Deliverable no.: D5.1b(i)

A manual for how to use existing buildings' heat profiles to improve the design and operation of buildings

Photo: By & Havn / Ole Malling

HOFOR
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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.

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Executive Summary

To understand a building's thermal capacity and its heat consumption you have to collect basic data about the building and its heating system, and then monitor and analyse the data collected by the buildings heat meter.

This makes it possible to create and visualize a building's heat profile, as well as to identify malfunctions and understand the reasons for the building's heat consumption. Thereby it will be possible to identify the reasons for i.e. high energy usage in a building and to evaluate whether it is caused by poor performance of the district heating substation, the central heating system, the domestic hot water (DHW) system or just a poor performance of the building envelope, being without any significant insulation and/or equipped with poor windows etc.

HOFOR therefore sees intelligent energy monitoring as a prerequisite for energy efficient renovation of buildings.

HOFOR will in the present report document the possibilities and value of a building's heat profiles as well as to provide a manual based on specific examples for understanding and concluding on real life heat profiles from both new and existing buildings.

The heat profile of a building may, depending on the time resolution and type, specifically be used for identifying different types of radiator systems (1- or 2-string) and/or DHW systems (tank or instantaneous water heater).

By clustering the different buildings according to relevant criteria like age, size, usage and the above mentioned central heating systems it will be possible to develop a benchmarking system based on heat consumption.

Thereby, it will be possible to identify the poorest performing buildings/customers within their respective cluster and then target specific energy optimization activities towards them.

In the present manual HOFOR provides documentation and real life examples of how heat profiles can be utilized to improve the design and operation of buildings.

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Author	Reviewer	Approver
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1. Introduction

The heat profile of a building shows how the heat consumption changes over a period of time. Heat profiles can reflect many things such as age and size of the building, design and construction of the building, operation and performance of the building`s heating central as well as the number of occupants and their behavior, and the weather conditions. All buildings have a unique heat profile, however trends in consumption patterns can be seen e.g. in the morning around 06.00-09.00, and in the afternoon around 17.00-20.00 as the majority of people in Copenhagen consumes more domestic hot water during these periods as shown in figure 1.

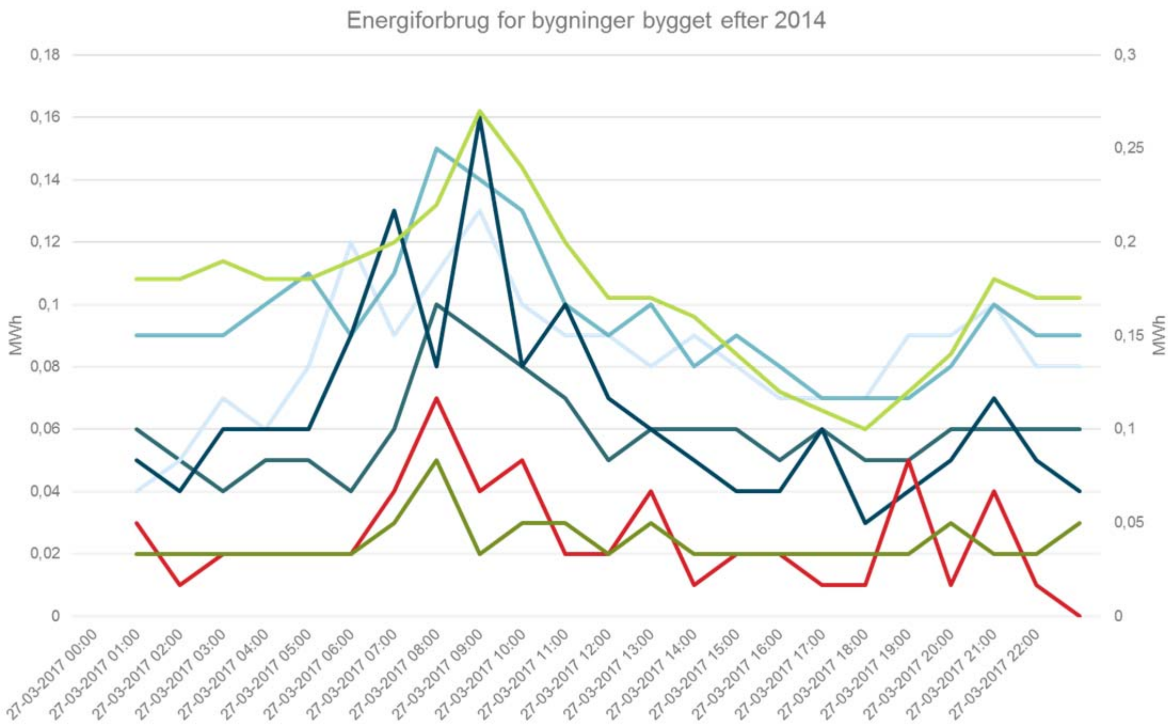

Figure 1: Heat consumption in 7 new multi-family buildings in Nordhavn, in Copenhagen on March 27th 2017

HOFOR has, by introducing remote energy metering in buildings, collected district heating data that provide valuable and specific information in regards to the heat profiles of specific buildings. By grouping similar buildings into relevant clusters, these heat profiles can provide valuable information about the design and usage of the building, and the operation of the buildings` heating central.

This manual will, based on specific examples, help to better understand what means are necessary to optimize the operation of the heating central in an existing building, as well as give an indication of how to improve the design of future buildings.

2. Background

Throughout the times, building design, heat production and fuels have changed, and also the buildings heating systems have changed accordingly.
In the 18th and beginning of the 19th century buildings were often equipped with central coal boilers in the basements, and water based radiator systems installed via the existing chimneys in the buildings as replacement of the individual stoves. Typically the radiators were small, and mounted away from the windows on the back wall, where the chimneys ran up through the buildings. The radiator system installed was typically a 1-string system, which required less piping but also high supply and return temperatures of 90/70 degrees. This was suitable for the operation of the coal boiler, and perfect in a time, when the energy was cheap and the installation and the materials were expensive.

When district heating was introduced in the early 19th century, and later became more popular, the coal boilers were dismantled and replaced by district heating centrals. However, the installations in the rooms and apartments were not changed, due to technical- and financial reasons. In Copenhagen, this has made it challenging to efficiently utilize the district heating system in the old buildings. Despite this, in combination with renovation of the building envelope (more insulation and better windows etc.) and optimization of the performance of the central heating system, it is however still possible to achieve reasonable energy efficient central heating systems that utilizes the district heating system in an acceptable manner.

In the years before the energy crises in the 1970´s many buildings were equipped with ventilation and humidification systems, but without any heat recovery. This typically resulted in large heat consumption, and very limited possibilities for flexibility and change of concept in the heat supply.

Even as late as in the 1990´s, radiator systems designed for very high supply temperatures were installed and resulted in high return temperatures. However, 2-string radiator heating systems also became more common at that time, and starting in the mid 1990´s the design supply and return temperatures for radiators were lowered to 70/40 degrees, making it possible to improve the cooling of the district heating water significantly.

Today most new buildings are heated by floor heating systems, requiring very low supply temperatures (35-40 degrees) in the apartments and thereby offering the possibility for even lower return temperatures to the district heating system when properly operated and maintained.

3. Grouping of buildings

Based on a number of measurements and investigations of the heat consumption in apartment buildings in Copenhagen it has been proven that the building`s physical structure, the structure and control of the building`s heating central, and heating system has a very great impact on a building`s heating profile.

An inappropriate operation of the building`s heating central, and heating system, when compared to the type, structure and intended use of the building might lead to an unnecessary heat consumption.

Therefore HOFOR has decided that in addition to grouping buildings based on age, size and usage (e.g. residential, or office), buildings will also be grouped based on the following three points in order to correctly asses their heating profiles:

1. Building envelope
2. Structure, and operation of the heating central
3. Type, and operation of the heating- and ventilation system

This knowledge will make it possible to provide recommendations on correct dimensioning and operation of district heating substations to achieve lower heat consumption. The intention is to share the gathered knowledge with consultants, architects, developers, installers and many other parties that play a role in minimizing heat consumption in buildings and will be documented in the following sections.

3.1 Building envelope

The building envelope and the inner construction of a building; together defines the thermal capacity of the building. This information indicates how sensitive the building might be to draft, and to any changes in the indoor thermal climate caused by changes in the weather conditions. The building envelope has a great impact on the heat demand in a building e.g. a new (well-insulated), heavy (brick, stone, concrete), building will have a small heating demand, and thereby the DHW will make out a larger share of the heat demand. Thus, the capacity need in a building like this commonly deviates significantly more from the average during peak load hours, than in an old building, or a light (wood, glass) building with a higher heating demand.

This difference is illustrated in the below 2 figures, where figure 2 is an example of a new multi-family building and figure 3 is an example of an old multi-family building.

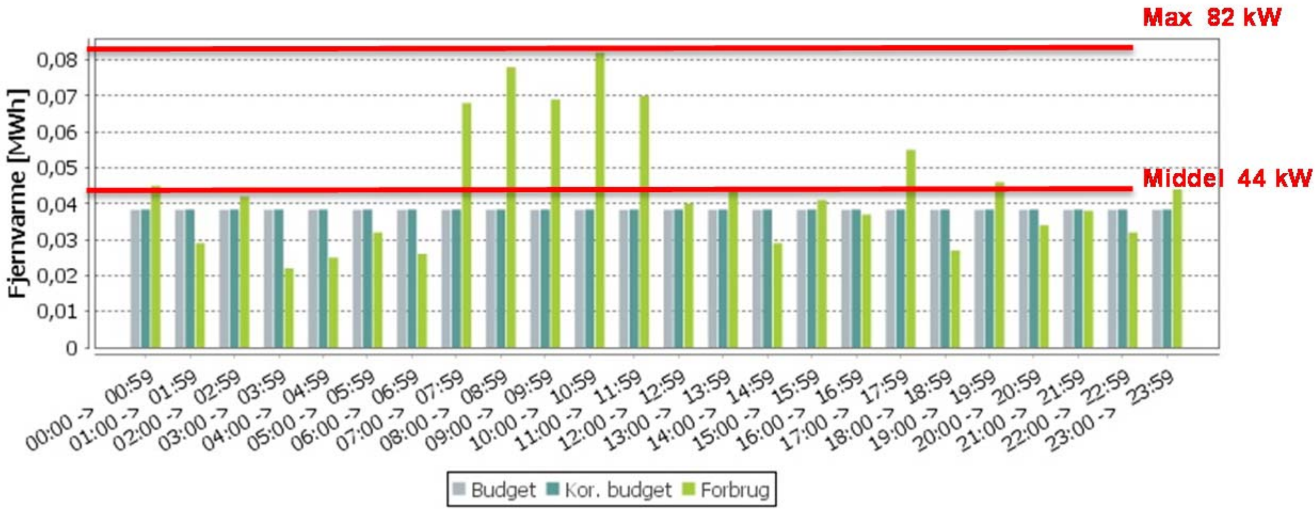

Figure 2: Multi-family building from 2015 and an area of appx. 4.300 m^2 - low energy consumption but large deviations in the capacity demand

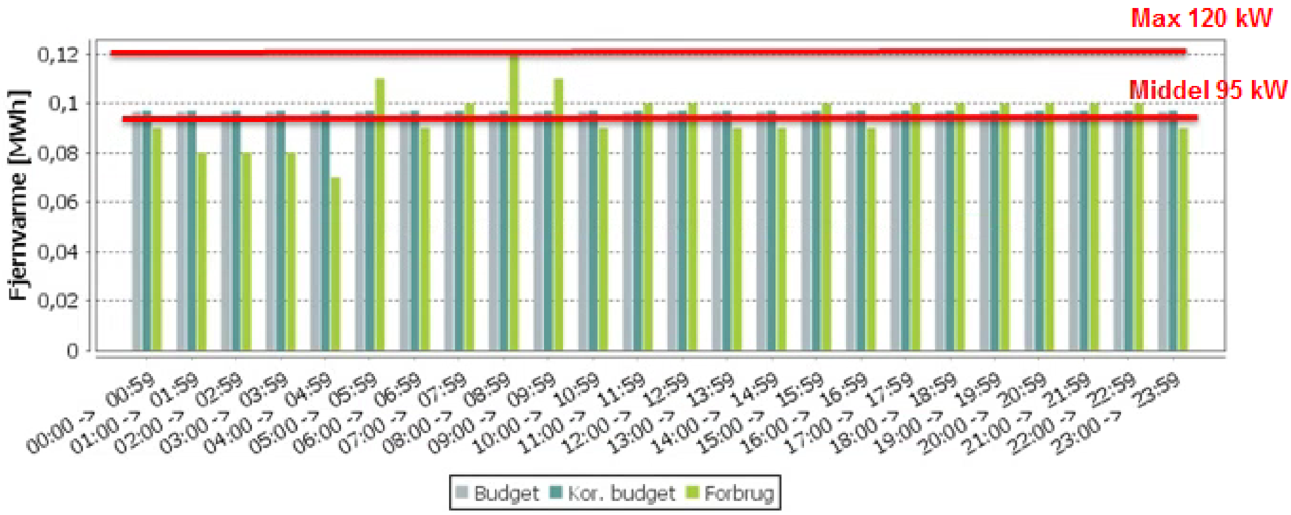

Figure 3: Multi-family building from 1893 and an area of appx. 4900 m2 – very stable energy consumption, even this building has night set-back

In the new multi-family building shown in figure 2, the capacity demand during peak load hours increases by almost 100 %, while in the old building shown in figure 3 the capacity demand only increases by 20 %.

However, as newer buildings have a very good building envelope, it is possible to utilize the heat accumulation of the building by pre-heating or reducing the heating supply for shorter periods to limit the demand during peak hours typically caused by the domestic hot water, and thereby offers some flexibility to the district heating system. This concept and its potential for peak load reduction will be documented in HOFOR´s deliverable “D5.2c Storing heat in the buildings” and is due in April 2018.

In connection with the development of a proposed new heat label system in HOFOR in deliverable D5.1b (ii), a template to collect information about the building envelope was developed. In the below figure 4 a building in Århusgadekvarteret in Nordhavn has been used as an example to illustrate the use of the template. The template will provide information on i.e. type of construction, insulation, windows, type of usage as well as whether non heated areas like parking and/or basements.

Klimaskærm:								
Vurderingsfaktor efter HOFOR effektfastsættelse:				**Kategori:**	4	(1-4; dårlig- veliso)		
Varmeakkumulering:	4.Tung (massiv ud/ind) beton	4						
	4. Tung (massiv ud/ind) mursten			**Vindueandel:**	2	(1-4 - 1 stort;4 lille)		
	3.Middel (massiv ud/ind) gasbeton							
	2.Middel (massiv ud/let gips)							
	1.Let (træ)							
Erhvervsareal	Særligt erhvervsareal Ja/nej- obs	Nej		**Særligt areal**		m2	**Bemærkning:**	
Kælder:	0. ingen kælder	X						
	1. alm. Kælder (fuldt opvarme)							
	2. alm. Kælder (delvis opvarm)							
	3. alm. kælder(ingen opvarm)							
	4. udnyt erhvervskælder (opv.)							
Parkeringskælder ja/nej.		Nej	Hvis ja	**Opvarmet eller isoleret inst:**			**Areal p-kld:**	

Figure 4: Template used to collect information about the building envelope

3.2 Heating central

In a heating central, it is very important to have information about the type of installations and their dimensions, as well as how they are controlled. E.g. the size of the DHW tank and the dimensions of the control valve and the control of the DHW usage can be critical to the building's total heat consumption and operation. The heating central will also have a heat exchanger producing the heating for the space heating system, and the performance of this unit says a lot about whether the dimensions are correct and/or whether the heating system is running optimally.

Typical technical installations in a heating central between the primary side (district heating) and the secondary side (central heating system) and their characteristics under optimal dimensional-, and operational conditions are:

- Heat exchanger for heating:
    - Pressure separation between the primary and secondary side, reducing consequences from leakage in the central heating system
    - Optimum control of flow and supply and return temperatures
    - Small heat losses – less than 3°C between primary and secondary side

- Domestic hot water (DHW) tank:
    - Small peak load capacity during usage
    - Low return temperature possible during stand still and usage periods, due to the temperature layers in the DHW tank

- Heat exchanger for DHW:
    - High peak load capacity need during usage
    - Higher return temperature during stand still periods, due to circulation, however at small flows
    - Low return temperature during usage

Information about the heating central is collected in a similar template as used when collecting information about the building envelope and again the building in Århusgadekvarteret in Nordhavn is used to illustrate the use of the template shown in figure 5.

Varmecentral:									
Antal	1								
Opvarmning:									
CV-veksler	Ja	**Antal:**	1						
				nr	**Type**	**Dimension**		**Automatik**	**Bemærk.**
Regulering CV':	Ventiler	**Antal**	1	1	Motor (AMV 10)			ECL310	2 stk.; en ECL310 til blandesløjfe p.-side
Bemærkning:									
Varmt vand (VVB/VX)	VVB	**Antal**	**Nr**	**Str.**	**Type**	**Vurderet dimension**	**Bemærk.**	**Sum VVB str.:**	1500 l
		2	1	750 l	RBC HP ANODE (fra 2015)	65-35°C	Serie-koblet		
			2	750 l	RBC HP ANODE (fra 2015)	65-35°C		**Bemærk:**	
		Antal			**Type**	**Dimension**			
Regulering VVB/X:		1			Motor				
									Alt. Mærkplade
Varmtvandsfaktor iflg HOFOR:						**W/m2**	**Andel:**		
Ekstra fjernaflæste følere		**PT-følere**	Nej	**Rumføler**	6 stk. IC-meter				

Figure 5: Template used to collect information about the district heating substation

In figure 6 is an example of a standard HOFOR district heating central application with a DHW tank, and a heat exchanger for the heating system being the interface between the district heating network and the central heating system of the building.

To the left you find the heat meter used by HOFOR for remote metering and billing, and to the right also a standard electronic controller for operating the central heating system.

Furthermore you can see all the required components for an optimum operation of a district heating substation.

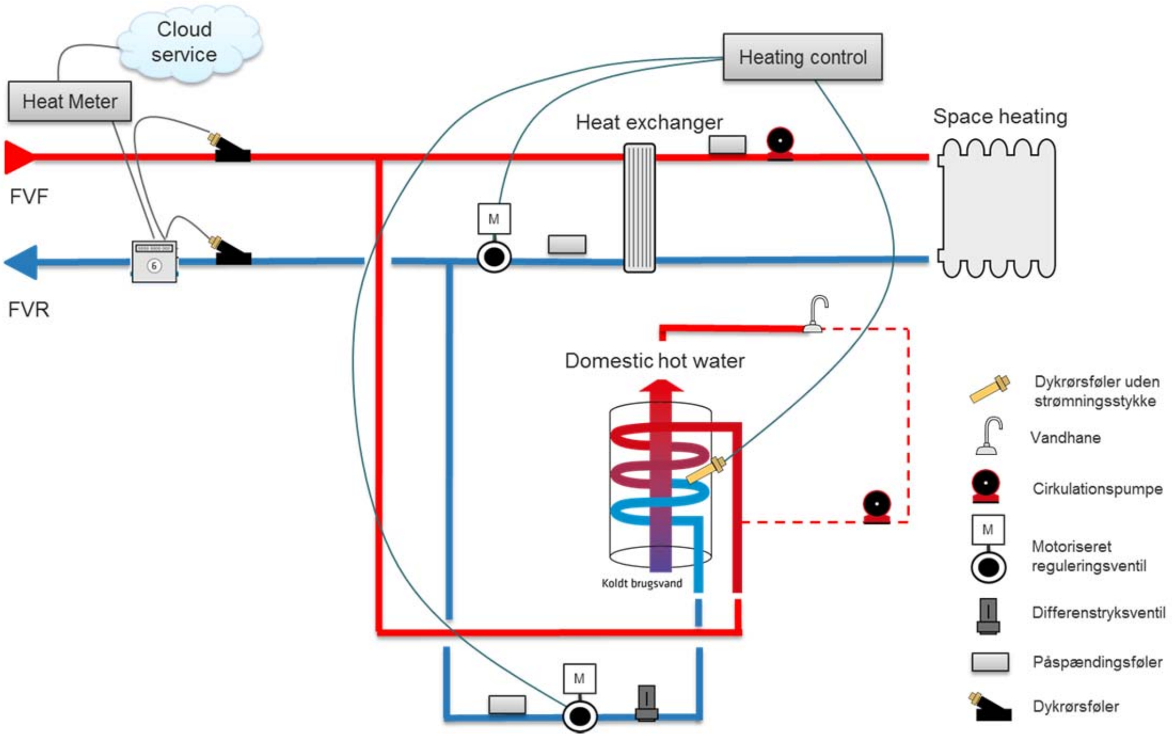

Figure 6: Example of a standard heating central application with a heat exchanger, and a DHW tank

3.3 Central heating system

When evaluating a building`s heating system, more detailed information about the building`s central heating and ventilation system is necessary. A building’s type of heating system can have a great impact on a building`s heating profile as different heating systems might be more, or less, sensitive to changes in the indoor temperature. E.g. a building that is partially heated by a ventilation system (water-based heating coil) might experience more abrupt changes in the heat consumption as this type of system has a very short reaction time. Whereas heating systems such as floor heating systems have a different behaviour, which are better at accumulating heat for longer periods and thus, have a slower reaction time. Below, different central heating systems and their characteristics, as well as control systems are presented:

Radiator system:

- 2-string system: Typically good cooling of the central heating water, and easier to control
- 1-string system: Not as good cooling of the heating central water as 2-string systems, and more difficult to control. In addition 1-string systems are sensitive to closed radiators in the building`s heating circuit

Floor heating system:

- Requires low supply temperatures (max supply temperature ~40°C), and therefore offers very low return temperatures from the heating system. Works as a thermo-active building system in heavy constructions, and therefore have a slow control-response time and is not sensitive to changes in the indoor environment. This might cause overheating issues during warmer periods

Ventilation system:

- Typically gives low return temperatures, but is very sensitive to changes in the indoor environment and in the control settings. Also reliant on a sufficiently large heating surface, and an efficient heat recovery to avoid excess consumption

Electronic controller, Building Management System (BMS), or autonomous controller etc.:

- Highly advanced control systems, which offers the opportunity of fine-tuning a heating system, but requires great monitoring of capable facility personnel as more advanced systems also increases the risk for errors

Manual controller – self acting controller:

- Very easy to manage by the facility personnel, but excess consumption often occur due to limited opportunities to fine-tune the heating system, as well as it being difficult to ensure monitoring of the system on a daily basis

There are many different ways to design and build a heating system, and only the most common ones in the Copenhagen area are mentioned above. Information about the central heating system is also collected in a template, developed in connection with the new heat label of HOFOR. Information about the central heating system is collected in the form as shown in figure 7.

Opvarmningsanlæg:

Opvarmningstype:		Andel%	Forsyning	Bemærkning	Lejlighed-/centralopv.
X	Radiator	10	Fjernvarme		Central
X	Gulvvarme	90	Fjernvarme		Lejlighed
	Ventilation		Ingen ?		Lejlighed

				Grundlag			
Type:	2-strengs	**Dim.foruds:**	55-35°C	Aflæsning	**FORDELINGS SYSTEM:**	type	andel%
Kobling	Selvst.kreds	**Dim.foruds:**	35-25°C	Aflæsning	Stigstrenge		
Opvarmning:		**luftmængder:**			Radiatorventiler		

VENTILATIONSANLÆG	Type	luftm. m3/h	Mærkepla	Forsyning	eff. behov kW	Anvend.:
1						
2						
3						
Alt. Samlet						

Vurdering af data om ventilationssanlæg: **(egne skøn/delvis skøn/dim.værdier)**

Figure 7: Information about the central heating system

4. Quality and time resolution of data – possibilities and limitations

In addition to the information presented in the previous three sections, the quality, and time resolution of the energy data is very important when evaluating a building`s heat profile. Data with a higher time-resolution, and quality (reliability), minimizes the need for assumptions. Remote metering of heat meters also gives the advantage of increased availability of data.

4.1 Time resolution of data

In the report *Energy Efficient Supply of District Heating*, the heat meter company Kamstrup describes a range of examples on how to improve the energy efficiency in the district heating network and the heating centrals, by utilizing data and measurements as presented below:

- Identify malfunctioning and not optimized heating centrals
- Monitor supply temperature levels throughout the distribution network
- Identify heat- and water losses in the distribution network
- Modelling of buildings based on real heat response to changes in the weather
- Leakage detection
- Reduction of peak load and improved return temperatures

- Identification and support to new and innovative tariffs, for a more energy efficient heat supply

Furthermore, Kamstrup has evaluated time resolution of data, in relation to possible value. This evaluation shows that the value of the data increases significantly with the time-resolution as shown in figure 8.

At HOFOR, it is possible to collect data at a time resolution down to 15 min; however, the standard data time-resolution is 1 or 4 hours, depending on the type of customer.

In the EnergyLab Nordhavn project, 1-hour time resolution is used as a standard when evaluating the heat demand in buildings. This is a compromise between the battery lifetime of the energy meter, as well as the evaluated necessity of higher value of data given by a shorter time-resolution.

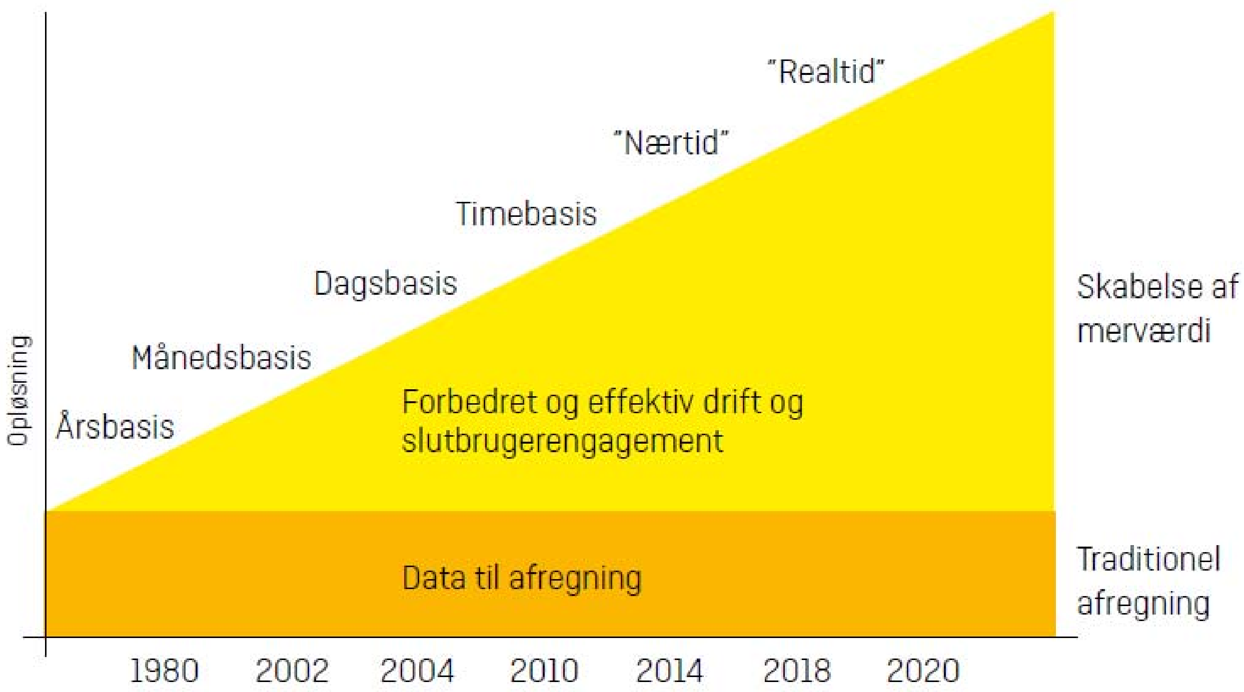

Figure 8: Illustration of databased value creation – Source: Kamstrup

In the below sections some of the possibilities and limitations with data collected at different time resolutions are described.

<u>Every minute:</u>
Typical applications evaluated are heat exchangers for DHW and DHW tanks, and is especially important in the new buildings where the domestic hot water demand is dominant. When evaluating a building`s heat demand on a minute basis it is possible to analyze quite precisely, e.g. how a DHW solution is working, and the

consequences on the capacity variations and the related return temperature when there is a DHW consumption.

Every 15 min.:
15-minute resolution of the heat demand in a building is useful when determining whether there are any issues with the control of the technical installations in the heating central, or the central heating system.

Every hour:
Hourly resolution of the heat demand in buildings is commonly applied to evaluate the general performance of typical technical components in a heating system and the DHW system. On an hourly resolution, it might be possible to spot errors in the control of e.g. the control valves, but if a further evaluation is necessary then a higher time resolution, (e.g. 15-minute as mentioned above) is used.

Every 4 hour:
4-hour measurements of the heat demand are usually used for billing purpose and to detect errors on the heating system. This time resolution is not high enough to accurately analyze i.e. the variations in capacity loads on the domestic hot water usage. The 4-hour measurements are also used for determining the average domestic hot water consumption, based on collected data from a summer situation, where there is no heat demand.

4.2 Quality of data

Regardless of the time resolution; the reliability and quality of the data is critical when analyzing the performance of a building – if only a single data set is invalid, or missing, the entire analysis might be damaged or useless. This is unfortunately a very common occurrence. When this happens a manual interference to remove, or repair, the data set is necessary and this can be both difficult and time consuming.

5. Heat profiles – common profiles and related knowledge

Heat profiles can, as previously mentioned, look quite different depending on their intended purpose. Below some examples of different heat profiles are presented to illustrate why clustering of buildings according to age, and usage is important in order to identify poor/incorrect design, and/or operation of a building`s technical installations.

5.1 Yearly heat profile – daily consumption in relation to different outdoor temperatures

The heat profile shown in figure 9 illustrates how the unit consumption in one old and one new residential building changes according to the outdoor temperature over a period of the year 2016. The horizontal x-axis shows the lowest to the highest outdoor temperatures from left to right and the y-axis the energy used in W/m2.

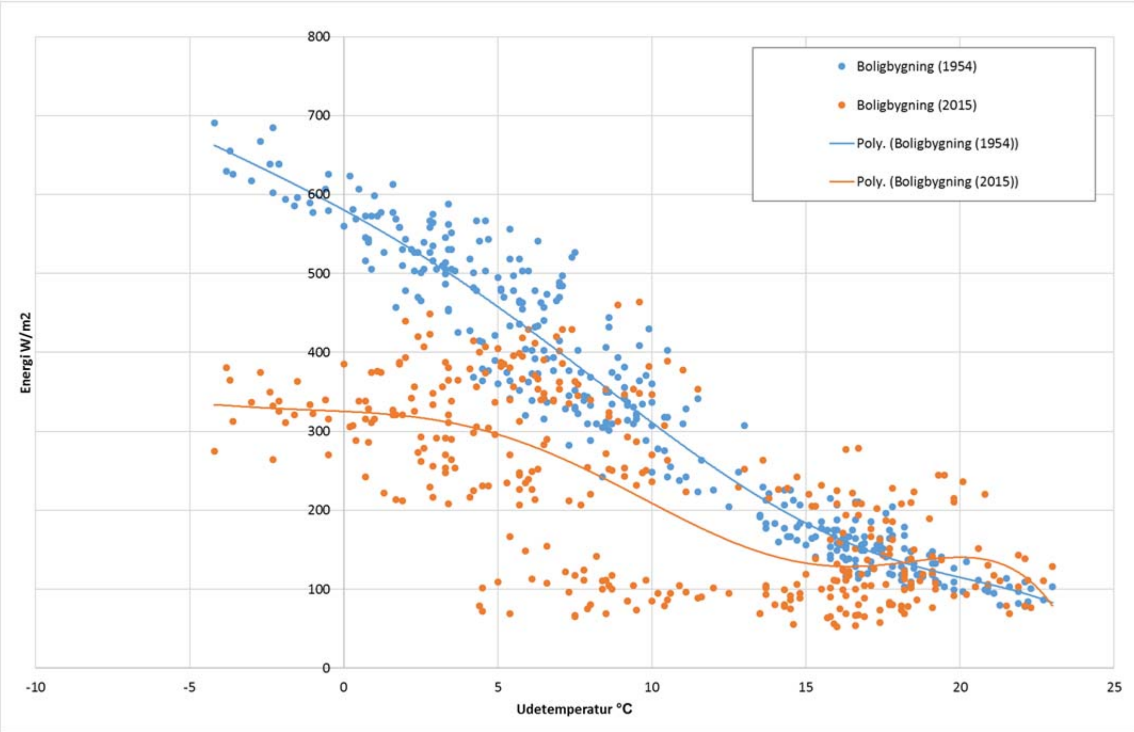

Figure 9: Polynomic heating profiles showing the change in unit consumption in relation to outdoor temperature over a period of a year for 2016, for one old and one new residential building in Copenhagen

The most prominent difference between the two buildings is the angle of the tendency line, which is a lot steeper in the old residential building (blue). This is because the heating demand (DDC- degree day dependent consumption), is greater in the old building, than in the new building. Thus, there is a greater difference in the total heat demand between warmer periods (summer) and colder periods (winter) causing the tendency line (blue) to appear steeper.

As the heating demand in the new building is minimal, the demand for domestic hot water is a larger share of the total heat demand. The DHW consumption is independent of the outdoor temperature (DIC – degree-day independent consumption) and is therefore approximately the same throughout the year, making the tendency line follow a more moderate angle.

Another thing that can be seen from the heat profile is that the consumption in the old building follows a more consequent pattern than in the new building, where the consumption is more widespread for outdoor temperatures from 0°C -15°C. The consumption in the new building stabilizes when the outdoor temperature reaches 15°C. This indicates that there might be a hunting issue with the regulation of the central heating system, as the consumption stabilizes in the periods when there is only a DHW demand.

5.2 Daily heat profile – hourly consumption in MWh

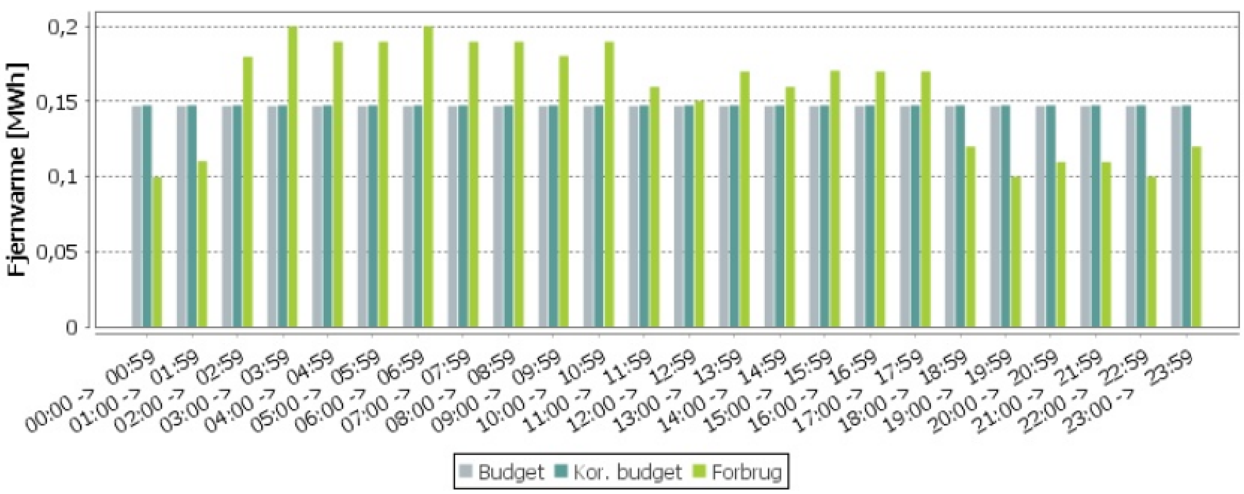

Figure 10: Daily heat profile showing hourly consumption during Monday 4th of December 2017 for an office building built in 2003 with a floor area of approximately 10.500 m^2

The daily profile is an important tool to evaluate how well a heating central is operating, and to some extent what type of DHW- and heating system is installed and how well they are operated.

Figure 10 shows the budgeted consumption (grey), the corrected budget (dark green), and the actual consumption (light green) in a large office building with a radiator heating system.

The budgeted consumption (grey) is degree-day adjusted with data from 2016, and the corrected budget (dark green) is also degree-day adjusted, but with data from 2017, and finally the actual consumption (light green) is the measured consumption as read on the meter in the specific hours for Monday 4th of December, 2017.

The budgeted consumption and the corrected budget in figure 10 are on hourly basis in average almost identical due to similar degree-days on December 4th in 2016 and 2017, as can also be seen in figure 11.

In office buildings DHW consumption represents a smaller share of the total heat demand, and therefore large short term peaks, do not commonly occur in office buildings. Thus, it is reasonable to assume by looking at figure 10, that the building is also partially heated by a ventilation system (characterized by a short response time), which is in operation from 03.00 in the morning to 18.00 in the afternoon, as the increased demand appears to be stable in this period. Outside this period, the actual heat demand is smaller than the budgeted demand, which indicates that the ventilation system is the primary heat source when in operation.

As the radiator system is constantly in operation it should be considered whether the operation period of the ventilation system could be limited to office hours, as it is costly to have 2 heating systems running simultaneously. Also, the temperature set point of the inlet air of the ventilation system should be reduced, in order for the radiators to heat more efficiently, which will have a positive effect on the morning peak demand (ventilation heating systems have a very short reaction time, and thus the peaks become larger).

5.3 Weekly heat profile – daily consumption in MWh

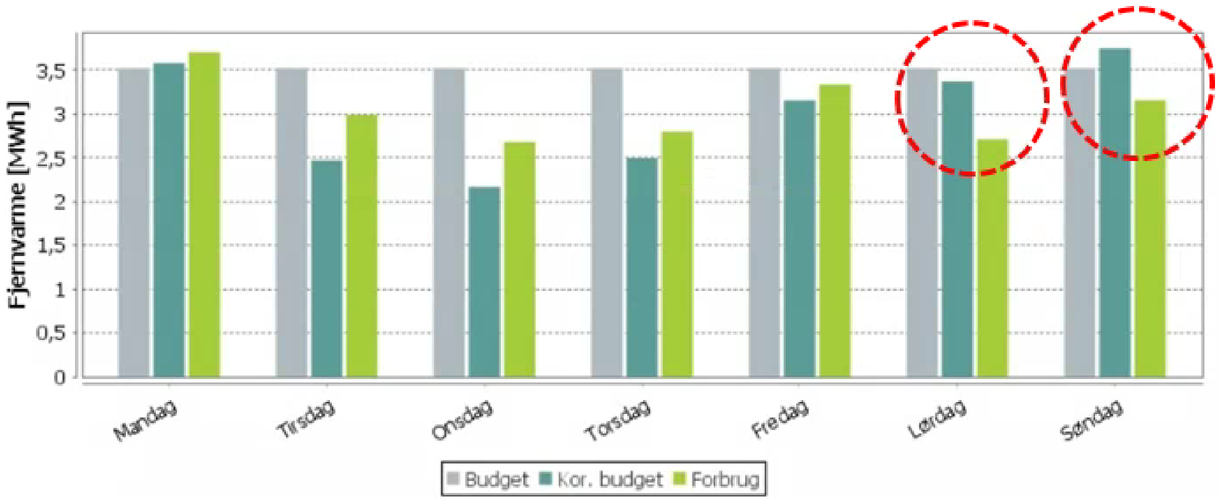

Figure 11: Weekly heat profile showing daily consumption in the week 49 of 2017 for an office building built in 2003 with a floor area of approximately 10.500 m^2

The weekly profile illustrates the usage pattern of the building e.g. in a multi-family building, the consumption will be more evenly distributed throughout the week than in an office building, where the consumption is typically smaller during weekends as there are no occupants and thus the DHW consumption is minimal (circulation only), and heating systems are typically not in full operation (weekend set back).

Figure 11 illustrates the weekly heat profile for the office building presented in the previous section. The actual heat demand deviates significantly from the budgeted demand in the weekend (circled in red), indicating that the ventilation system is shut down during this period. However, the weekly heat profile should be monitored to evaluate whether this operation of the heating systems is optimal for this type of building, or eventually whether the ventilation system can be further optimized to reduce capacity peaks in the mornings.

5.4 Monthly heat profile – daily consumption in MWh

A monthly heat profile can be used to spot tendencies in the heat consumption, mainly caused by e.g. user patterns, and in some cases it might also be possible to spot malfunctions, or ineffective/incorrect operation of the technical systems.
Figure 12 shows the daily consumption during November of 2017, also for the office building. It can be seen, by looking at the heat consumption during weekends (circled in red), that the actual consumption deviates from the budgeted consumption similarly. Also, the actual consumption is commonly larger than the budgeted consumption during weekdays. Thus, the assumptions made in the previous section is reinforced – the ventilation system is not in operation during weekends, and the radiator system is most likely not allowed to heat efficiently because of the set points of the ventilation system.

Figure 12: Monthly heat profile showing daily consumption in November 2017 for an office building built in 2003 with a floor area of approximately 10.500 m^2

On Wednesday the 1st, and Monday the 27th as well as Sunday the 26th, there are also significant deviations between the budgeted and the actual consumption; they do however not follow any distinct pattern. This indicates that there could be the possibility, or necessity for further optimization of the heating system.

5.5 Yearly heat profile – monthly consumption in MWh

The yearly heat profile provides a more complete overview of the building`s performance, as it is possible to compare the heat demand during the different seasons e.g. outside heating season (summer) there is mainly a heat demand to DHW consumption, whereas during the heating season the heating system(s) is also in operation. Thus, it is easier to spot the location of a malfunction, or the source of an unnecessary heat consumption (heating vs. DHW) when comparing the consumption during the different seasons.

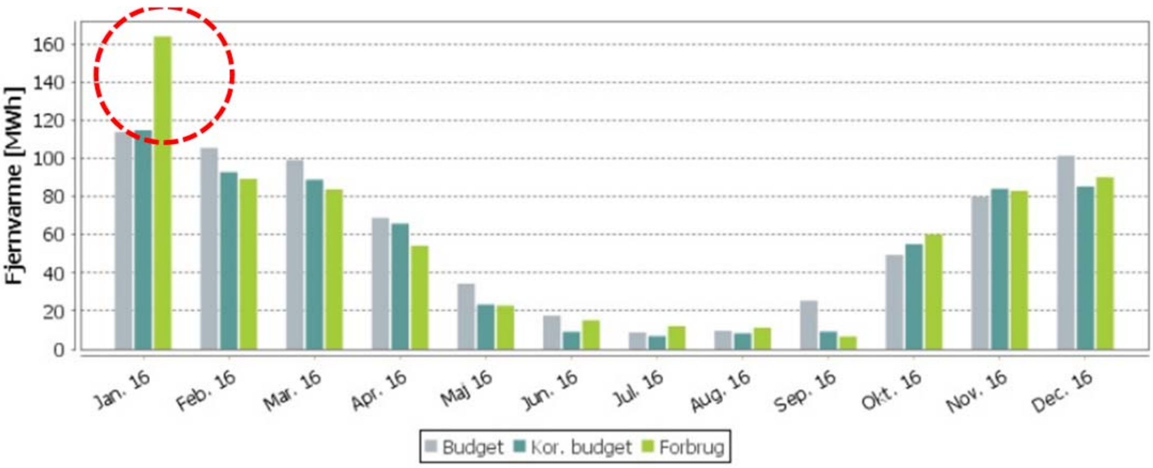

Figure 13: Yearly heat profile showing monthly consumption in 2016 in an office building built in 2003 with a floor area of approximately 10.500 m^2

In figure 13 the yearly heat profile for the office building shows the monthly consumption. During the summer months, the heat consumption is slightly higher than what is budgeted, indicating that the heating system is still in operation despite of HOFOR`s recommendations. However, the too high consumption might also be due to an issue with the regulation of the DHW. A more concerning observation though is that the actual heat consumption is about 30% larger than the budgeted consumption in January. In this case, the information gained from the yearly heat profile is insufficient when evaluating the cause of this extreme over-consumption. Thus, a heat profile with a higher time resolution is necessary.

By analyzing the daily consumption in the monthly heat profile for January 2016 it was found that dramatic changes occurred between January 4th and 26th see figure

14. This is probably caused by the ventilation system being in operation constantly in this period.

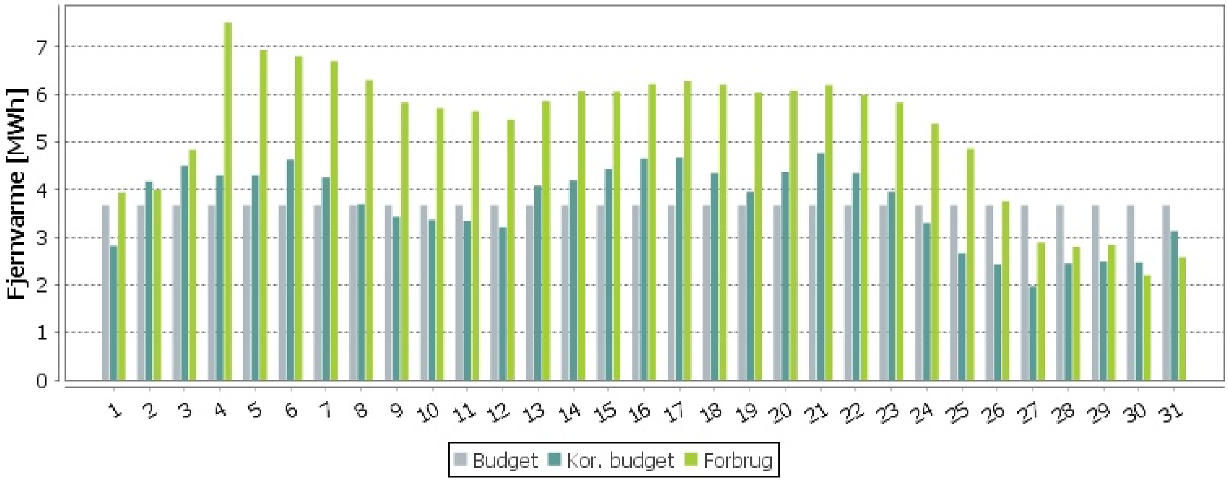

Figure 14: Monthly heat profile showing daily consumption in January 2016 for an office building built in 2003 with a floor area of approximately 10.500 m^2

5.6 Year to year profile – annual consumption in MWh

Over the years you will also be able to analyze and compare the energy demand and from this identify any change in performance either due to a change in the condition of the installations (wear and tear), or malfunction of the heating central. Also it will be possible to identify if the building envelope has been improved and/or if equipment in the heating central has been replaced.

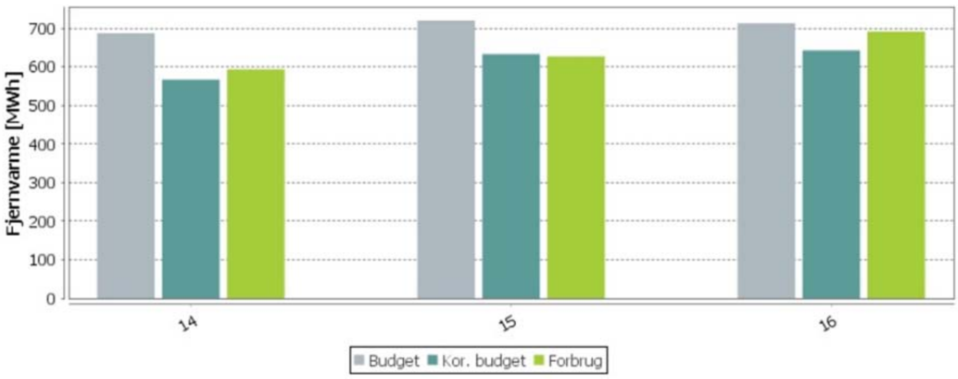

Figure 15: Year to year heat profile showing annual consumption in an office building from 2003, in year 2014, 2015 and 2016

The main reason for the high heat consumption in 2016 for this office building can more or less be addressed to the earlier mentioned very high heat consumption caused by the ventilation system in January of 2016.

6. System temperatures – supplementary data to heat profiles

In some cases assessing the heat consumption alone, even at the highest time resolution, might be insufficient when evaluating the cause of a malfunction, or incorrect operation of the system. Thus, supplementary data is needed.

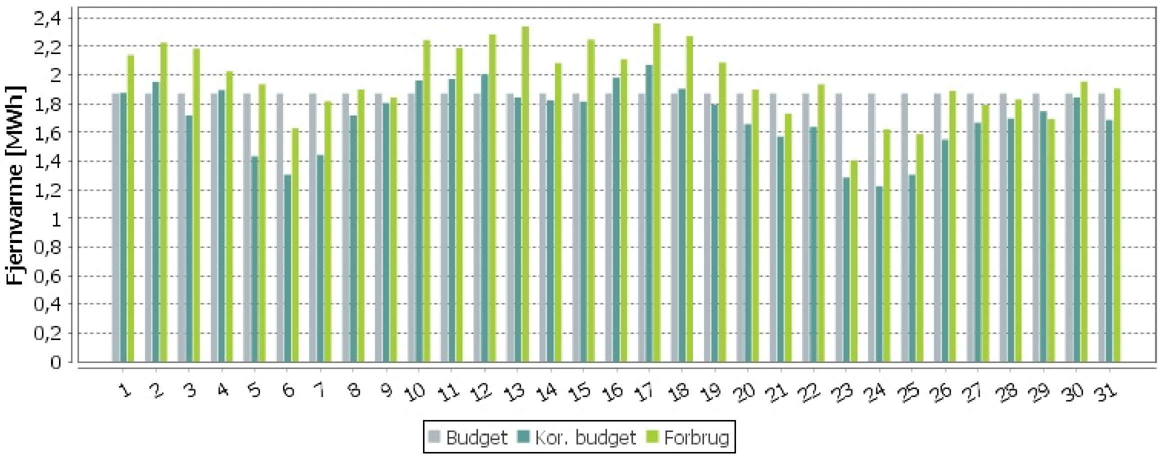

Figure 16: Monthly heat profile showing daily consumption for a new multi-family building in December of 2017

HOFOR`s remote meters do not only measure the heat consumption in buildings, but also the supply and return temperatures of the district heating system to buildings` heating centrals. In figure 16 the heat consumption in a new multi-family building in December of 2017 is shown. The actual heat consumption is very fluctuating, and significantly larger than the budgeted heat consumption.

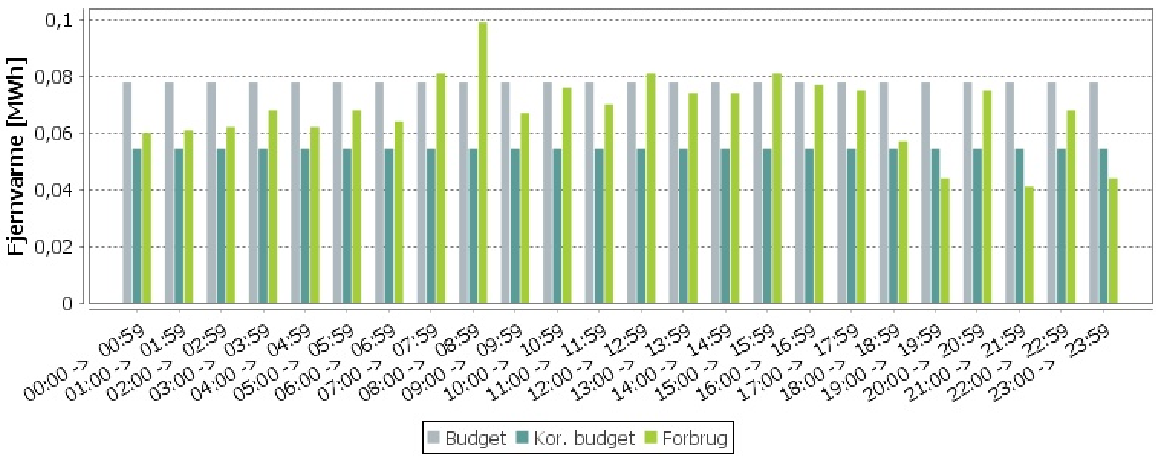

Figure 17: Daily heat profile showing hourly heat consumption for a new multi-family building on December 6th 2017

The daily heat profile for the same building on December 6th 2017 in figure 17, shows that the heat consumption in general is above average. Especially the morning peak demand is too high. In new multi-family buildings equipped with large DHW tanks, the morning peaks, which are mainly cause by a demand for DHW, should be smaller. Also, the heat demand during the day in newer buildings should be minimal (well-insulated) as there is very little DHW consumption during this period.

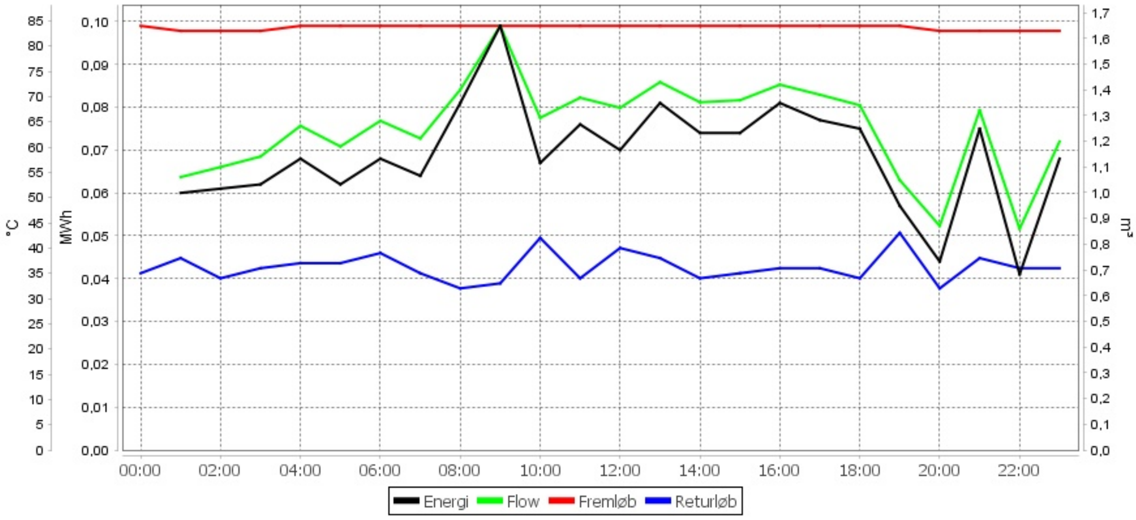

Figure 18: District heating supply- and return temperature to the heating central, and flow (m^3/h) and heat consumption (MWh) in the new multi-family building on December 6th 2017

Figure 18 shows the supply- and return temperature to the heating central from the district heating system, as well as the flow (m^3/h) and the heat consumption (MWh) on December 6th 2017. The return temperature back to the district heating system (blue line) is a combination of the return temperature from the central heating circuit, and the DHW circuit. From figure 18, it can also be seen that the return temperature to the district heating system is fluctuating and it is difficult to achieve an overall acceptable return temperature.

6.1 Monitoring with additional temperature sensors

In district heating systems with advanced data loggers it is possible to install and monitor extra temperature sensors in the heating central to provide a better overview of the performance of the central heating system. Typically, a total of 6 sensors are installed as shown in figure 19.

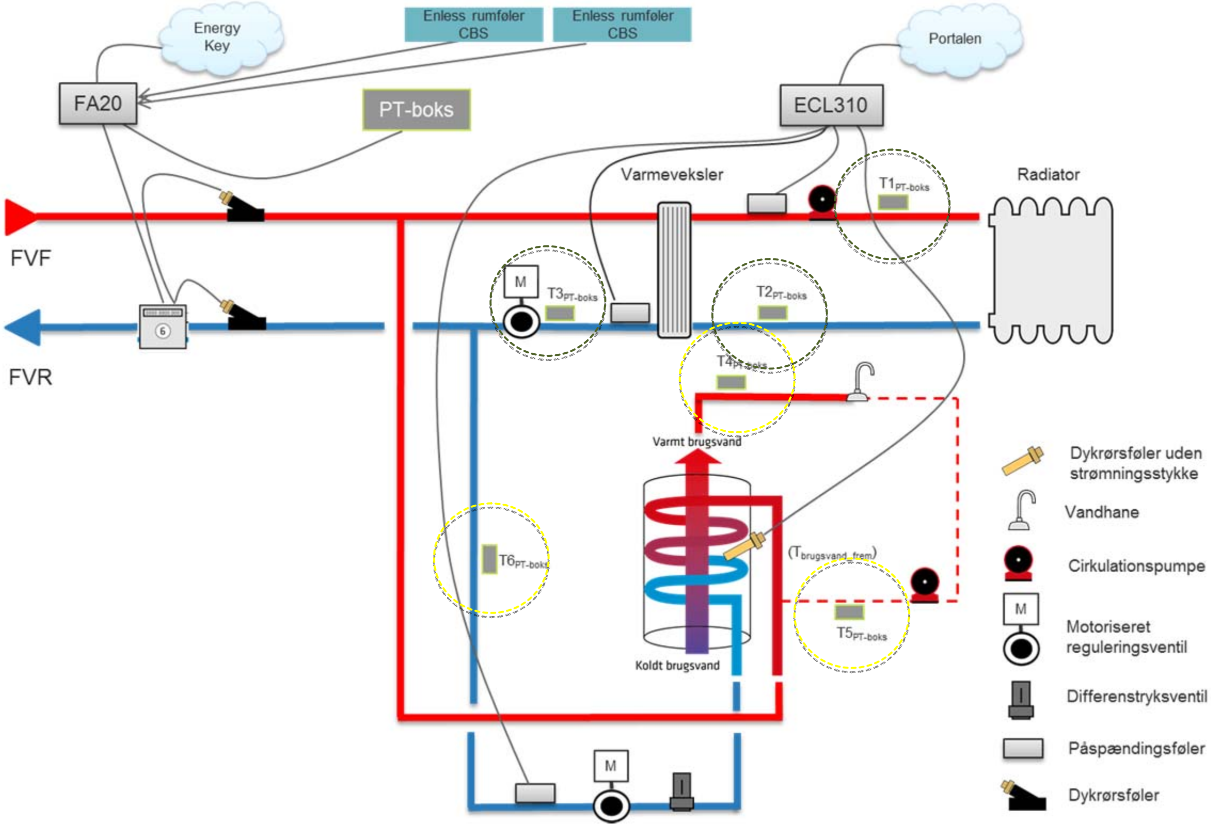

Figure 19: Illustration of a building`s heating central with 6 additional temperature measurement points – 3 on the central heating circuit circled in green, and 3 on the domestic hot water circuit circled in yellow

With the extra sensors, the heating circuit and the domestic hot water circuit can be assessed separately, making it easier to detect the cause of a malfunction/ incorrect dimension of the heat exchanger, or by an incorrect operation of the system.

In the case of the new multi-family building from the previous section, it can be found that the main issue is with the heat exchanger. As shown in figure 20 there is a temperature loss of 5°C through the heat exchanger (this should be no more than 2-3°C). This is most likely because the heat exchanger is too small, as the building is new it is unlikely that it is calcified. And as the exchanger is too small, it cannot exchange enough heat and thus the capacity is much too low.

The heat exchanger should eventually be replaced with a larger one, however a temporary solution might also be to reduce the supply temperature to the central heating system in order to reduce the morning peak load to below average.

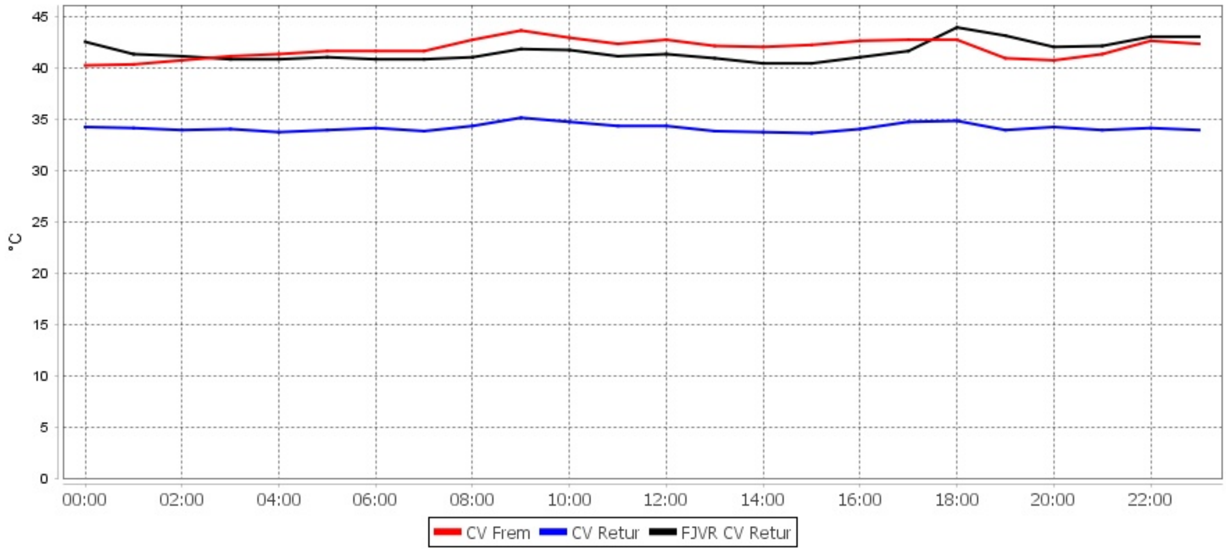

Figure 20: Supply- and return to the heating circuit, as well as return from the heat exchanger back to the district heating system in the new multi-family building on December 6th 2017

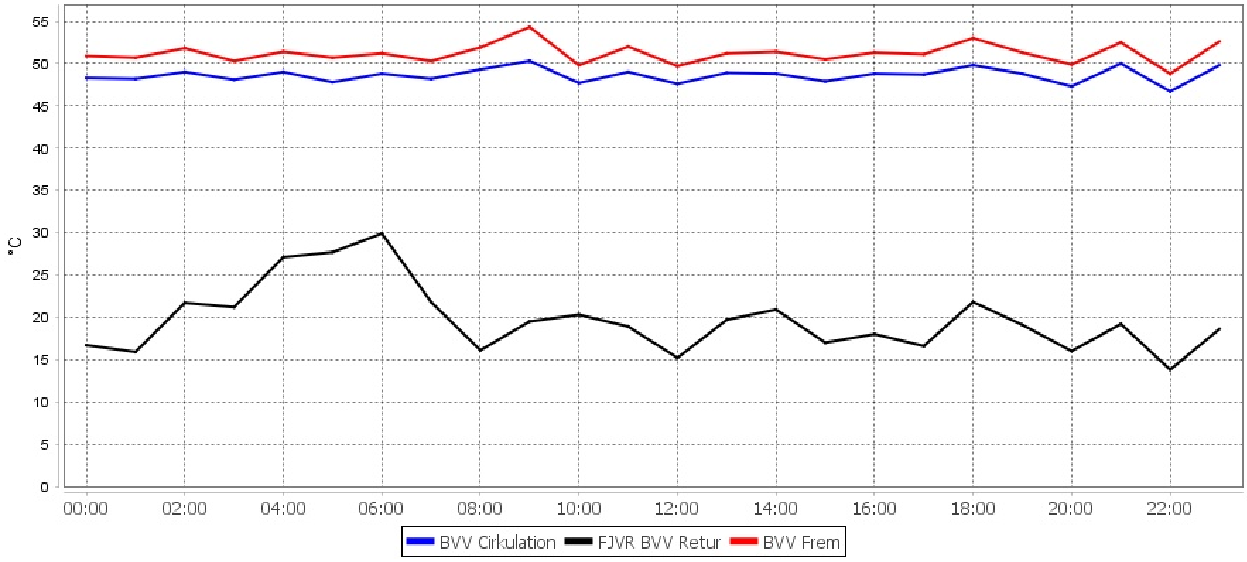

Figure 21: DHW supply- and return, as well as DHW circulation temperature in the new multi-family building on December 6th 2017

From figure 21, it can be seen that both the temperature of the DHW supply and DHW circulation is a bit too low. These settings give a very good return temperature to the system, however the temperature of the DHW supply must be at least 55°C as recommended by HOFOR to avoid legionella, and consequently to meet the requirement of 50°C temperature at the most distant DHW tap installed in the building.

These types of malfunctions might not be detected when looking at the heat consumption or heat profile alone, and this is the reason why it sometimes is necessary to supplement a building`s heating profile with the system temperatures.

6.2 Further examples of troubleshooting using system temperatures

Below are 4 examples from HOFOR´s ForsynOmeter heat optimization system, illustrating how data from the main heat meter in the building, can generate a heat profile that provides valuable information about the design and operation of a building.

ForsynOmeter is an integrated part of HOFOR´s system for data collection and energy management called EnergyKey.

6.2.1 Malfunction of control valve for the central heating system

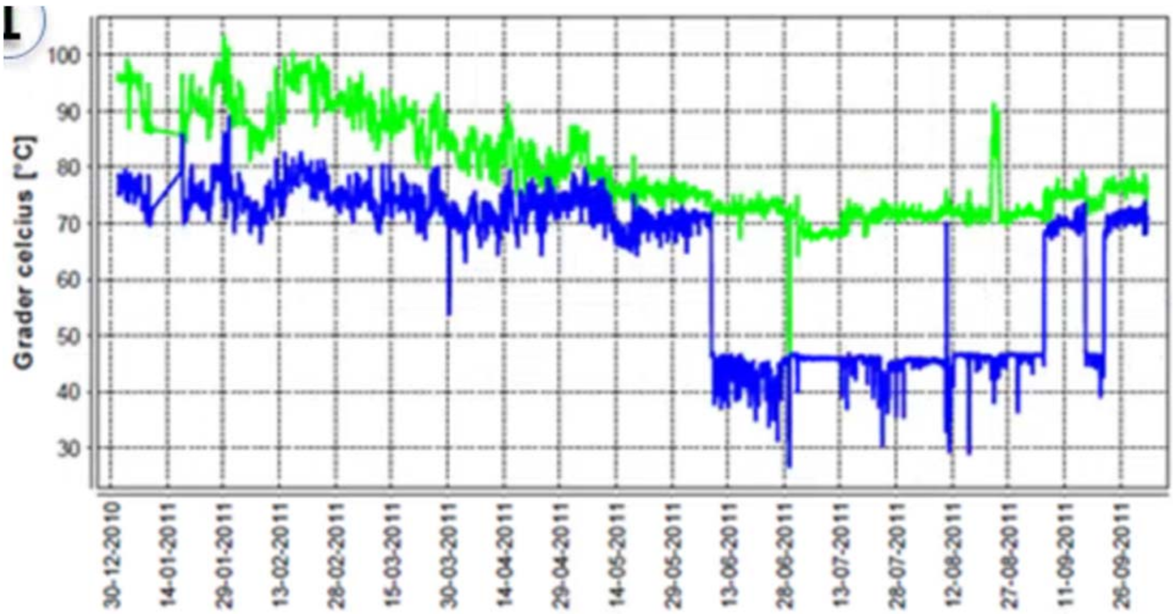

Figure 22: Example 1- Yearly overview for 2011 over the system temperatures in a heating central

The figure 22 shows a fine summer cut-out of the heating system in May, and the DHW system works perfect over the summer with a good cooling of the district heating supply (green line) and a low return temperature (blue line). However in the winter season there is almost no cooling and thus a too high return temperature.

6.2.2 Poor performing DHW system, and too high temperatures in the central heating system

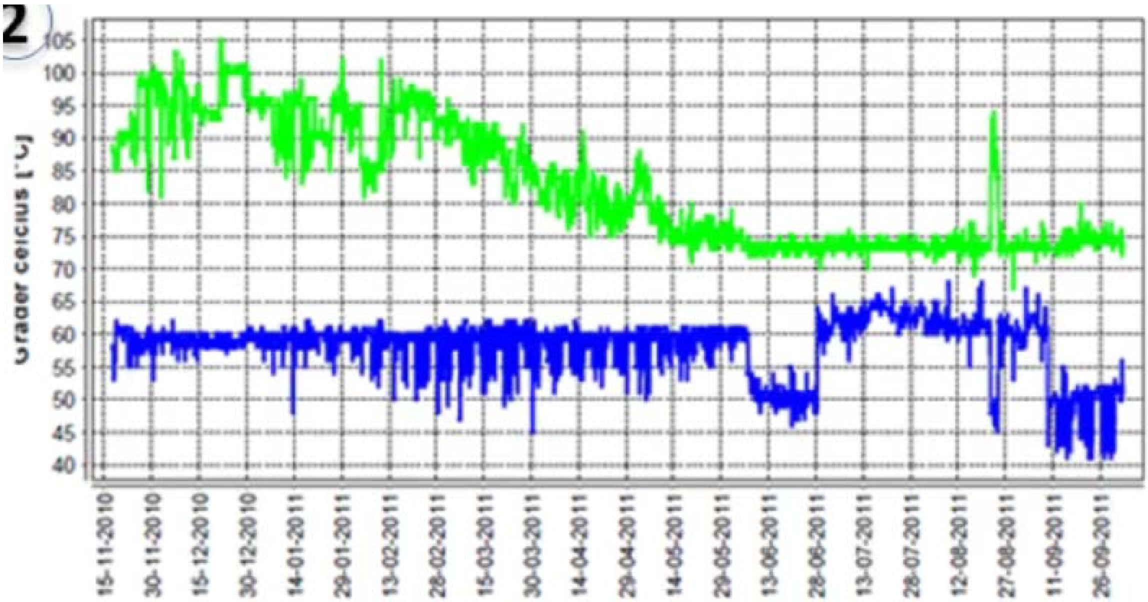

Figure 23: Example 2 - Yearly overview for 2011 over the system temperatures in a heating central

The heating system in figure 23 is operated at much too high supply temperatures on the central heating side during winter season and this can be seen on the high return temperature (blue line) from the building and during the summer period there is a very poor cooling of the district heating (the difference between the green and blue line)

6.2.3 Incorrect dimensioned control valves, or inappropriate control of the central heating system

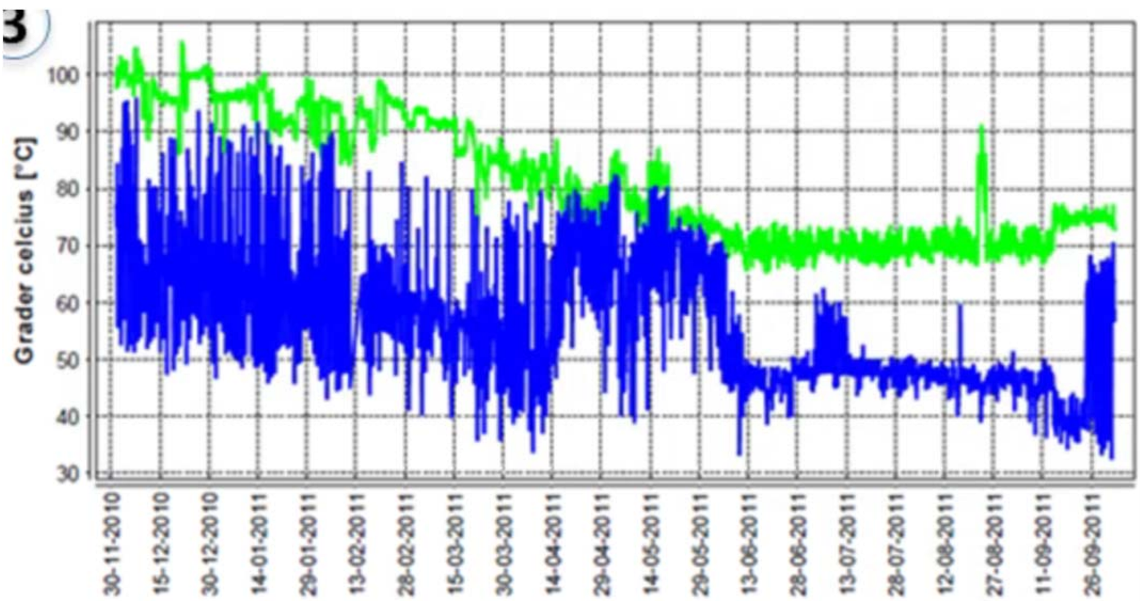

Figure 24: Example 3 - Yearly overview for 2010 over the system temperatures in a heating central

The district heating return temperature in figure 24 is hunting during all of the heating season indicating a too large motorized control valve or improper settings of the controller for the central heating system. The DHW system also has a too high return temperature during the summer season.

6.2.4 Heating central with optimal performance

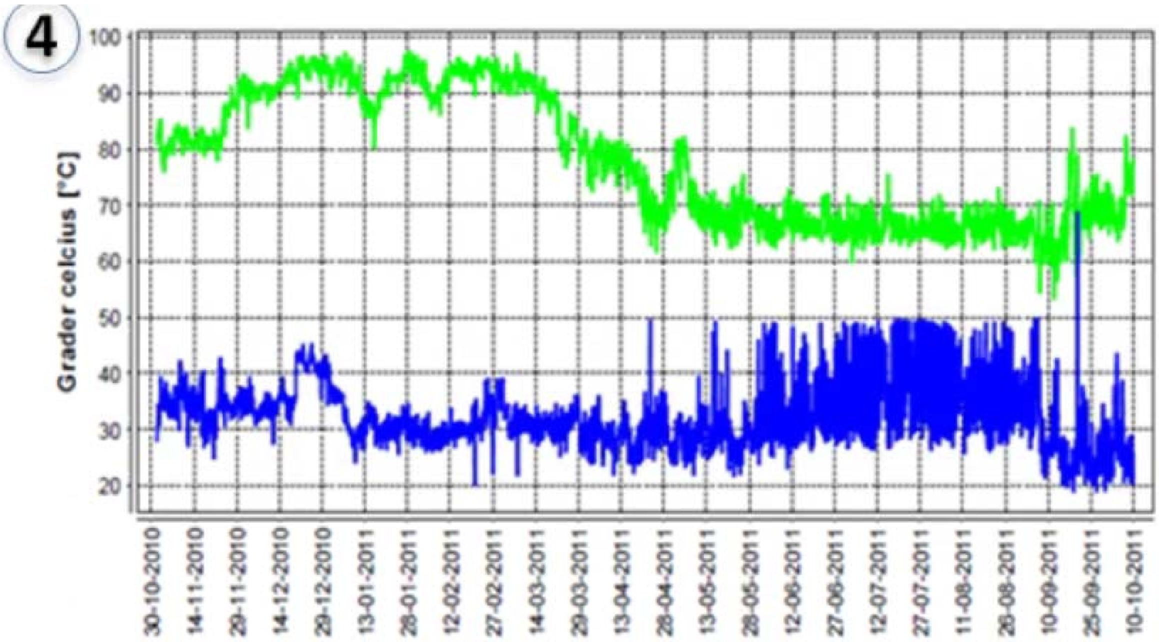

Figure 25: Example 4 - Yearly overview for 2011 over system temperatures in a heating central

The district heating customer/installation in figure 25 is optimally operated and has a very low return temperature from both the heating system in winter time as well as from the DHW system in the summer time.

7. Conclusion and value of heat profiles

HOFOR sees a great value in generating and analysing heat profiles from the data in HOFOR’s energy management system EnergyKey and the heat optimization system Forsynometer.

The heat profiles makes it possible to identify poor performing and/or mal-functioning central heating systems, and is an important tool for HOFOR´s energy saving activities.

Furthermore heat profiles can be used for benchmarking purposes i.e. for year-on-year comparisons or heat consumption between similar types of buildings.

8. Next steps and prospective work

8.1 Next steps

HOFOR is working on two new and different solutions for adding more data, measurements, know-how and optimization possibilities of the heating centrals in the buildings:

1. Integration of HOFOR´s own energy monitoring systems EnergyKey/Forsynometer with the Danfoss ECL 310 portal.

   The Danfoss ECL 310 controller is often used as the electronic controller in the heating central and by upgrading this with an internet connection to the Danfoss ECL 310 portal it will be possible for HOFOR to access the controller and the sensor data for additional knowhow, optimization and diagnostics. Please see figure 19 for an overview of the additional data that can be collected by the Danfoss ECL 310 portal.

   Other brands of controllers can also be upgraded to other internet solutions and thereby also provide the same level of information to HOFOR.

2. Installation of additionally 6 extra temperature sensors to collect more data on the central heating circuit and the DHW circuit as shown in figure 19 and described in part 6.1.

   The data will via a small I/O module and 6 wired surface mounted sensors be collected in the HOFOR data collection device (FA40) for remote metering, and then via a wireless connection, sent to the HOFOR EnergyKey system.

   HOFOR is considering a major roll-out of the concept in connection with the large steam conversion project in down town Copenhagen, to secure optimum operation of the new heating centrals being installed.

8.2 Prospective work

All larger HOFOR customers are remotely monitored and thereby heat consumption data exist for several years on more than 10.000 energy meters.

This data is very valuable for optimization purpose and for introducing new and innovative solutions like within machine learning, and HOFOR already has some experience with the IBM´s Watson machine learning tool from a project targeted on preventive maintenance of district heating pipes.

The machine learning tools are capable of analysing, detecting and identifying patterns across thousands of different data sets to be able to find malfunctioning or poor performing heating central, heat exchangers or DHW tanks, which could be a very valuable tool for HOFOR and the customers to improve and optimize the overall operation of the district heating system in Copenhagen.

According to the experience of HOFOR it is very important to identify problems as soon as they occur and then quickly solve them, as only one or just a few customers can severely disturb the whole performance and operation of an entire district heating network.

HOFOR will in the coming years invest more in digitalization, and foresees that it will be possible to develop a machine learning algorithm within the next few years to generate heat profiles and provide relevant benchmarks automatically.

Eventually this will hopefully and probably make it possible for HOFOR to offer a "virtual caretaker" providing tips and tricks to our customers and partners based on machine learning algorithms fed with real and actual heat meter data from our customers heating centrals.