFOR	Torben Schmidt Ommen, DTU-MEK	WPL Group

Status of deliverable		
Action	**By**	**Date**
Sent for review	Kristian Honoré, HOFOR	11.11.2019
Review	Torben Schmidt Ommen, DTU-MEK	17.11.2019
Verified	Kristian Honoré, HOFOR	21.11.2019
Approved	WPL group	06.12.2019

1. Circulation Booster for Domestic Hot Water Circulation

1.1 Introduction

As part of the Energylab Nordhavn project, HOFOR has in cooperation with DTU-BYG, DTU-MEK and Danfoss installed a Circulation Booster (CB) for DHW circulation in a multifamily house located at Strandboulevarden, close to the Nordhavn area in Copenhagen. The installation was made December 2018. The purpose of the CB is to heat the DHW circulation water from 50°C to 55°C, and at the same time secure a low DH return temperature from this part of the service.

Especially in buildings where the DHW circulation loss is high compared to the DHW consumption, it is a challenge to realize a low DH return temperature, due to the high share of DHW circulation return water at the required 50°C.

A low DH return temperature is a precondition for efficient production at the CHP´s due to their flue-gas condensers requiring low return temperatures. Furthermore it will not be possible to reduce the DH supply temperature.

1.2 The demonstration site at Strandboulevarden

The building on Strandboulevarden is from 1902 with a heated area of appx. 3.000 m2 and includes 15 spacious apartments.

The connection capacity is dimensioned for 209 kW and it has a yearly corrected consumption of 290 MWh.

The central heating system is based on a 2-string radiator system with an average cooling difference of 34°K.

Other characteristics for this building is the high DHW circulation loss relatively to the DHW consumption, being quite common for old multi-family buildings.

In this case, the DHW circulation loss accounts for around 70% of the total energy use for DHW consumption and circulation.

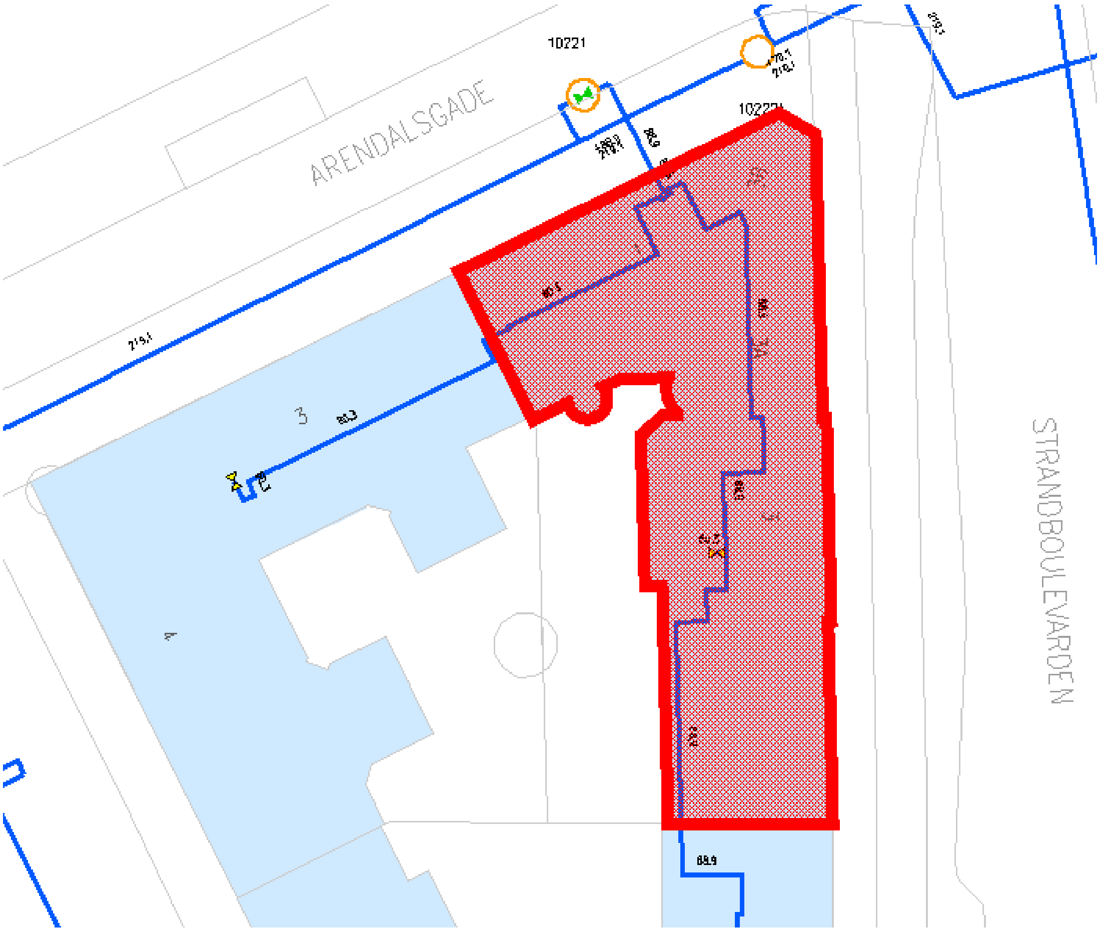


Figure 1: Pictures of the building at Strandboulevarden, where the CB is installed

The CB is installed in the technical room in the basement of the building and is connected to the existing DHW system in a flexible way, giving the opportunity for an easy switch back to the original installed system concept, see Figure 2.

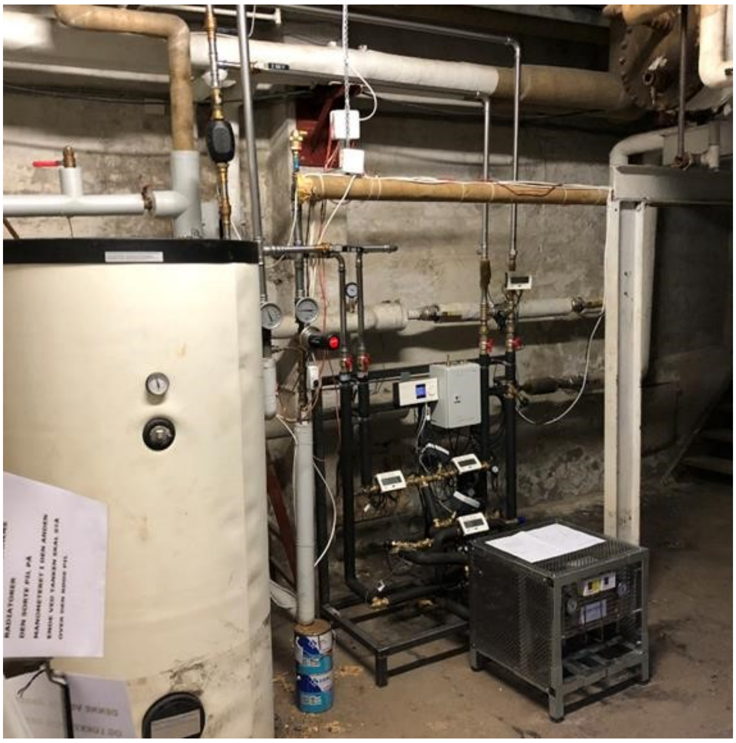


Figure 2: CB installed in technical room at Strandboulevarden

The CB is seen in the lower right corner of the figure. The meters, control valves, pump, electric cabinet and controller can be seen behind the heat pump. The existing DHW tank appears in the left side of the figure.

2. Circulation Booster layout

The basic principle of the CB can be seen in Figure 3, where only the main components are shown for simplicity. The energy transferred to heat up the DHW circulation from 50-55°C is applied in two steps. The return water from the DHW circulation system is first heated by the heat pump condenser and in the second step by direct heat exchange. The source of energy for the second step is DH, where the direct heat exchange heats up the DHW circulation to 55°C and cools down the DH to approx. 53°C. In this way the DH is cooled down to the extent possible by direct heat exchange. The DH water at 53°C is as well the energy source for the heat pump evaporator, and the heat pump is cooling the DH water down to 20-25°C, while it heats up the DHW circulation water from 50°C to approx. 53-54°C.

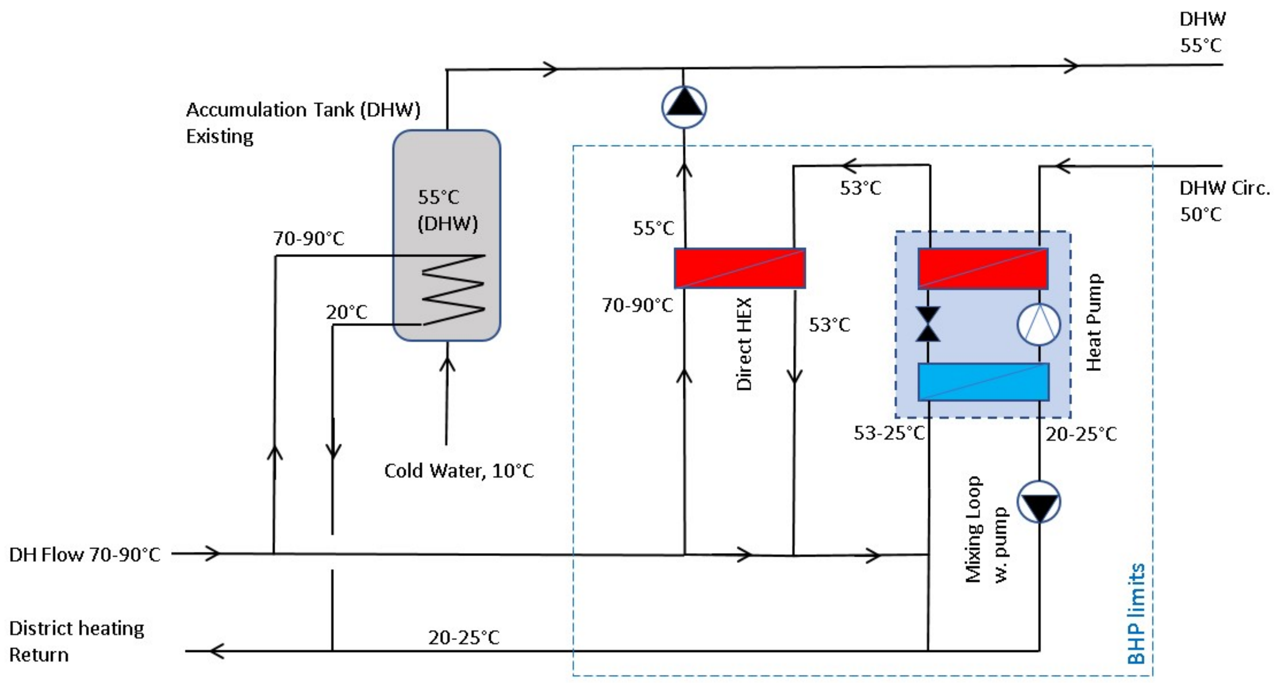


Figure 3: The basic principle of the CB

By introducing this two-step concept, the capacity of the heat pump can be reduced (the direct heat exchange covers a part of the needed capacity) and subsequently the electric consumption is reduced. The capacity split between the direct heat exchange and the heat pump gives the trade-off between the reduction of the DH return temperature and the electric consumption of the heat pump. The heat pump control is based on constant speed operation, i.e. the capacity control is limited to be based on varying the evaporation temperature of the heat pump. This is done by adjusting the DH evaporator inlet temperature by means of the mixing loop. Under normal operation no DH flow is bypassing the direct heat exchange.

2.1 Operation of DHW system without CB

The DHW temperature is electronically operated at a temperature of 55°C in the tank and every Sunday night at 60°C with an anti-legionnaires disinfection program. Otherwise there is no other set-points for the operation of the domestic hot water tank.

In the below figure 4 it is possible to see the energy usage without the operation of the CB equal to the initial case.

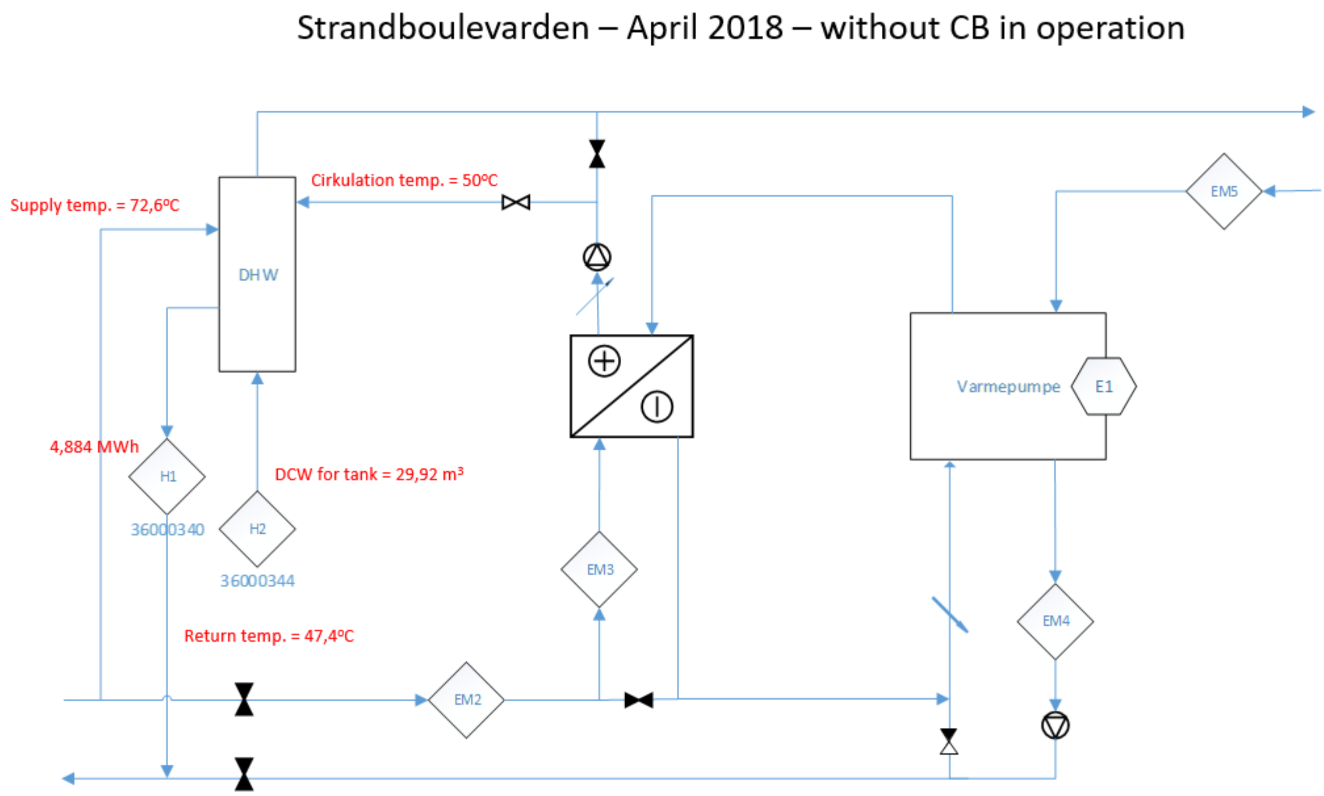


Figure 4: DHW system energy usage without CB in operation

2.2 Operation of DHW system with CB

In the below figure 5 it is possible to see the energy usage with CB in operation.

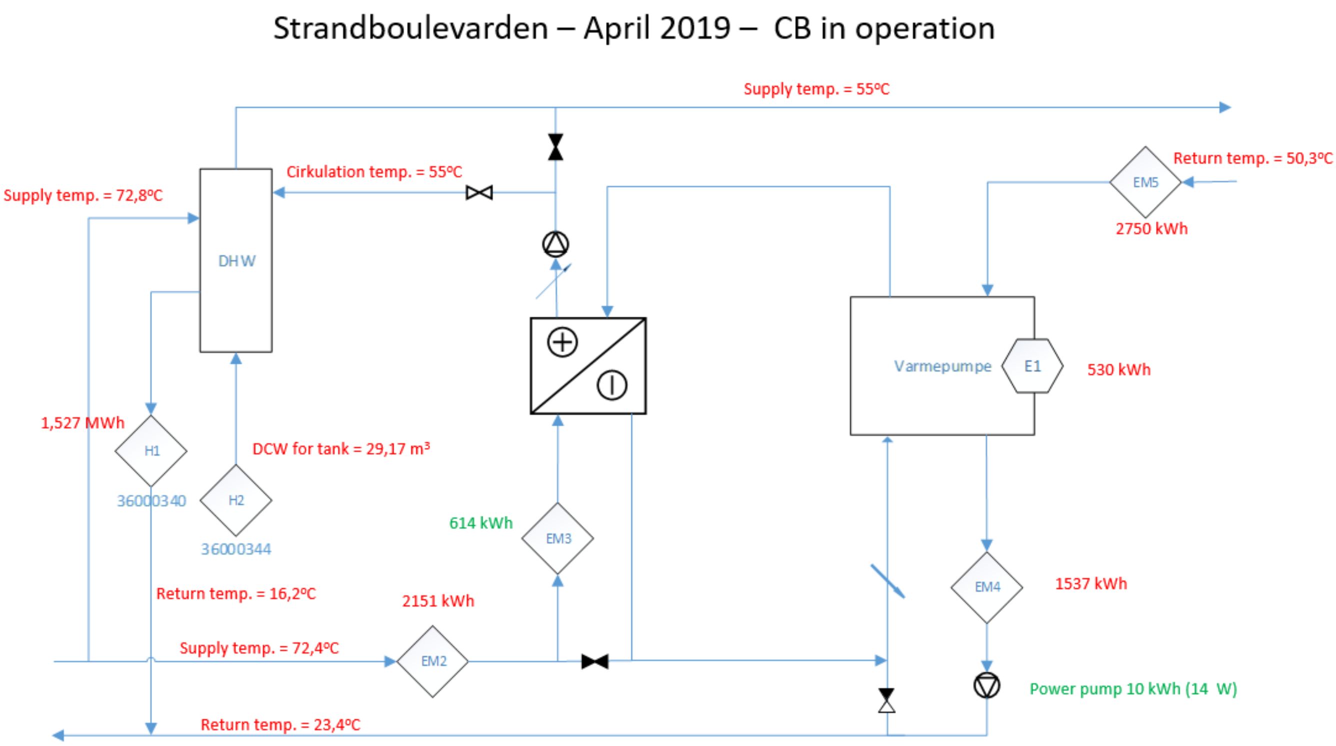


Figure 5: DHW system energy usage with CB in operation

3. Performance of the CB

The main parameter influencing the performance of the CB is the DH flow temperature. Therefore, the following figures are using this parameter as x-axis. The circulation heat flow rate is partly dependent on the ambient temperature and therefore also partly dependent on the DH forward temperature, since those are typically linked, see Figure 6 (left). Also in this case the data spread is related to the varying amount of tapped DHW over time, influencing the needed energy input from the CB.

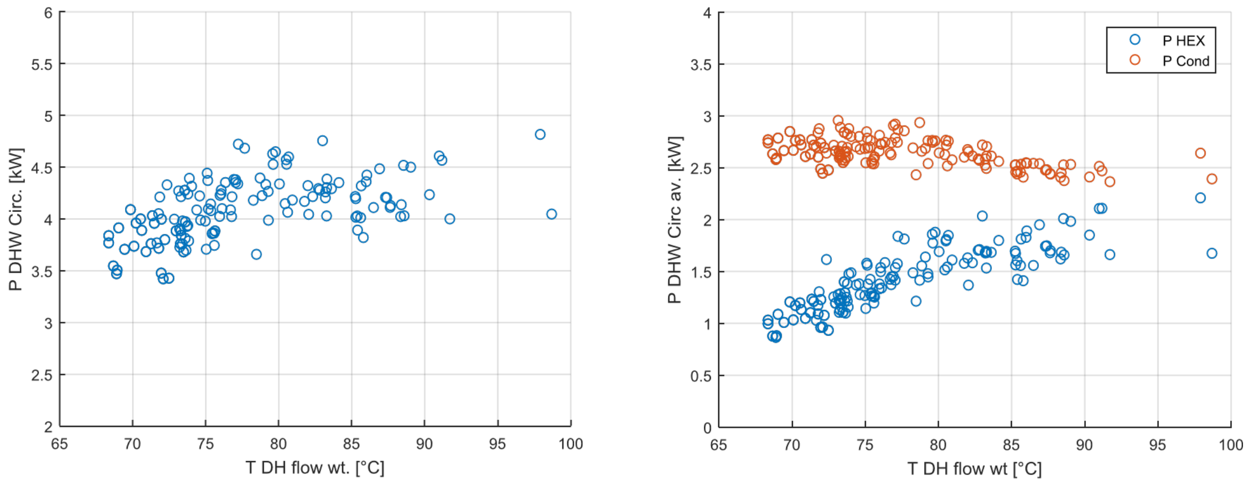


Figure 6: DHW circulation heat capacity total and split into direct heat exchange (HEX) and condenser

The split between the heat capacity input from the direct heat exchange and the condenser is shown in the right figure. At increasing DH flow temperatures, the direct heat exchange increases and the condenser heat power decreases. This is because the evaporation temperature decreases at increasing DH flow temperature due to the lower DH flow through the evaporator, see Figure 7, and thus results in a lower heat pump capacity. The direct heat exchanger adjusts to maintain 55°C DHW flow temperature.

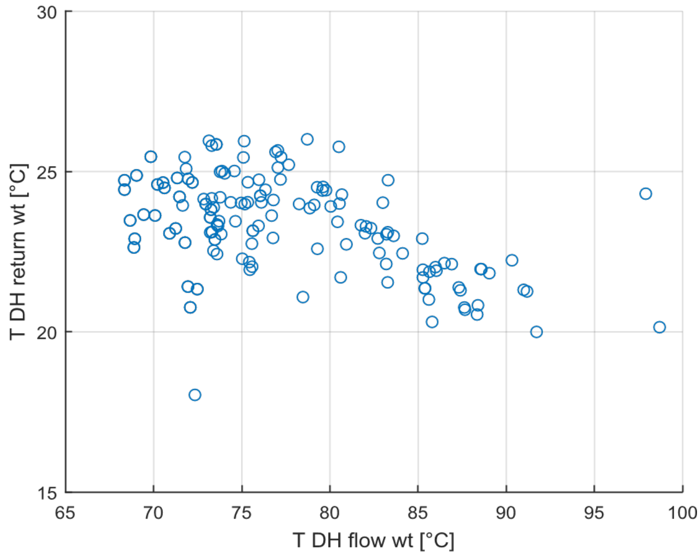


Figure 7: DH return temperature dependency of DH flow temperature

3.1 Performance of DHW system, without and with CB

The below graphs clearly show the lowered return temperature from the DHW by having introduced a CB in the system.

Legend:
Red – DHW temperature
Black – DHW return temperature

Below figure 8 from April 2018, illustrates the initial operation of the DHW system, without CB at the demonstration site:

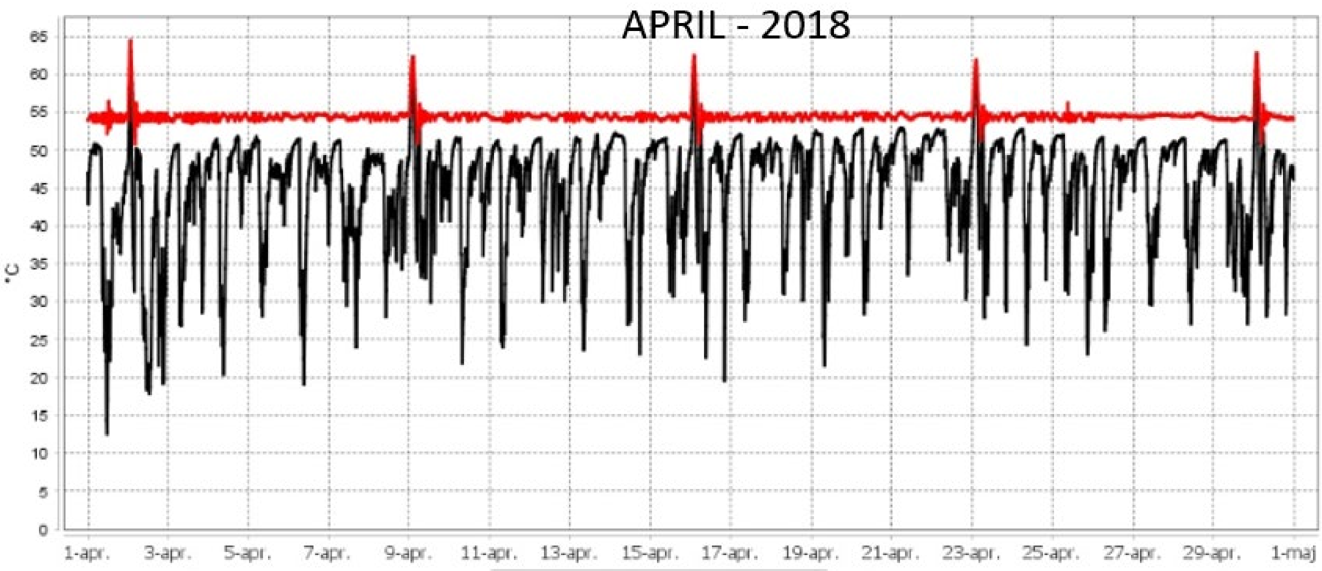


Figure 8: Initial operation of DHW system without CB

Below figure 9 from April 2019, illustrates the operation of the DHW system with the CB installed, however with a not optimally installed DHW circulation pipe outside of the DHW tank resulting in the fluctuating DHW temperature. This problem leads to lower losses in the DHW tank and also a bit lower return temperature compared to a correct installation. But still the overall results are quite realistic and show that the average DH ΔT (ºC) for the DHW system almost doubles (from 28ºC to 53ºC) with the CB.

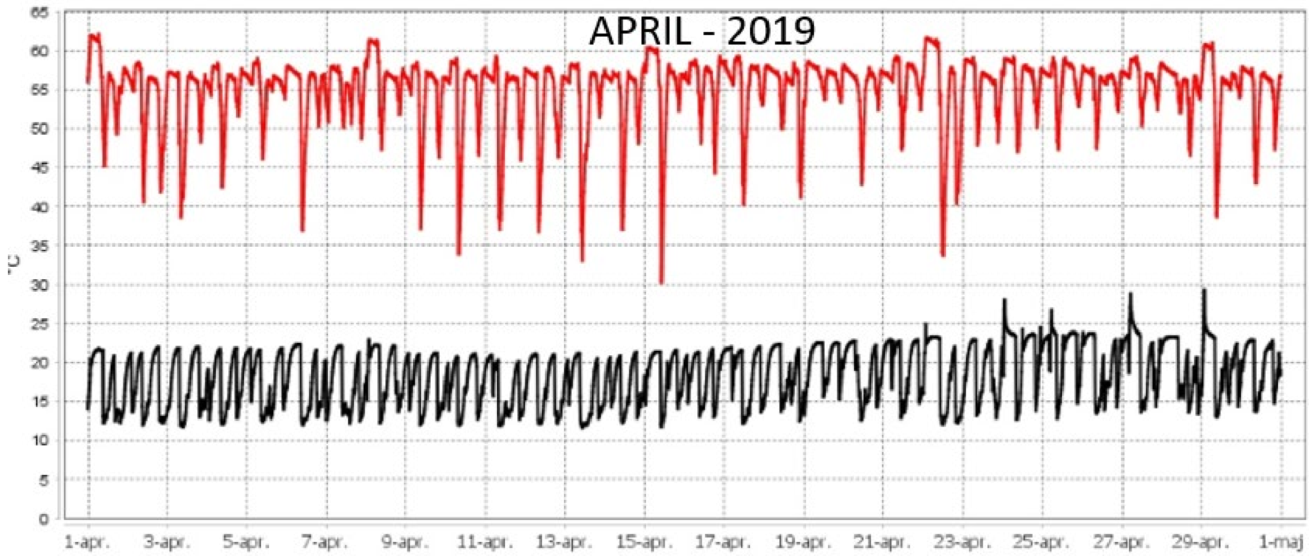


Figure 9: Operation of DHW system after installation of CB and DHW circulation outside of tank

Below figure 10 from August 2019, illustrates the operation of the DHW system with CB installed and a correctly installed DHW circulation pipe inside the tank. This results in a more stable DHW temperature, and a slightly higher return temperature.

But again is shows the potential of the new system to reduce the DH return temperature, and in this example from 47°C to 22°C.

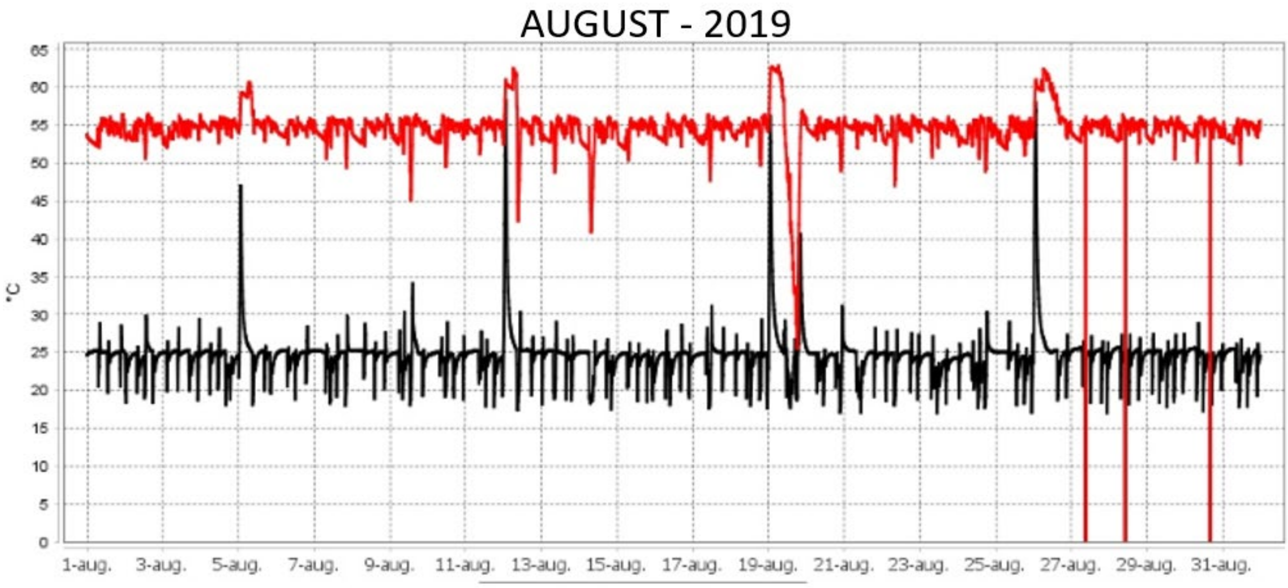


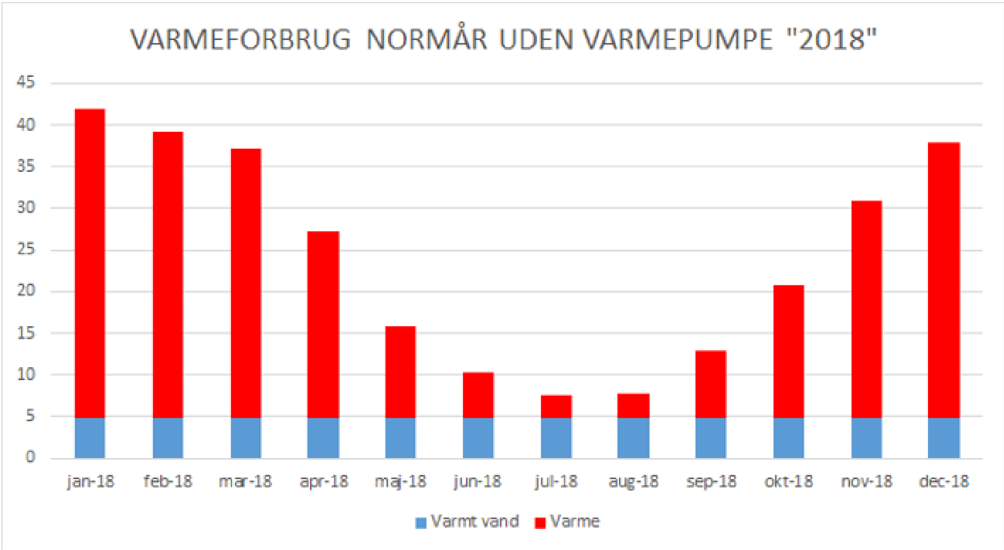
Figure 10: Operation of DHW system after installation of CB and DHW circulation inside of tank

4. Economic analysis for CB

The below results are based on the initial case without the CB for 2018, and corrected for the poorly placed/installed DHW circulation connection.

4.1 Heat consumption, normal year without CB, 2018

Measured data (corrected to normal year) without CB, 2018



			Realistiske fjernvarmetemperaturer 80-45 til centralvarme DT = 35 C								
			Realistiske fjernvarmetemperaturer 75-47 til brugsvand DT = 28 C								
Baseret på april18 data hvor der var nogle forhold med føler og cirk.kobling											
Excl effektbetaling											
Variable forbrug											
231	MWh	varme	Fjernvarme		675	kr/MWh	155.925	kr		5676	m3
59	MWh	varmt vand	Fjernvarme		675	kr/MWh	39.825	kr		1812	m3
18	*MWh*	*opvarm koldt*							I alt	7488	m3
41	*MWh*	*cirkulationstab*									
290	**MWh**	**total**				I alt	195.750	kr	Total DT	33,3	C

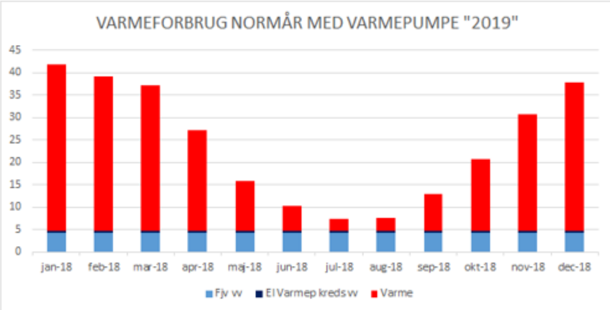
Figure 11: Heat consumption, normal year – without CB 2018

To compensate for the poorly placed/installed sensor a minor consumption has been added to the circulation losses.

Based on this an estimate for the complete year of 2019 with CB has been prepared:

4.2 Heat consumption corrected, normal year with CB, estimate for 2019

Measured data (corrected to normal year) – realistic data, estimate for 2019



MED DAGSREALISTISKE PRISER											
REN FJERNVARME:				Realistiske fjernvarmetemperaturer 80-45 til centralvarme DT = 35 C							
				Realistiske fjernvarmetemperaturer 75-47 til brugsvand DT = 28 C							
Excl effektbetaling											
Variable forbrug											
231	MWh	varme	Fjernvarme		675	kr/MWh	155.925	kr		5676	m3
59	MWh	varmt vand	Fjernvarme		675	kr/MWh	39.825	kr		1812	m3
18	*MWh*	*opvarm koldt*							I alt	7488	m3
41	*MWh*	*cirkulationstab*									
290	**MWh**	**total**				I alt	195.750	kr	Total DT	33,3	C
FJERNVARME MED VP:			Realistiske fjernvarmetemperaturer 80-45 til centralvarme DT = 35 C								
			Realistiske fjernvarmetemperaturer 75-22 til brugsvand DT = 53 C								
Excl effektbetaling											
Variable forbrug											
231	MWh	varme	Fjernvarme		675	kr/MWh	155.925			5676	m3
53	MWh	varmt vand	Fjernvarme		675	kr/MWh	35.775			860	m3
19	*MWh*	*opvarm koldt*							I alt	6536	m3
8,8	*MWh*	*eftervarmefl*									
25	*MWh*	*fjv til vp konds*							Total DT	37,4	C
6	**MWh**	El	El		2000	kr/MWh	12.000				
290	MWh	**total**					203.700				
					Fradrag afkøling		-6.362				
							197.338		Afkølpris	5,4	kr/MWh*C

Figure 12: Heat consumption corrected, normal year with CB, estimate for 2019

With comparable and corrected data for year 2019 the cost with CB in operation is 197.338,00 DKK and without the CB in operation the cost is 195.750,00 DKK and thereby the CB solution in operation is 1.588,00 DKK higher than the normal DH operation.

This means that there, in this way of calculating, is no business case for the CB concept.

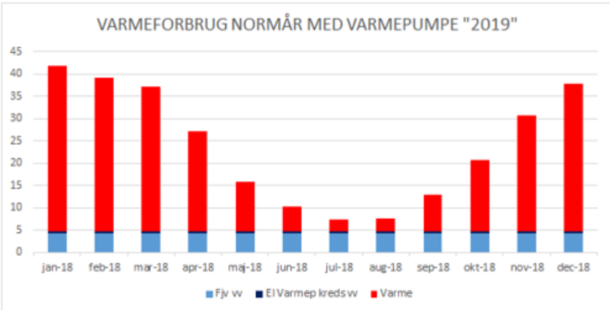
4.3 Economic scenarios for the CB concept

To look into future scenarios for the CB concept, calculations are made for a very low electricity price for normal consumers as well as a scenario where HOFOR is increasing its cooling bonus significantly. See below scenarios 1 and 2:

- Scenario 1: Electricity price of 1 DKK/kWh (currently 2 DKK/kWh incl. VAT)
- Scenario 2: Cooling bonus increased to 10 DKK/kWh (currently 5,40 DKK/kWh incl. VAT)

4.4 Scenario 1: New electricity price, normal year with CB, estimate for 2019

Measured data (corrected to normal year) – Realistic data, estimate for 2019



MED ÆNDRET EL-PRIS! TIL 1 KR/kWh

MED DAGSREALISTISKE PRISER - JUSTERET MED LAVERE EL-PRIS											
REN FJERNVARME:				Realistiske fjernvarmetemperaturer 80-45 til centralvarme DT = 35 C							
				Realistiske fjernvarmetemperaturer 75-47 til brugsvand DT = 28 C							
Excl effektbetaling											
Variable forbrug											
231	MWh	varme	Fjernvarme		675	kr/MWh	155.925	kr		5676	m3
59	MWh	varmt vand	Fjernvarme		675	kr/MWh	39.825	kr		1812	m3
18	*MWh*	*opvarm koldt*							I alt	7488	m3
41	*MWh*	*cirkulationstab*									
290	**MWh**	**total**				I alt	195.750	kr	Total DT	33,3	C
FJERNVARME MED VP:			Realistiske fjernvarmetemperaturer 80-45 til centralvarme DT = 35 C								
			Realistiske fjernvarmetemperaturer 75-22 til brugsvand DT = 53 C								
Excl effektbetaling											
Variable forbrug											
231	MWh	varme	Fjernvarme		675	kr/MWh	155.925			5676	m3
53	MWh	varmt vand	Fjernvarme		675	kr/MWh	35.775			860	m3
19	*MWh*	*opvarm koldt*							I alt	6536	m3
8,8	*MWh*	*eftervarmefl*									
25	*MWh*	*fjv til vp konds*							Total DT	37,4	C
6	**MWh**	El	El		1000	kr/MWh	6.000				
290	MWh	**total**					197.700				
					Fradrag afkøling		-6.362				
							191.338		Afkølpris	5,4	kr/MWh*C

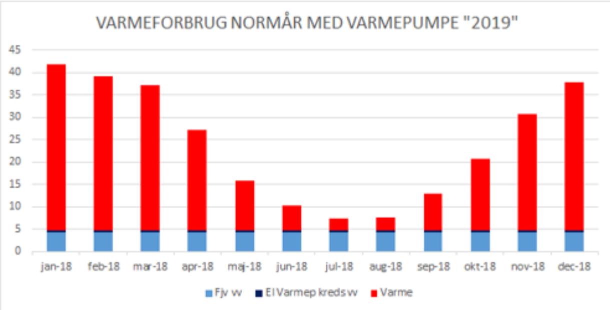
Figure 13: Scenario 1 New electricity price, normal year CB, estimate for 2019

With a cost of electricity of 1 DKK/kWh the cost of CB in operation is 191.338,00 DKK compared to without CB operation being 195.750,00 DKK and thereby 4.412,00 DKK lower than the normal DH operation. With a CB price installed of appx. 35.000,00 DKK incl. VAT a simple pay-back period would be less than 8 years.

The scenario may however be a bit unrealistic, because even it is expected that electricity prices will become lower, it is probably not in this magnitude and maybe not even applicable for private consumers.

4.5 Scenario 2: High cooling bonus, normal year with CB, estimate for 2019

Measured data (corrected to normal year) – Realistic data, estimate for 2019



MED ÆNDRET AFKØLINGSPRIS - TIL 10 KR/kWh

MED DAGSREALISTISKE PRISER - JUSTERET MED HØJERE AFKØLINGSPRIS											
REN FJERNVARME:				Realistiske fjernvarmetemperaturer 80-45 til centralvarme DT = 35 C							
				Realistiske fjernvarmetemperaturer 75-47 til brugsvand DT = 28 C							
Excl effektbetaling											
Variable forbrug											
231	MWh	varme	Fjernvarme		675	kr/MWh	155.925	kr		5676	m3
59	MWh	varmt vand	Fjernvarme		675	kr/MWh	39.825	kr		1812	m3
18	*MWh*	*opvarm koldt*							I alt	7488	m3
41	*MWh*	*cirkulationstab*									
290	**MWh**	**total**				I alt	195.750	kr	Total DT	33,3	C
FJERNVARME MED VP:			Realistiske fjernvarmetemperaturer 80-45 til centralvarme DT = 35 C								
			Realistiske fjernvarmetemperaturer 75-22 til brugsvand DT = 53 C								
Excl effektbetaling											
Variable forbrug											
231	MWh	varme	Fjernvarme		675	kr/MWh	155.925			5676	m3
53	MWh	varmt vand	Fjernvarme		675	kr/MWh	35.775			860	m3
19	*MWh*	*opvarm koldt*							I alt	6536	m3
8,8	*MWh*	*eftervarmefl*									
25	*MWh*	*fjv til vp konds*							Total DT	37,4	C
6	**MWh**	El	El		2000	kr/MWh	12.000				
290	MWh	**total**					203.700				
					Fradrag afkøling		-11.781				
							191.919		Afkølpris	10	kr/MWh*C

Figure 14: Scenario 2 High cooling bonus, normal year with CB, estimate for 2019

With a cooling bonus increased to 10 DKK/kWh the cost of CB in operation is 191.919,00 DKK compared to the initial operation without the CB in operation of 195.750,00 DKK and thereby 3.831,00 DKK lower than the normal DH operation. With a CB price installed of appx. 35.000,00 DKK incl. VAT a simple pay-back period would be around 9 years.

This scenario could in specific cases be realistic, especially with very problematic customers and/or in stressed parts of the networks, where the CB would give a high positive impact on the operation of the district heating system.

5. Discussion and future work

HOFOR is continuously working towards lowering the return temperatures in the overall DH network of Copenhagen for improving the efficiency of the CHP production where especially the flue-gas condensation is affected by too high return temperatures in the DH network. Lower return temperatures however, also increases the capacity of the DH network and makes it possible to operate with lower supply temperatures in the DH network, and is thereby also an enabler for more efficient operation of heat pumps and introduction of geothermal energy and heat from industry and supermarkets.

The CB concept is an interesting instrument for HOFOR that can be applied at existing customers having too high DH return temperatures from their DHW systems. The concept could also be seen as part of a more local solution to overcome hydraulic challenges in stressed parts of the district heating network.

HOFOR already have a number of new application sites in mind, which could benefit from having the CB concept installed for the benefit of both the customer and HOFOR.

There is also possibilities for future and further development and optimization of the CB concept that would bring additional value to HOFOR:

- "Stop and go" operation strategy, to avoid the highest electricity peak load prices during morning and evening peaks
- Higher COP due to better/"mixed" cooling medias
- Lower CB cost

6. Conclusion on CB for DHW circulation

Based on the 10 months of operation, it can be concluded that the CB is successfully installed and demonstrated.

The share of electric energy consumption for the CB concept is 10% for the total DHW production over the entire year. The representative DH return temperature from the previous DHW tank and DHW circulation solution and the new CB solution including the DHW tank is reduced from 47°C to 22°C.

A number of economic scenarios have been made, and with the current HOFOR DH tariff structure and the electricity prices, the CB concept does not give a feasible economic case for standard applications. But considering a future more site specific bonus scheme for low DH return temperature, and maybe even combined with lower electricity prices, the CB solution could be interesting.

The overall conclusion is that the demonstration of the CB concept has been very successful and provides HOFOR with an additional and quite simple retrofit solution for solving problematic customer installations with high DH return temperatures.