Deliverable no.: D5.2e

District heating flexibility - Automation of short term heat storage in buildings - phase 2 of 5.2c (Analysis of the potential for storing heat at interruptible customers)

Photo: By & Havn / Ole Malling

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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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Table of Contents

Executive Summary

Oil and natural gas fueled boilers are started up to cover the peak loads that occur in shorter, and longer periods in a district heating network.

By managing the heating demand at the customers, more flexibility is added to the energy production, and thus it is possible to reduce the CO_2 emitting peak load production, and increase the share of renewables.

In D5.2c the potential for exploiting the short term heat storage in different buildings` thermal mass to manage the customers` heating demand was investigated by remotely controlling the heating control in buildings, and for shorter periods, lowering the heat supply.

The findings from the investigations in D5.2c proved that old, massive concrete or brick buildings without ventilation systems, as well as new, heavy buildings was ideal flexible heating customers. However, to implement flexible heating customers in the future district heating system, the remote control process must be automated.

Thus, the purpose of D5.2e is to investigate to what extent the control process of the flexible heat customers can be automated by using artificial intelligence. In this project the intelligent heating control developed by the Finnish company Leanheat is tested in eight buildings in Copenhagen.

Version Control

Version	Date	Author	Description of Changes
1	19.03.2019	Christine Sandersen	Synopsis/master
2	09.05.2019	Juha Saloheimo	2. draft
3	10.05.2019	Christine Sandersen	3. draft
4	15.05.2019	Kristian Honoré	Revision and comments
5	16.05.2019	Christine Sandersen	Final draft
6	11.06.2019	Kristian Honoré	Sent for external review
7	17.06.2019	Palle Holdt	External review feedback
8	02.07.2019	Christine Sandersen	Revisions
9	08.07.2019	Kristian Honoré	Sent for WPL-approval

Quality Assurance

Author	Reviewer	Approver
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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. The municipality of Copenhagen have set the very ambitious goal of becoming 100 % CO_2-neutral by 2025 [11]. By 2020, the largest proportion (80%) of heat distributed in the capital area will be produced on CO_2 neutral biomass and organic waste incineration. The remaining share is produced on non-organic waste incineration (16%) and short term peak load and backup boilers fueled on natural gas and oil (4%).

A part of the solution to removing the remaining CO_2 emitting oil- and natural gas heat production in the capital area is to make the energy production more flexible by managing the heat consumption at a building level – making the customers flexible heat consumers, as investigated in *D5.2c Short term heat storage in buildings*. However, to make it manageable to implement flexible heat consumers at a greater scale in the future district heating (DH) system in Copenhagen, the remote control process must be automated.

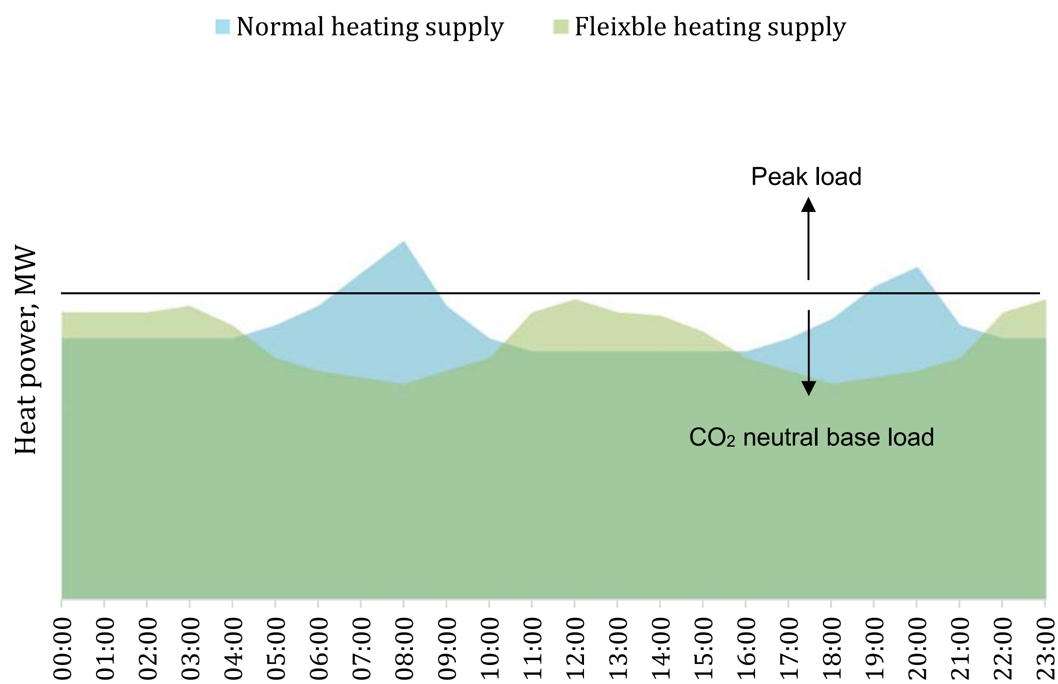
The purpose of deliverable D5.2e is thus to demonstrate a solution to how the control process can be automated, as well as to evaluate the benefits of two different flexible heating control strategies.

2. Background

Short term peak load demand typically occur in the morning from 6-9 am when residents shower, and heating systems are started up in office buildings, and again in the afternoon from 5-8 pm. During these periods the CO_2 neutral base load production is not able to meet the heat demand, thus the fossil fueled peak load boilers are started up.

From the investigations conducted in 23 buildings in D5.2c, it was found that it is possible to shift the heating demand from high demand to low demand hours by reducing the heating supply by up to 7°C without compromising the thermal comfort of the buildings` occupants. New residential buildings, and old residential buildings without ventilation systems proved to be the best equipped for flexible heating supply.

It is believed that if a greater share of the buildings in Copenhagen where to be made flexible heat consumers, it is possible to consequently reduce the short term peak demand, and thus need for the fossil fueled peak load boilers. See example of heat consumption in a DH distribution net with normal vs. flexible heating supply at building level.



Figur 1 Heat consumption in a district heating distribution net with normal vs. flexible heating supply

During the investigations in D5.2c the 23 buildings` heating central was remote controlled manually. However, if a greater share of the heat consumers in Greater Copenhagen are to be made flexible heat consumers the control process must be automated for it to be manageable.

The Finnish company Leanheat have, among others, developed an intelligent heating control based on artificial intelligence (AI) which is believed to be a possible solution to the challenge of automated control of the flexible heat consumers.

2.1 Leanheat Intelligent heating control

Leanheat intelligent heating control optimizes the total heat consumption of the buildings by controlling the secondary side supply water temperature. Leanheat AI learns a building specific thermodynamic model by using, among others, weather data, building automation measurements, inside temperature measurements and data from reference buildings. Typical optimization goals in Leanheat control are peak power reduction and energy savings. In large scale installations Leanheat optimization can also be connected to production and network optimization modules with various approaches. Standard Leanheat solution with room sensors cuts on average 20% of peak power demand and 10% energy consumption compared to typical heating curve control.

3. Method

With HOFOR, Leanheat control was conducted without room sensors. The aim of the control was peak demand reduction in the network with two different approaches: continuous peak load control and dynamic peak load control. Energy savings were not in the scope of this phase of the project.

3.1 Continuous peak power optimization

Continuous peak power optimization (PPO) aims at flattening the total heat consumption profile of the site. Leanheat model learns the building specific consumption profile and its thermodynamic characteristics. Space heating component is then adapted so that the total consumption profile, which includes, among others, domestic hot water consumption, is as flat as possible as shown in figure 2. Changes to the space heating component are kept within accepted limits so that the inside comfort is not compromised.

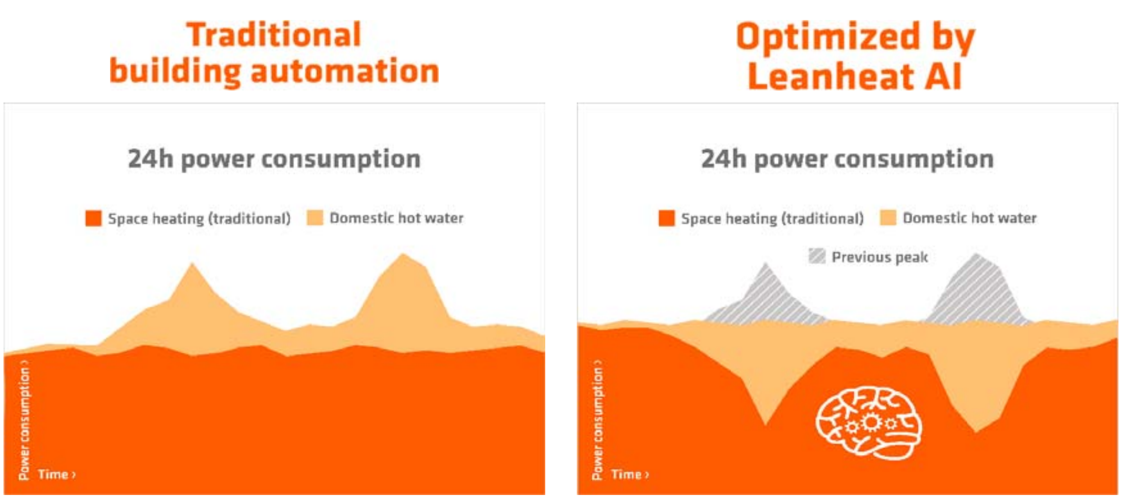


Figure 2 Heat consumption in buildings with, left: traditional building automation. Right: Optimized by Leanheat Artificial intelligence

3.2 Dynamic peak power optimization

Dynamic PPO minimizes the total heat consumption of the site during given hours of the day (e.g. morning and evening peaks) and keeps the consumption as flat as possible during the remaining hours of the day. The sites controlled in this fashion can be thought as counterweights to other loads as the consumption peaks in other sites are compensated by holes in the sites controlled by dynamic approach. Site specific constraints determine the boundaries for the control.

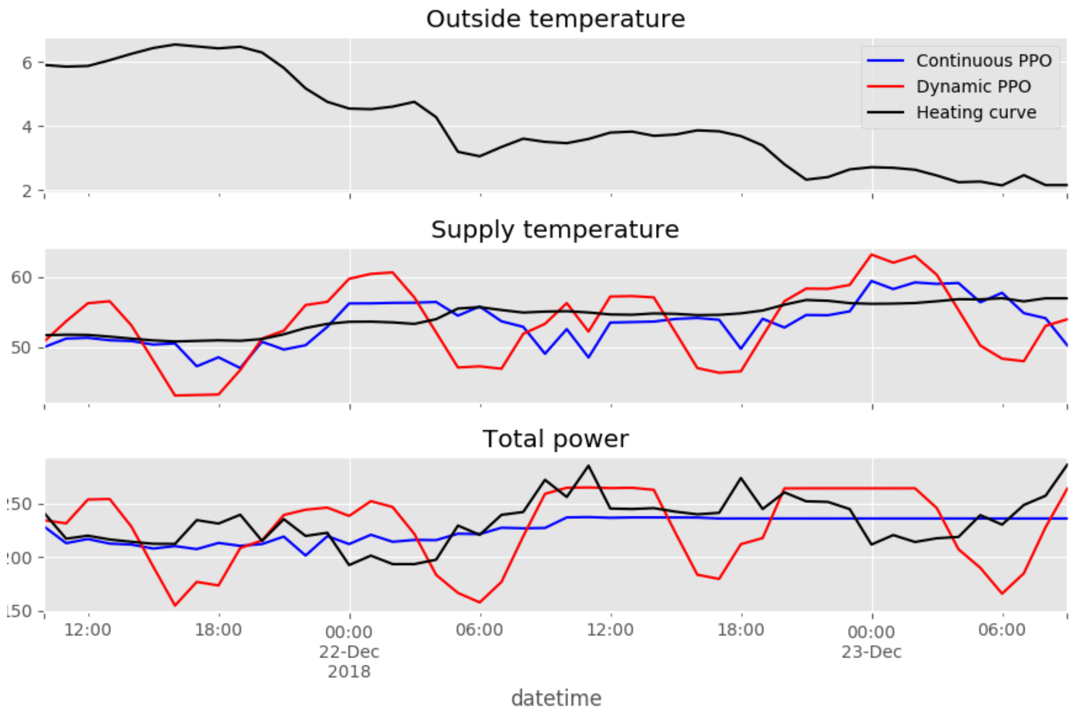


Figure 3 Supply temperature and total power consumption simulated for continuous peak load control (blue line) and dynamic peak load control (red line)

Figure 3 shows simulated results for the two presented approaches and standard heating curve optimization. As a result of shifts in secondary side supply temperature, total power is either flattened (Continuous PPO, blue line) or minimized during given hours (Dynamic PPO, red line) compared to heating curve optimization (black line).

4. Results and discussion

Both continuous and dynamic PPO approaches were tested in pilot sites during the heating season 2018-2019.

Please be noted that the daily average heat power profile is corrected to account for variations in outdoor temperature during the period of continuous PPO, and dynamic PPO. A correctional factor is calculated based on the difference in daily average mean power during reference and each test. Because the reference daily average heat power profile is corrected, it appears, from looking at figure 4 & 6, that two different reference periods have been used.

4.1 Continuous peak power optimization

On average, daily peak power was reduced by 15% and from figure 4 it can be seen that the aggregate consumption profile was close to flat as a result of peak power optimization. From figure 5 which shows the average daily heat profile for each pilot site, it is notable that each site has a unique consumption profile and best results are reached by optimizing the consumption on site level.

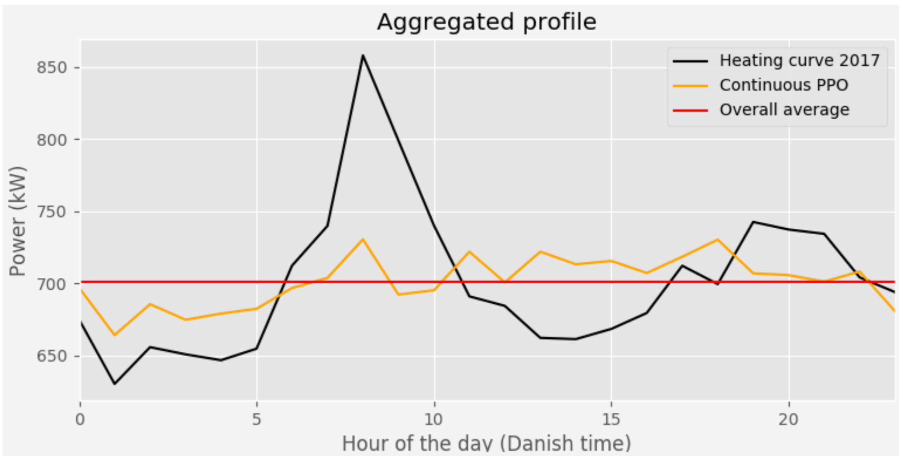
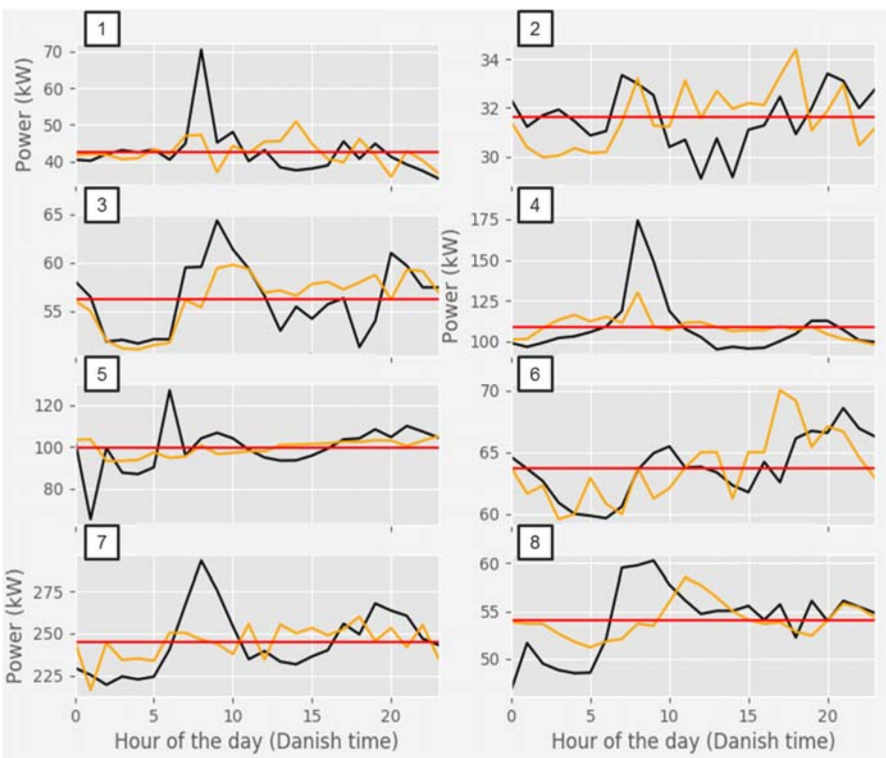


Figure 4 Aggregated daily average heat profile for all sites with continuous peak load control (orange line: 18.12.18-23.01.19), and standard heating curve control (black line: 30.10-24.11.17)



Figur 5 Aggregated daily average heat profile for each of the eight pilot site with continuous peak load control (orange line: 18.12.18-23.01.19), and standard heating curve control (black line: 30.10-24.11.17)

4.2 Dynamic peak power optimization

Dynamic PPO was tested by minimizing the consumption during the hours of 06:00-09:00 and 17:00-20:00 in all pilot sites. Two different parameter values for maximum allowed energy drop within an hour were tested. The optimization was first run with the parameter value of 10% (24.-29.01.2019) and following with a value of 6 % (4.2-3.3.2019). Parameters were chosen conservatively and can be further improved.

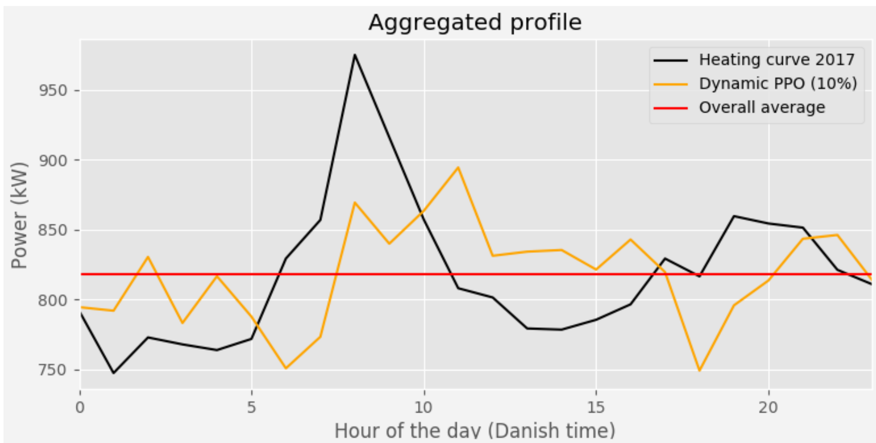


Figure 6 Aggregated average daily heat profile for all sites with dynamic peak load control at 10% parameter value

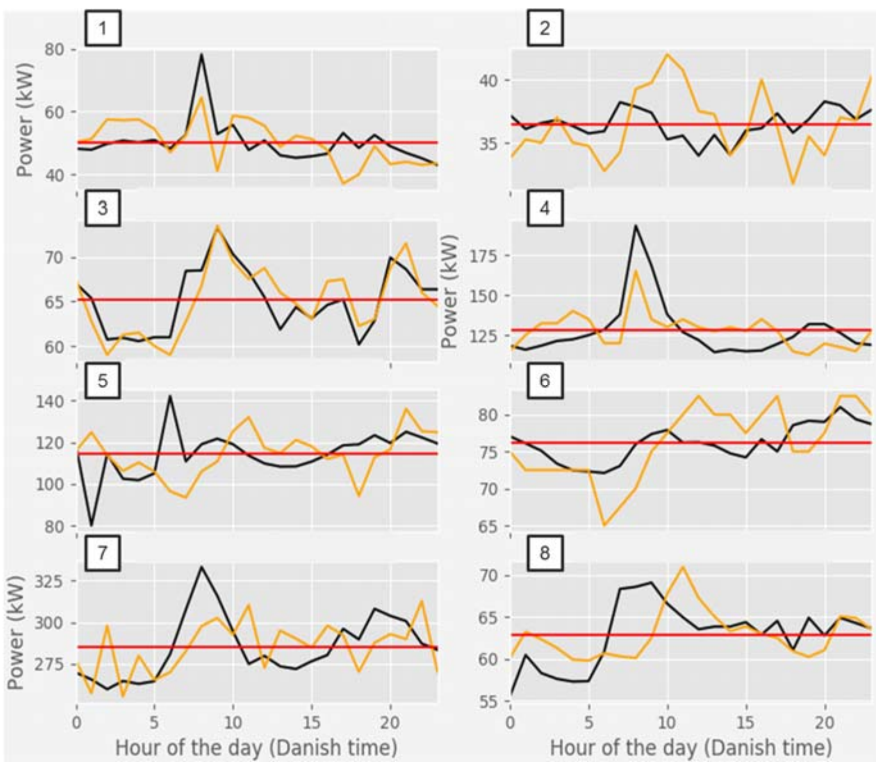


Figure 7 Average daily heat profile for each site with dynamic peak load control at 10% parameter value

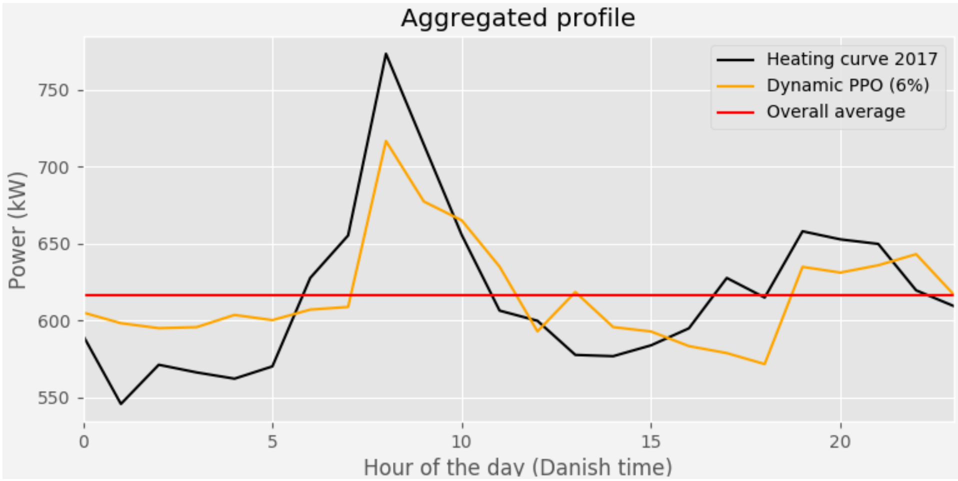


Figure 8 Aggregated average daily heat profile for all sites with dynamic peak load control at 6% parameter value

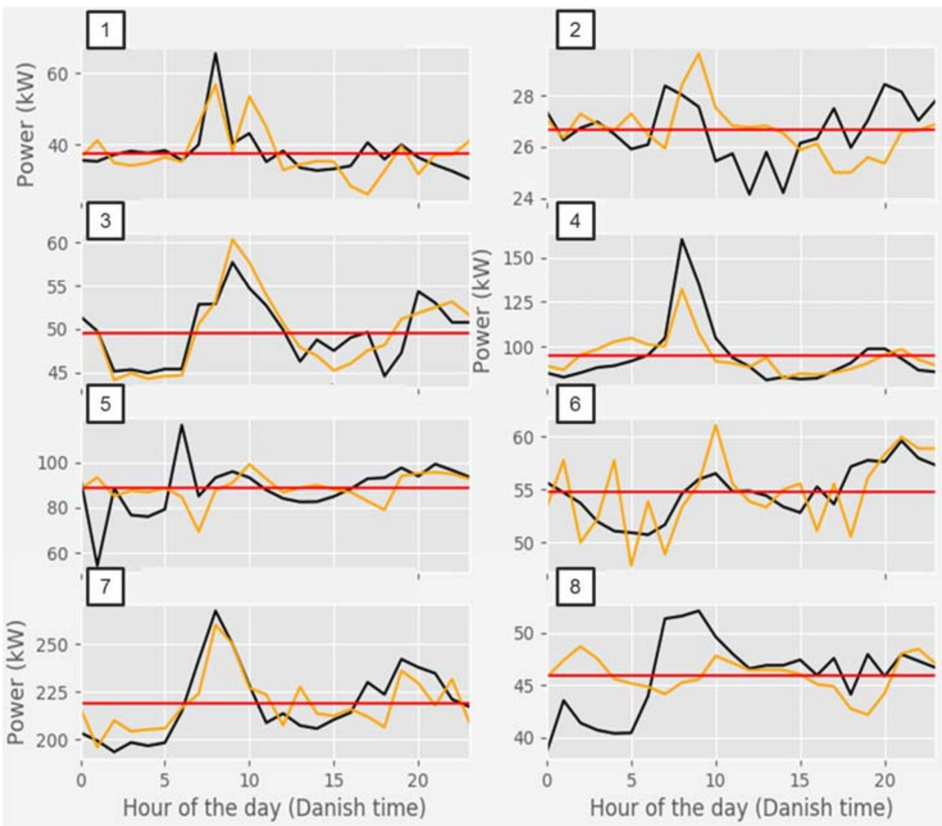


Figure 9 Average daily heat profile for each site with dynamic peak load control at 6% parameter value

Effect of the chosen parameter value can be clearly seen in figure 6 for all sites together, and in figure 7 for each pilot site. With the 10% parameter value, on average 8% of the consumption load was moved from the peak hours to other hours.

However, with the 6% parameter value, 6% of the consumption load was moved to the other hours.

Reduced consumption during peak hours is compensated with additional heating during the other hours of the day. Based on the results from the dynamic PPO, the majority of this compensation occurs during the hours following immediately after the load reduction periods. This is something that can be further improved in the optimization procedure.

As for the continuous PPO it can be seen from figure 7 and 9 that each site has a unique consumption profile and thus the best results for the dynamic peak load control is also reached by optimizing the consumption on site level.

5. Conclusion

In general, it can be concluded that both continuous and dynamic PPO are methods for smoothing the consumption peaks in the district heating system. It is not possible at the present to conclude what method is the most promising, as it depends on the demand for peak power optimization.

With the continuous PPO approach, the daily heat power profile is made as flat as possible on site level. If the peak power reduction is on average 15%, as in pilot sites, and continuous PPO would be applied to 50% of the sites (consumption-wise), total network consumption peak would be reduced by 7,5%.

Whereas in case of dynamic PPO, the aim of the approach is to counterweight the other remaining loads in the network. In the pilot the dynamic approach was tested by a binary control signal where optimizer tried to minimize the consumption during the given hours. More effective way would be to optimize site loads against the total network load. This way more weight would be given to the hours with highest power need and site heating demand would be compensated during the most optimal hours.

Further, with the dynamic approach it is possible to flatten the total network consumption profile by only controlling subset of the sites. The needed site number for achieving this depend on how aggressively heating can be reduced in the sites during the peak hours. This is a site specific parameter that depends on, among other, heating system and site specific thermodynamic characteristics.

6. Prospective work

To fully establish the potential for continuous and dynamic PPO respectively, the demand must be further investigated in terms of magnitude, and length of peak.

In the future, it will also be possible to connect Leanheat sites to production- and network optimization tools. Leanheat can provide data to the tools on consumption forecasts, and related boundaries, and receive control signals from the tools in return for more complex control approaches.

There are many other development possibilities for the automated and remote controlled buildings and some activities and ideas are listed below:

1. The energy saving potential will be investigated during the following heating season and can potentially be achieved by using weather forecasts, consumption characteristics of similar sites and measurements from the heating automation system.

2. Optimizing control of domestic hot water tanks and thereby reduce the daily peaks.

3. Implementation of automated and remote controlled buildings as a flexibility tool in the production planning by:

   - Activating flexibility in buildings instead of starting short term peak and/or reserve load boilers

   - In a future production scenario where district heating is produced by heat pumps that need flexibility towards fluctuating electricity prices