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Designing smart, resilient cities for all

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Executive Summary

Background

All buildings have a thermal capacity determined by the mass of their constructions. The thermal inertia of the materials of the construction enables a temporary reduction of space heating supply, without jeopardizing the comfort in the building. Depending on the buildings design and material choices, the storage capacity may vary quite a lot- so called *thermal flexibility*. This phenomenon has been tested and verified in earlier projects[1].

By exploiting the thermal flexibility with use of AI-ML[2], it is possible to achieve a *Peak Load Shaving*[3] benefit, i.e. reducing peak loads, and thus, reducing climate impact of the building complexes' space heating, and an energy saving potential to the property owners.

Purpose

The purpose of the project was to explore the potential of such technology in cold climate conditions of Umeå, and the mix of different building complexes of the RUGGEDISED testbed area of Umeå[5].

To what extent can the technology lead to energy savings and reduction of climate impact concerned?

Method

By installing the *WIPE*[4] on the feed signal to the buildings heat supply control systems, it was possible to 'trick' the building complexes to discharge/charge its thermal capacities in a controlled way, without jeopardizing the indoor climate comfort.

The project chose three different building complexes, with different kind of purposes: hospital, office and dwellings. This was done to examine differences in the thermal flexibility and peak load shaving potential of these different kind of buildings.

Results

The *WIPE*-system hook up were tested in real life applications during the heating season of 2018-2019, and proved results as follows-

table 1. Results of test period from 2018-12-28 to 2019-04-03 *(see appendix 1 for details)*

Item	Results	Note
Energy savings in buildings (%)	7,8 %	Mean of all building complexes
Peak load shaving potential (%)	23 %	At a duration of 2hrs and outdoor temp between -5°C/ +5°C
CO2eqv- reduction TOTAL (kg)	946 kg	CO2, N2O, CH4
CO2eqv- reduction per invested Euro (kg/ €)	0,946 kg/€	*At* investment=10k€, annuity= 3years, discount rate= 8%

[1] see reference list, chapter 6

[2] *AI-ML* – Artificial Intelligence- Machine Learning

[3] *Peak load shaving*- even out peaks and slopes on a space heating supply load curve, and thereby reducing the need of peak production capacity.

[4] *WIPE- Web based Information Platform for Energy (NODA Energyview™)*

Conclusions

The system proves successful in reducing both energy and climate impact, whilst being cost effective since its simplistic hardware and smart application of AI and Machine learning improves virtually any supply chain of said technology.

Continued work

The business model of a cooperative, relation-oriented, type is preferred, due to the fact the hardware installations are made in the property owners substation, but the value creation is made across the whole value chain. By this we mean the value creation need to be shared between property owners and utility. There are also possibilities to make a value creation around the CO_2- reduction obtained.

The project will track these value components during the rest of the project to estimate an aggregated cost-benefit of the system.

Contents

Abbreviations

DH- District Heating
CHP- Combined Heat and Power plant
MSW- Municipal Solid Waste
WIPE- Web based Information Platform for Energy

1. Introduction

This is the report of the RUGGEDISED action U2/ WP3 deliverable D 3.7- *'Web based Information Platform for Energy management' (WIPE)*. The report displays the findings, and describes the potential of *Peak load shaving*[5] in the RUGGEDISED test bed area[6].
The platform has been designed, configurated and tested to completion during the project implementation phase, 2017-2019. The evaluation will also continue during the measure and monitoring phase (2020-21) of the RUGGEDISED project.

The platform is a cloud -based service which collects data from the buildings and the District Heating (DH) substations. The data is then used for governing the space heating demand-supply in a more efficient way, and to visualize the buildings energy performance.

The improvement is made possible by a feedback loop of the actual heat load of the buildings, instead of just using the outdoor temperature, which is usually common practice.

Another important upside is the possibility for the Utility company Umeå Energi to use Peak load shaving of the customers heat demand. This enables optimisations by:

- Avoiding- decreasing use of peak load boilers which lowers climate and environmental impact.
- Balancing heat demand over time to maximise revenues of power sales from CHPs[7] owned by the utility.
- Decreasing heat momentarily in case of supply malfunctions.
- Automatic forecasting of heat loads of the connected DH-substations.

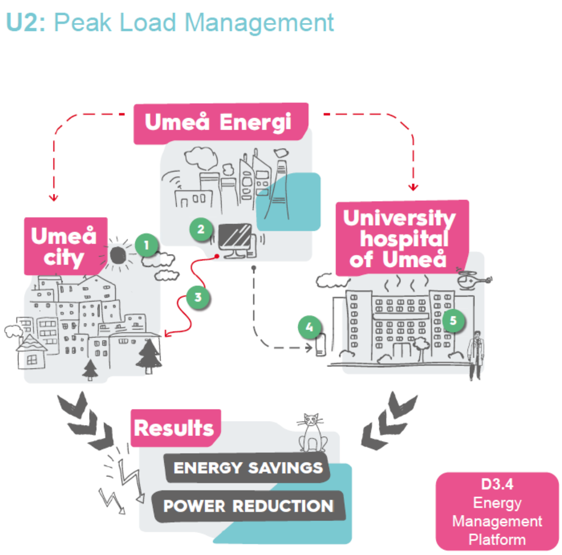


Figure 1- Schematic view of design(left) Smart meter connected to the energy management platform (right)

[5] *Peakload shaving;* A technology to reduce climate impact by even out energy consumptions over time. see e.g. https://www.sciencedirect.com/science/article/abs/pii/S0360544217311040

[6] *Testbed area;* Campus, Hospital and dwellings in the vicinity- aka 'Universitetsstaden' (*eng*- 'University city')

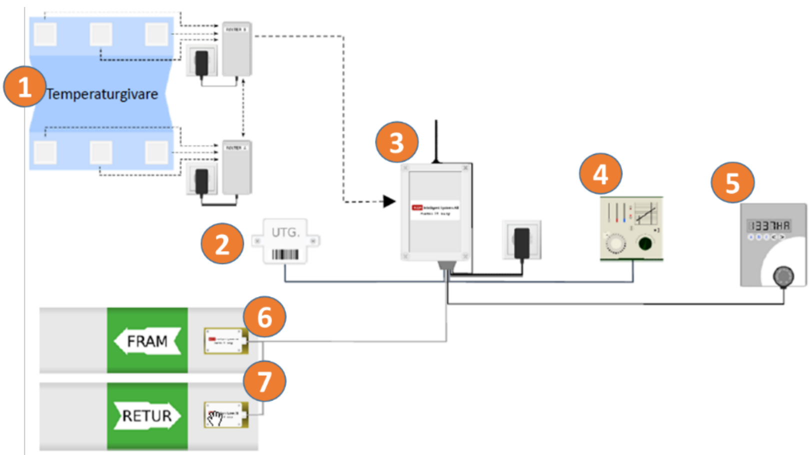
[7] *CHP- Combined Heat and Power plant;* Umeå Energi has two CHPs (MSW and Biomass) providing heat to the DH system of Umeå (including the RUGGEDISED testbed area)

2. Methods and results

2.1 General description of the system and governing principle

All buildings have a thermal capacity determined by the mass of their constructions. Depending on design and material choices the storage capacity may vary quite a lot- so called *thermal flexibility*. Heavy buildings contains materials - eg concrete - with higher thermal capacity than lighter materials, e.g. wood.
This has been put to test in previous research projects [8]

The system hardware hook-up is simple, which makes it possible to install these units in most existing systems.
The control unit needs out- and indoor temperatures feed, in combination with data from the secondary and primary side of the substation. From these feeds it sets the controlling unit and accesses the building's current control systems. see figure 2.
The system will use the measurement data in combination with weather data to predict the coming heat load. From these predictions, the systems always optimizes the building's heat demands, while keeping the indoor temperatures in check.
The gain of the system is twofold - it both saves energy for the property owners, along with also reducing the peak loads of the district heating grids. When controlling the systems to minimize district heating peak power, the system can quickly react to significantly lower the space heat demand of a building.



1. Indoor temperature sensors
2. Outdoor temperature sensor
3. Energy management platform (WIPE)
4. Building Energy Supply Controller
5. Heat meter
6. Secondary side temperature sensor (feed)
7. Secondary side temperature sensor (return)

Figure 2- System hook up

[8] TEMPO (Horizon 2020, #768936, https://www.tempo-dhc.eu/).

2.2 Project contents

2.2.1 Actions

The following actions have been executed in the project:

- Gathering reference data of the three building complexes
- Connection of three building complexes, including indoor temperature sensors to the WIPE.
- Optimization of energy use for heating of the connected building complexes.
- Calculation of the building complexes thermal flexibility.
- Defining peak load(shaving) potential, i.e. the thermal flexibility of the buildings.
- Connection to web-based information platform for energy- *WIPE*- 'EnergyView'[9]
- Collection and visualisation of energy consumption data.

2.2.2 Gathering reference data

During space heating season (October to April) of 2017-2018 reference data of energy (timestamped, per hour) was collected from the metering systems of the building complexes. This data formed our baseline.

2.2.3 Building complexes connected

Following building complexes have been connected to the platform during the project and onwards-

- Matematikgränd 1-15 and 17-23 (apartment buildings)
- Samverkanshuset, Umeå Universitet (office buildings)
- Tvistevägen 2, Ålidhem (hospital buildings)

Note: The Samverkanshuset building complex is indirectly connected to DH through the local heat network of Campus, which in turn gets its heat supply off the DH network. This affects the load shaving capability of this specific unit, since there is no possibility to track a direct cause and effect on the DH system. The energy saving is easier to follow up due to sub metering installations.

2.2.4 Design principles

Optimization overview

The general optimization process involves several steps relating to forecasting, planning and distribution control actions. The forecasting models are based on neural networks and tree-based regression systems used for feature selection and deep learning[10]. The planning and distribution processes are primarily based on ADMM-like optimization methods[11]

Optimization of energy use for heating

To every building, an indoor temperature setpoint was decided between the system stakeholders- utility and property owners.

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[9] NODA Patent.

The web-based frontend in itself is not patented. It's the underlying algorithms and how they interact with the hardware.

[10] See reference no 4 in Reference list, page 14.

[11] The alternating direction method of multipliers (ADMM) is an algorithm that solves convex optimization problems by breaking them into smaller pieces, each of which are then easier to handle. It has recently found wide application in a number of areas. (Parikh N., and Boyd S. 2014. „Proximal algorithms") *see also reference register in chapter 6, page 14.*

This setpoint represents the preferred indoor temperature and adjusts the heating supply accordingly. The maximum allowed deviation of the actual indoor temperature related to the setpoint is 0,5°C.
Next step was to gather data of the building's current energy consumption, fed from the heat metering. The readings of the meters were then correlated to the actual outdoor temperatures outside the buildings.
By compiling this data it is possible to create a model of the heat demand of the building.
Improvements of load curve quality were made by iterations with comparisons of load shift campaigns to days with zero load shift. (see figures 3 and 5)

Optimization of peak load shaving

During wintertime, the period between 21/12-18 to 8/4-19, the peak load shaving capacities of the buildings were investigated. The purpose was first and foremost to establish the thermal flexibility of the different buildings at different outdoor temperatures and levels of manipulation. The flexibility is described as percentage of the buildings heat demand. (*see figure 4*)
To establish an estimation of available flexibility potential in the current system, there needs to be several test runs to adapt the system and identify the flexibility. These test runs were performed during the test phase, 21/12-18 to 8/4-19.

Analysis of heat substation performance

The supplier[12] provides a fully automatic self-diagnostic function for analyses of the district heating substations connected to the system. This function leaves information of performance ratings for maintenance personnel to act upon. It may also be used in customer dialogues between utility and property owners.

2.2.5 Results of Optimization of energy use for space heating

The optimization has been tried out in two different campaigns: from September 1st to December 20th 2018, and from April 9th 2019 to May 31st. (The units will be in continued operation during the remaining time of the project, and beyond). Table 1 below shows the results of the optimization.

Table 2. Energy savings[13] of the different building complexes.

Building complex	Energy savings 2018.09.01- 12.20	Energy savings 2019.04.09-05.31
Matematikgränd 1-23	9,5 %	10,4 %
Samverkanshuset	5,5 %	N / A
Tvistevägen 2	6,0 %	N / A

Note. The differences between the two periods and building complexes are due to the various factors beyond the projects reach- such as condition of the buildings, type of activities and more.

[12] NODA Intelligent Systems AB
Telefon +46 454-10 271 webpage : www.noda.se

[13] The baseline was calculated using normal year correction with the energy signature method

2.2.6 Results of Optimization of peak load shaving

The available flexibility is due to the thermal inertia of the mass of the construction and its thermal capacity. The inertia creates a delay between supplied energy and changes in the user's experienced indoor climate. In other words, it is possible in short periods to cut the heat supply without jeopardizing the indoor climate. When this is made in an orderly fashion, coordinated within a whole block of buildings, it can lead to load shifting possibilities for the total DH-system.

Feedback tests of individual buildings

In every building there is a control unit which governs the space heating supply depending on outdoor temperatures. This is normally run by a preset load curve, which sets a feed temperature for the heating corresponding to present outdoor temperature.

In this system the control unit is manipulated by an offset signal feeding in to the control unit, instead of the normal outdoor temperature. This offset signal 'tricks' the control unit with a false outdoor temperature that is either much higher or lower than the actual outdoor temperature. By that, the control unit responds by either decrease or increase the heat supply to the building according to the trick signal.

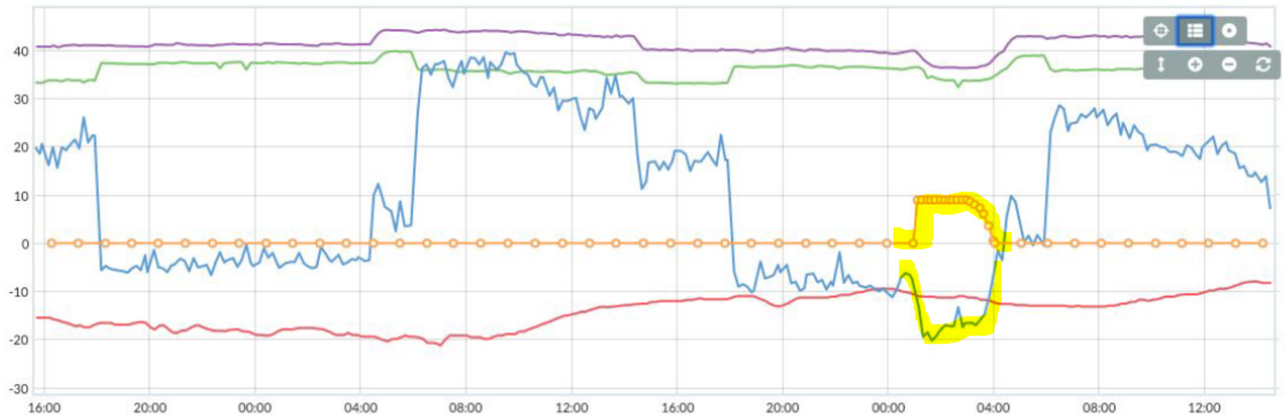

Figure 3- Peak load shaving with maximum offset +9°C (yellow marker pen shows the actual test period)

Purple line- feed temperature to building (left Y-axis, °C)
Green line- return temperature from building (left Y-axis, °C)
Yellow line- Offset signal (left Y-axis, °C),
Blue line- Space heating supply (right Y-axis, kW)
Red line- outdoor temperature (left Y-axis, °C)

Figure 3- above- shows a test with maximum positive offset 'trick signal' +9°C (*yellow line*), leading to an immediate response of the space heating drop of supply from ~54 to ~42 kW, (*blue line*). This means that the building will *discharge* its thermal flexibility.

In a similar fashion it is possible to *charge* the buildings flexibility by using a negative offset signal (max -9°C).

By combining these two functions, an optimization system is made possible which will be functional over the whole space heating season (October to April).

Note

The impact an offset signal actually makes needs to be correlated to a whole range of different parameters, such as the user's appreciated indoor climate- often depending on what type of activities are performed in the building, local climate parameters (sun loads, wind etc.), building physics (insulation, number of *windows) etc. This max offset must be tested individually for every building*.

Feedback tests on aggregated thermal flexibility

The aggregated thermal capacity is displayed in figure 4, below. It shows every hourly reading of the normal energy consumption during the test period (blue dots) and every hourly reading of offset energy consumption (orange dots). The averages of each is represented by the lines in the clusters.

As an example, the figure shows an average thermal flexibility of ~114 kW at mean outdoor temperature of -5,0 °C. (*figure 4)*

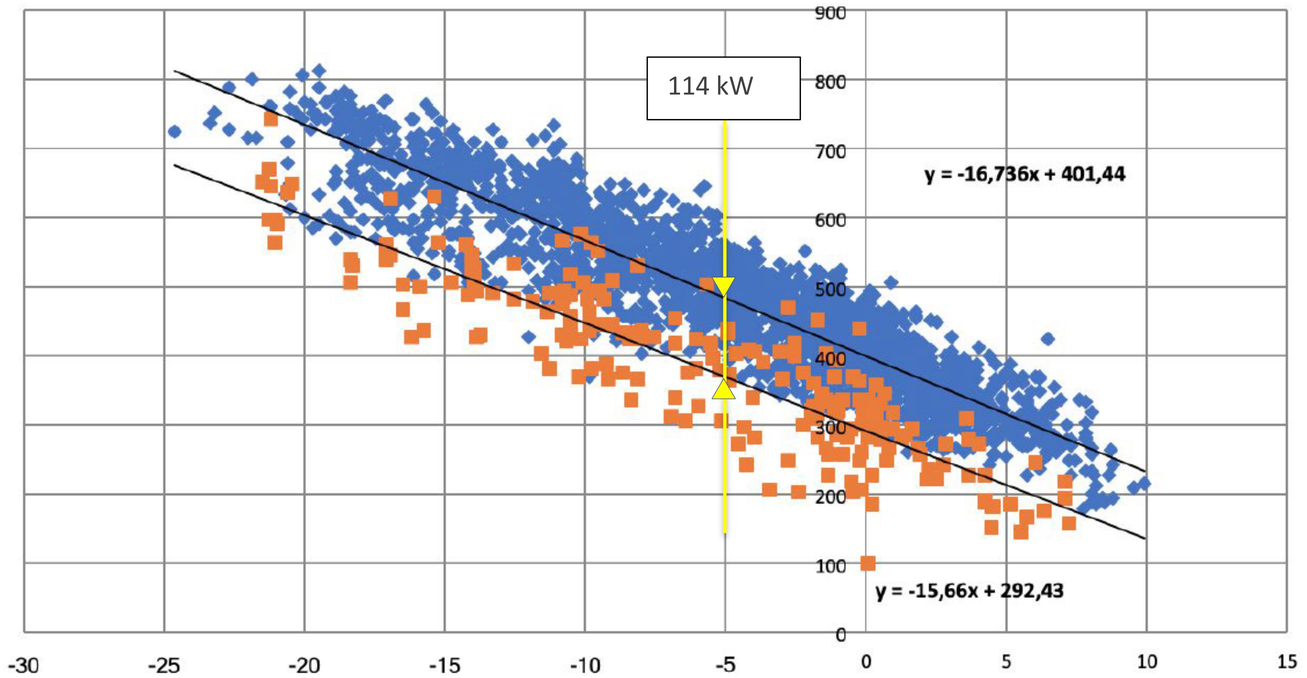

Figure 4- Flexibility curve- Aggregated thermal flexibility

Blue dots- Baseline data (hourly readings 2018.12.21- 2019.04.04)
Orange dots- Peak load shaving (hourly readings 2018.12.21- 2019.04.04)
Y-axis - heat demand, kW
X-axis- outdoor temperature, °C
(All buildings)

2.2.7 Impact on Indoor temperatures

In the connected building complexes, there are sensors measuring the indoor temperature. During the tests made in this project, no complaints[14] or other anomalies have been registered.

In figure 5 below the relation between offset signal and indoor temperature of one of the connected building complexes is displayed. (Samverkanshuset)

The graph includes 4 days and shows a drop of indoor temperature during nighttime, regardless of any offset signal or not. This is due to the nature of activities of the users (office building) which means the building is empty during nights. No extra drop is detectable due to the offset signal.

[14] No information of the tests were disclosed to the tenants before and during the tests. This is to avoid bias of results.

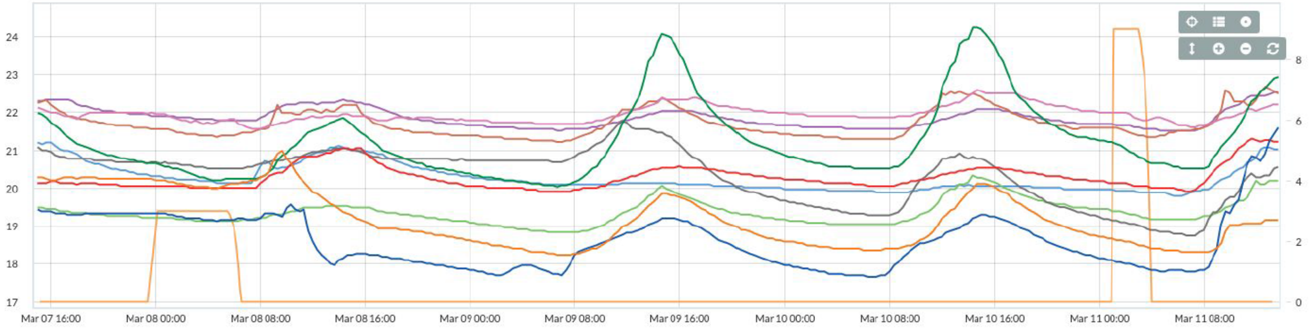

Figure 5: Indoor temperature response to offset signal
Yellow line(bottom)- off set signal (°C)
All other colour lines- Indoor temperature sensors
Y-axis left – Indoor temperature (°C)
Y- axis right- Offset signal (°C)

(Samverkanshuset 7/3 to 11/3- 2019)

2.2.8 DH Return temperature[15]

As mentioned earlier, there is not only the heat load that is possible to optimize through the platform. The return temperature is equally of interest and is to be regarded as a part of the optimization potential. Normally the grid operator of the utility strives to obtain as low return temperature as possible, since it (in theory anyway) makes it possible to extract more electric power of the CHP out of the steam turbine-/ generator train, due to the lower condensation pressure a lower DH return temperature causes.
Another upside of lower DH return temperatures are the possibility to gain better use of renewable heat sources[16], which often needs lower temperatures to work properly.

Figure 6 below shows the results of a DH return response test of all the building complexes. The drop of the DH return temperature due to the offset signal is apparent. The drop is significant due to the different building complexes' characteristics.

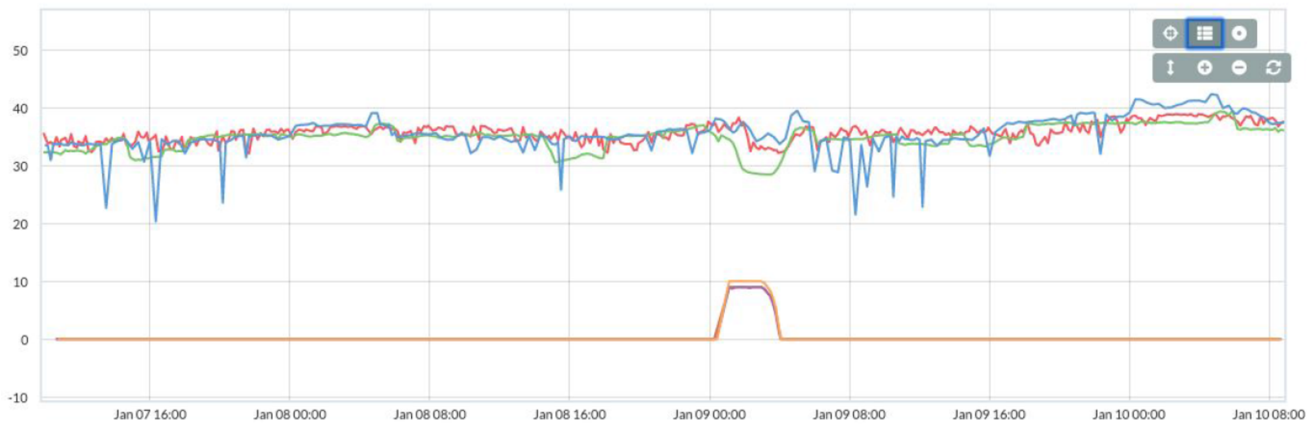

Figure 6: DH return temperature response to offset signal
Yellow line (bottom)- Off set signal, Y-axis to the left (°C).
All other colour lines- DH return temperature sensors, Y-axis to the left (°C)
(all building complexes)

[15] *DH Return temperature*; the temperature of the hot water in the DH return pipe back to the CHP
[16] *Renewable energy sources*; e.g. Heat pump hook ups, fluegas condensation scrubbers etc

3. Conclusions and Discussions

Conclusion

The Web based Information Platform for Energy (WIPE) seeks to make operative cohesion within a DH value chain- all the way from production, through distribution, to end user wellbeing. These are the most important aspects of the optimization philosophy; lowered environmental impact through lesser use of peak production- as this may be based on fossil fuels[17]-and strengthened DH business case.
The WIPE coordinates the load curves of the different building complexes along with the production and distribution conditions at any given moment.

From our tests we have made the following conclusions-

- The energy savings during the test periods are on average 7,85 % compared to baseline. (The baseline was calculated using normal year correction with the energy signature method.)
- The results vary significantly due to very different weather conditions of different test periods and different thermal flexibility of building complexes.
- When the three building complexes are "shaved" simultaneously the heat supply (peak load) can be decreased by up to average 23% for a 2 to 6 hours duration, at outdoor temperatures between -5 to +5 °C. (*see table 2*)

Table 2. Peak load shaving results. (All buildings)

Shaved (kWh/h) [2]	Unshaved (kWh/h) [3]	Energy Reduction (kWh/ %)	CO2-eqv reduction (kg) [1]	Annual Cost of *WIPE* (€ per annum) [4]	CO2eqv-reduction/ Euro (kg/ €)	Outdoor temp (°C) [5]
381,6	496,8	19 283 / 23	946	1008	0,94	- 5,7

[1] Source: Swedish Greenhouse Gas inventories for 1990-2018 years' emissions to the UNFCCC
[2] Y= (-15,66* -5,7)+292,43 Mean of the test period 218 hours of load shaving
[3] Y= (-16,736* -5,7)+401,44 Mean of the test period 218 hours of load shaving
[4] Annuity calculation; Investment total 10k€, discount rate 8%, calculation period 3years, residual value 0
[5] AVE ODT Average outdoor temperature of test period

Discussion

- The analyses encompasses only three building complexes. This makes it harder to deduce a statistically robust analysis of the overall operational behaviour, since individual buildings (that might have abnormal deviations) have a significant impact on the mean, and therefore may cause results not representative in a larger scale operation.
- The fact that the building complexes differs a lot in size affects the assessments too.
- One of the building complexes (Samverkanshuset) is measured through a submetering

17 In 2018, the production of DH to Umeå where 1008 GWh, where of 22,7 GWh (~2,3%) were based on fossile oil fuelled boilers. (2018)

arrangement (i.e. the building has no direct connection to the DH system, it gets its heat supply through a secondary grid) leads to different conditions compared to the others. This fact needs to be further analysed in the project, as how it may affect the load shaving capacity and energy optimisation.

- The results of these initial tests will be followed further along the project, correlated and quality checked with the WP5 and WP6- proof of results and the dissemination to fellow cities.

4. Recommendations

The project can recommend the WIPE to any other utility or property owners, since its simplistic hardware and clever application of AI and Machine learning improves virtually any supply chain of said technology. The WIPE is a cost effective way of adressing climate change challenges.

5. Risk Register

Table 3. Risk register

Risk	What is the risk	Level of risk[18]	Solutions to overcome the risk
Software malfunction	Bugs, hackers, malwares etc impedes or disrupts function of the WIPE.	2	The WIPE is secured by cryptography and also features a two way method identification tool.
Hardware malfuntion	Connectivity issues, sensor brake downs, power shortages etc leads to none or false detection of parameters	2	The WIPE is equipped with a failsafe function which bypasses the WIPE, and restores basic functions.
Data privacy	That data related to individual persons are compromised	3	The WIPE platform is fully compliant with GDPR. The data collected in the project primarily relates to the building level, rather than individual person level.

6. References

1. Guelpa, Elisa, Giulia Barbero, Adriano Sciacovelli, and Vittorio Verda. 2017. "Peak-shaving in district heating systems through optimal management of the thermal request of buildings". Elsevier. https://www.sciencedirect.com/science/article/abs/pii/S0360544217311040

2. Johansson, Christian, Dirk Vanhoudt, Jens Brage, and Davy Geysen. 2018. "Real-time grid optimisation through digitalisation- results of the STORM project". Elsevier. https://www.sciencedirect.com/science/article/pii/S1876610218304855

3. Johansson, Christian. 2020. "NODA Resultatrapport SHG UEAB 2019"

18 Risk level: 1 = high risk, 2 = medium risk, 3 = Low risk

https://www.noda.se

4. Suryanarayana, Gowri, Jesus Lago, Davy Geysen, Piotr Aleksiejuk, and Christian Johansson. 2018. “Thermal load forecasting in district heating networks using deep learning and advanced feature selection methods”
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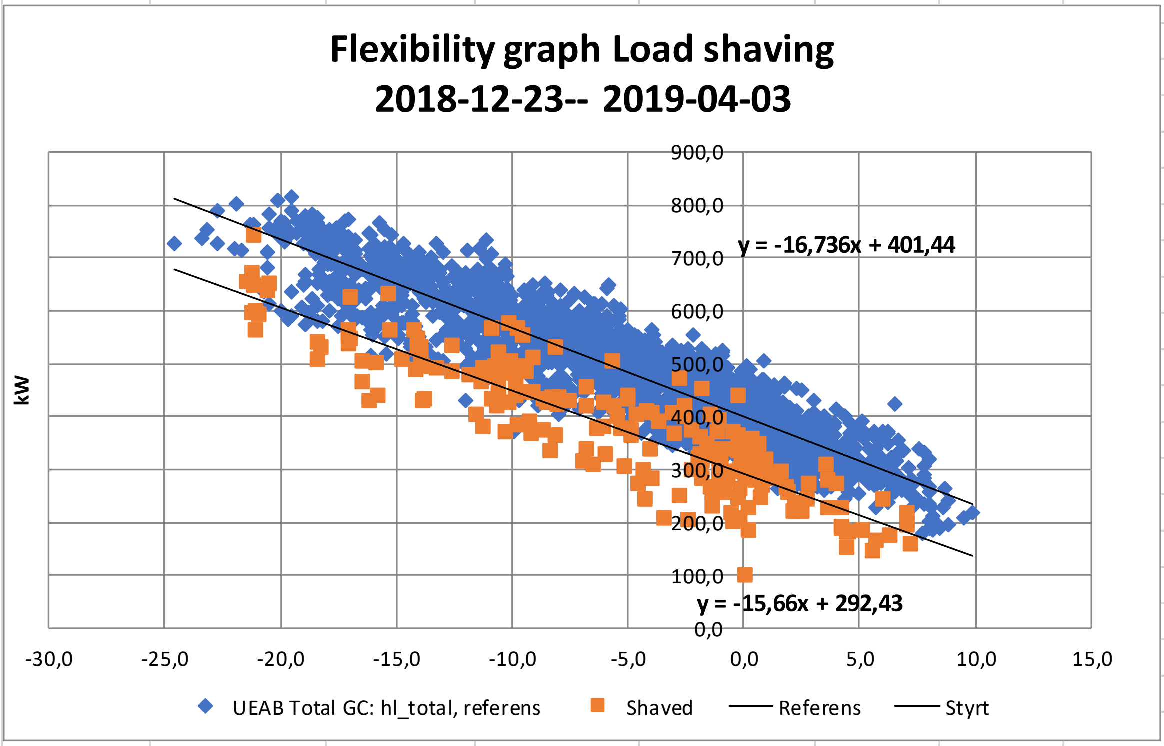
Appendix 1- Flexibility graph and emission calculations



Emission factors of District Heating production in Umeå (2018)

1	2	3	4	5	
BIOMASS	HP-EL(SEER 3,0)	BIOPELLETS	BIOOIL	FOSSILOIL	
0,05	16,67	0,05	0,01	274,33	kg CO2-eqv / MWh [1]

Margin fuels during test period

1	2	3	4	5	
BIOMASS	HP-EL	BIOPELLETS	BIOOIL	FOSSILOIL	TOTAL hrs
108	55	26	4	25	218
49,5%	25,2%	11,9%	1,8%	11,5%	100,0%

Results

Shaved (kWh/h) [2]	Unshaved (kWh/h) [3]	Energy Reduction (%)	Total energy save (kWh)	Total CO2- eqv reduction (kg)	Outdoor temp (°C) [4]
381,6	496,8	23%	19 283	946	-5,7

[1] **Source:** Swedish Greenhouse Gas inventories for 1990-2018 years' emissions to the UNFCCC

[2] Y= (-15,66* -5,7)+292,43 Mean of the test period 218 hours of load shaving

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