



Research Centre on  
ZERO EMISSION  
NEIGHBOURHOODS  
IN SMART CITIES



# ZEN CASE STUDY: END USER FLEXIBILITY POTENTIAL IN THE SERVICE SECTOR

A case study on the flexibility potential of service buildings and the  
barriers needed to unlock this potential

ZEN REPORT No. 27 – 2020





Research Centre on  
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**ZEN Report No. 27**

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## Preface

### Acknowledgements

This report has been written within the Research Centre on Zero Emission Neighbourhoods in Smart Cities (FME ZEN). The author gratefully acknowledge the support from the Research Council of Norway, the Norwegian University of Science and Technology (NTNU), SINTEF, the municipalities of Oslo, Bergen, Trondheim, Bodø, Bærum, Elverum and Steinkjer, Trøndelag county, Norwegian Directorate for Public Construction and Property Management, Norwegian Water Resources and Energy Directorate, Norwegian Building Authority, ByBo, Elverum Tomteselskap, TOBB, Snøhetta, Asplan Viak, Multiconsult, Sweco, Civitas, FutureBuilt, Hunton, Moelven, Norcem, Skanska, GK, Nord-Trøndelag Elektrisitetsverk - Energi, Smart Grid Services Cluster, Statkraft Varme, Energy Norway, Norsk Fjernvarme and AFRY.

### The Research Centre on Zero Emission Neighbourhoods (ZEN) in Smart Cities

The ZEN Research Centre develops solutions for future buildings and neighbourhoods with no greenhouse gas emissions and thereby contributes to a low carbon society.

Researchers, municipalities, industry and governmental organizations work together in the ZEN Research Centre in order to plan, develop and run neighbourhoods with zero greenhouse gas emissions. The ZEN Centre has nine pilot projects spread over all of Norway that encompass an area of more than 1 million m<sup>2</sup> and more than 30 000 inhabitants in total.

In order to achieve its high ambitions, the Centre will, together with its partners:

- Develop neighbourhood design and planning instruments while integrating science-based knowledge on greenhouse gas emissions;
- Create new business models, roles, and services that address the lack of flexibility towards markets and catalyze the development of innovations for a broader public use; This includes studies of political instruments and market design;
- Create cost effective and resource and energy efficient buildings by developing low carbon technologies and construction systems based on lifecycle design strategies;
- Develop technologies and solutions for the design and operation of energy flexible neighbourhoods;
- Develop a decision-support tool for optimizing local energy systems and their interaction with the larger system;
- Create and manage a series of neighbourhood-scale living labs, which will act as innovation hubs and a testing ground for the solutions developed in the ZEN Research Centre. The pilot projects are Furuset in Oslo, Fornebu in Bærum, Sluppen and Campus NTNU in Trondheim, an NRK-site in Steinkjer, Ydalir in Elverum, Campus Evenstad, NyBy Bodø, and Zero Village Bergen.

The ZEN Research Centre will last eight years (2017-2024), and the budget is approximately NOK 380 million, funded by the Research Council of Norway, the research partners NTNU and SINTEF, and the user partners from the private and public sector. The Norwegian University of Science and Technology (NTNU) is the host and leads the Centre together with SINTEF.



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FME ZEN (page)

## Summary

The electricity grid is designed to handle peaks in electricity consumption and is usually dimensioned to handle peak loads at the coldest hours of the year. Over the years to come, investment plans in the Norwegian electricity grids amount to up to 135 billion NOK [1]. A substantial share of the grid investments will be made to avoid bottlenecks that are expected to occur only a few hours each year. Local demand side flexibility, where the user adapts to reduce the electricity consumption in the peak load times, is an economically attractive alternative to grid investments. In the ZEN definition guidelines, it is stated that a ZEN should be able to manage energy flows (within and between buildings) and exchanges with the surrounding energy system in a flexible way.[2]

This report is the result of a ZEN case study by the ZEN-partners SINTEF, NTNU, GK and NVE. The aim of this study was initially to 1) analyse if – and quantify how much service buildings can reduce their peak loads during the Norwegian peak load hour based on actual measured electricity consumption data, and 2) examine what is needed to unlock this, based on case studies on different service buildings with electricity and district heating measurements for different energy purposes. Due to a limited number of detailed measurements of energy use in buildings, the scope of the first part was reduced to a qualitative evaluation of the flexibility potential (rather than quantitative) in the grid's peak load hour, and the number of buildings focused on eight case studies. The flexibility potential of the eight cases was evaluated through analysing the capability of each building to reduce or shift energy consumption during 1) the building's peak load hour and 2) grid's peak load hours in 2019 that occurred on the 31st of January during the hours 07:00-09:00 and 16:00-18:00.

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*" There is a potential in reducing the building loads during the peak load hours, but there are several barriers linked to unlocking this potential. "*

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The analysis of the eight buildings studied suggests that there is a potential in reducing the building loads during the peak load hours. In the four buildings with electric heating, the share is at least 28 % at 8 hrs, 16- 20 % at 9 to 10 hrs and at least 17-24 % at 16-20 hrs. The share is somewhat lower at the remaining buildings due to few possible flexibility resources being known in these buildings. The results show a large flexibility potential in the buildings with detailed energy measurements. The findings in the study suggest that there is a potential in reducing the building loads of service buildings during the peak load hours, but there are several barriers linked to unlocking this potential. Currently, the largest barriers are the large investment need to achieve the necessary level of smartness for the building and the lack of off-the-shelf technologies for demand response control. This study has shown that even fewer buildings than expected have the necessary smartness level, and large investments is required to release the full flexibility potential. The control system and sales of flexibility must be profitable for the user, where the investments, loss of thermal comfort and inconvenience is sufficiently compensated.

The development of technologies and solutions for the design and operation of energy flexible neighbourhoods and buildings will be further investigated in FME ZEN WP4.

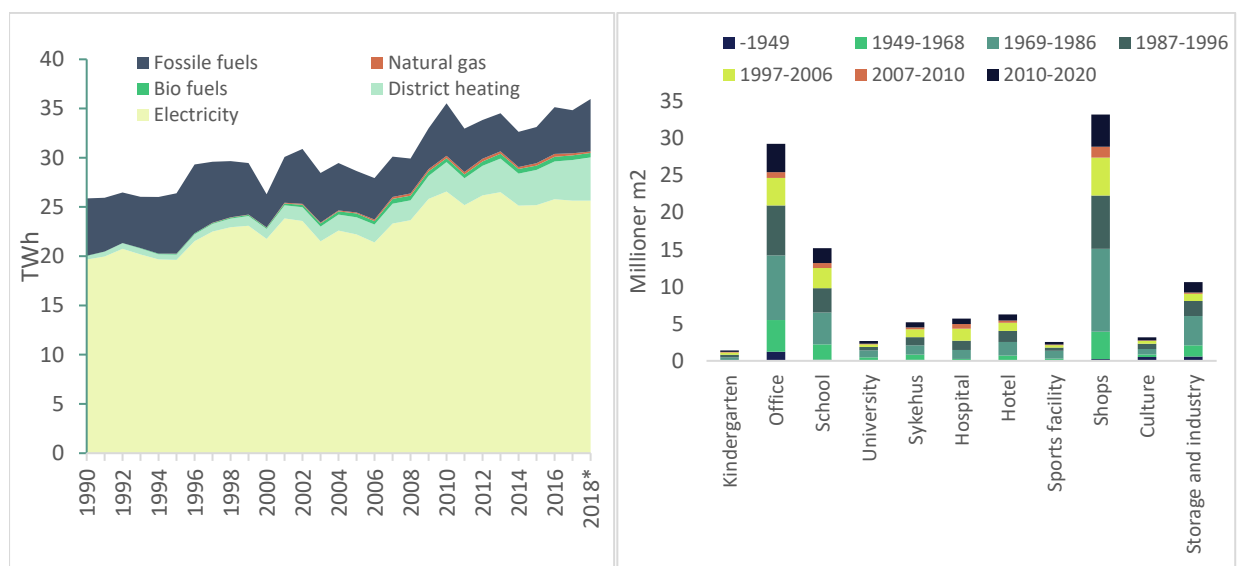
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## 1. Introduction

The total energy use the Norwegian service sector accounted for about 36 TWh in 2018, where electricity [3] makes up 26 TWh, as shown in Figure 1. The service sector building area is estimated to become approximately 116 million m<sup>2</sup> in 2020, where shops, offices and schools make up approximately 70 % of the building area [4]. The building area is of varying quality and age. Some of the area has gone through upgrades and renovations, while a significant share of the service building area remains energy inefficient. The composition of service building area in 2020 is shown in Figure 2.

The Norwegian electricity grid consists of three levels: the transmission grid, the regional grid, and the distribution grid. The electricity grid system must be able to cope with both short- and long-term variability in production and consumption to ensure that electricity supplies are maintained. The grid system is designed to handle peaks in electricity consumption, and hence, the peak load is the most important dimensioning factor for the grid. Due to historically low prices on electricity, electricity has been widely used for heating purposes in Norwegian buildings. About 60 % of the electricity used in Norwegian buildings (commercial and households) is used for heating purposes[5]. Due to this, the peak load on electricity is highly affected by the outdoor temperature and the resulting electricity demand for heating.



**Figure 1 and Figure 2: Historical development in annual energy consumption in the service sector in Norway[3] and the expected area of service buildings in 2020 per building category and age [4].**

Over the years to come, investment plans in the Norwegian distribution grid and regional grids amount to up to 135 billion NOK [1]. Production and consumption trends imply that a substantial share of the grid investments will be made to avoid bottlenecks that are expected to occur only a few hours each year. Norwegian buildings have traditionally been operated according to user needs only, and the electricity generation, transmission and distribution adopt to balance the exact electricity demand. However, due to new controls and increased availability of real-time consumption data, the peak loads may be avoided by use of local demand side flexibility, where the building adapts to reduce the electricity consumption in the peak load times. Hence, local flexibility emerges as an economically attractive alternative to grid investments[6]. By utilizing flexibility in on the demand side, bottlenecks

in the grid - and the following grid investments - can be avoided through reduction in the electricity consumption during the time of the peak loads in electricity consumption in the distribution and regional grids. This is reflected in the ZEN definition of FME ZEN: In the ZEN definition guidelines, it is stated a ZEN should be able to manage energy flows (within and between buildings) and exchanges with the surrounding energy system in a flexible way[2].

### **1.1 Scope**

The aim of this case study was initially to study 1) if - and quantify how much - service buildings can reduce their peak loads during the Norwegian peak load hour based on actual measured electricity consumption data, and 2) examine what is needed to unlock this flexibility potential.

As previous studies rely on simulation data the intention of this study was to be based on detailed energy measurements of several service buildings provided by the digital platform GK Cloud. The availability and the quality of the data on electricity and district heating consumption did, however, turn out to be more limited than expected at first. With few energy purposes being measured and logged separately for the different buildings, it turned out to be challenging to identify which energy purposes that made up the total electricity load of the buildings at different times, and hence to quantify the flexibility potential. As a direct consequence of lacking data, the scope of the first part was reduced to a qualitative evaluation of the flexibility potential (rather than quantitative) in the grid's peak load hour, and the number of buildings was reduced to eight case studies. The flexibility potential was evaluated through analysing the capability of each building to reduce or shift energy consumption during the grid's peak load hours in 2019 that occurred on the 31<sup>st</sup> of January during the hours 07:00-09:00 and 16:00-18:00.

The second part was unchanged, and the report also identifies the barriers for utilizing the demand side flexibility and what is needed on the technical side, to unlock the flexibility potential of commercial buildings in Norway.

## 2. Flexibility – strategies, demand, and utilization

### 2.1 Demand side flexibility for peak load reduction

Power system flexibility is defined as “the ability of a power system to reliably and cost-effectively manage the variability and uncertainty of demand and supply across all relevant timescales, from ensuring instantaneous stability of the power system to supporting long-term security of supply” [7]. In other words, flexibility is the concept that describes the extent to which a power system can modify electricity production or consumption in response to variability in both supply and demand.

Demand Response (DR) is flexibility on the demand side that can be used for reducing the peak loads in the power grid or increasing the use of locally available renewables. Demand response (DR) programs provide an opportunity for a utility to increase the flexibility by motivating consumers to decrease or shift their consumption during peak load hours by responding to price signals or bilateral agreements with the utility. Therefore, DR programs can contribute to energy and ancillary services, thereby increasing the reliability of the transmission system. In 2010, California ISO allowed aggregators to participate in the energy and ancillary service market by placing bids of flexibility resources called proxy demand response (PDR) which are similar to bids from generator/virtual-generator in the intraday and day-ahead markets [8], [9].

Demand response mechanisms is usually classified in two main categories; however, they often tend to have several names. The first category includes Dispatchable flexible resources and include incentive-based mechanisms such as bilateral contracts of direct load control. Another name for this is also Explicit Demand Response. The second category include non-Dispatchable flexible resources (also called Implicit Demand Response) and include price-based options that send a price signal to the end-user that (s)he shall respond to. Please see an overview in Table 1 and further explanations of the different programs in



Table 2. [10][11]

**Table 1 Different types of DR programmes [10]**

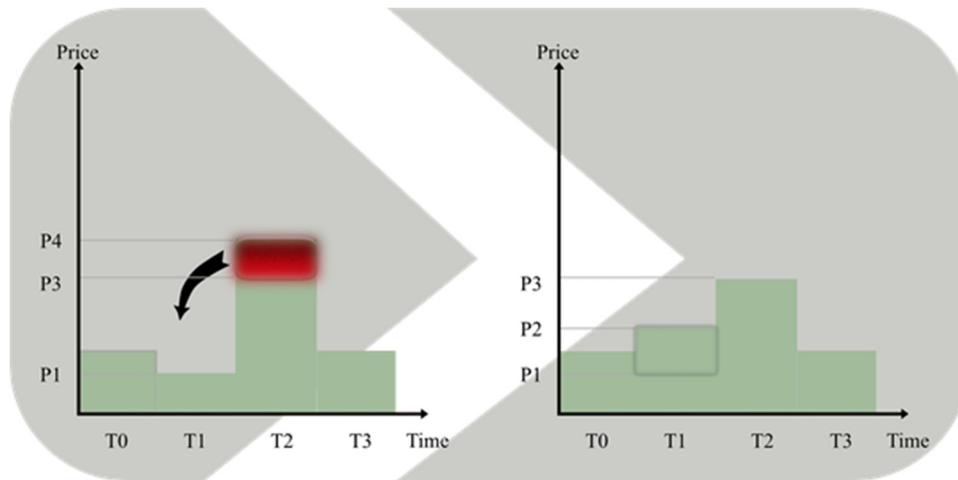
<b>Dispatchable DR (explicit demand response) (incentive-based mechanisms)</b>	<b>Non-Dispatchable DR (implicit demand response) (price-based mechanisms)</b>
<i>Energy-Voluntary:</i> Emergency Demand Response (EDR)	<i>Time sensitive pricing programs:</i> Time-of-Use (TOU), Real-Time-Pricing (RTP), Critical Peak Pricing (CPP), and System Peak Response Transmission Tariff (4CP Response).
<i>Energy-Price:</i> Demand Bidding and Buy-Back (DBB)	
<i>Capacity:</i> Direct Load Control Management (DLC), Interruptible/Curtailable Load (ICL), and Load as a Capacity Resource (LCR)	
<i>Reserve:</i> Spinning Reserves (SR), Non-Spinning Reserves (NSR)	

**Table 2 DR programs description [10] [11]**

<b>DR program</b>	<b>Description</b>
Emergency Demand Response (EDR):	This program is designed to meet the demand when the system encounters reserve shortfall. The program provides incentives to customers and asks them to reduce load.
Demand Bidding and Buy-Back (DBB):	Large customers try to act the same as suppliers and earn money from the wholesale market. They place bids of load reduction in the market.
Direct Load Control Management (DLC):	This program allows the operator to shut down or turn on customer's appliances and electrical end users (e.g. heating packages) from the centre of operation system. The program is designed to influence residential and small commercial sectors on short notice.
Interruptible/Curtailable Load (ICL):	This program offers a rate discount on retail tariffs or a bill credit to large-scale industrial and commercial customers for accepting to decrease consumption during peak load time. The operator may impose penalties in the case that customers do not reduce load.
Load as a Capacity Resource (LCR):	Customers act as system capacity and propose a specific amount of load reduction that can be utilised instead of some peak generation. The operator sends daily notice to inform about the event and payments are up-front. The program will impose penalties for any failure to load reduction.
Ancillary Services Market Programs (ASM):	This program allows customers to play role as operating reserve. They can bid load reduction in the market and receive market price for being ready to curtail load. If their action is needed, ISO/RTO call them, and customers change from being on standby to active players. For each unit of load curtailment, they receive the same as the market price.
Regulation:	The system operator can send real time signals to customers and change the load automatically during a commitment period. This program helps system operators to regulate the grid frequency.
Time-of-Use (TOU):	A time-of-use tariffs charge cheaper rates at certain times of night or day. Often the higher prices are set when demand is high, and vice versa. The customers may then react to these price signals, by lowering their demands when prices are high, reducing both their electricity bill and the peak load of the grid.
Real-Time-Pricing (RTP):	Customers change their electricity consumption by regarding wholesale market price fluctuation per hour. The information about RTP prices is provided a day ahead or an hour ahead.
Critical Peak Pricing (CPP):	This program is built on the TOU structure; however, the higher pricing only occurs during the critical peak load hours. As opposed to the ToU-scheme, where the peak pricing occurs every day, the CPP might only occur a few times of the year when the system reliability is at stake.
System Peak Response Transmission Tariff (4CP Response):	The main purpose of this program is reducing load to decrease transmission charges. The program is designed to send notifications with different probabilities of calling load reduction during a day.

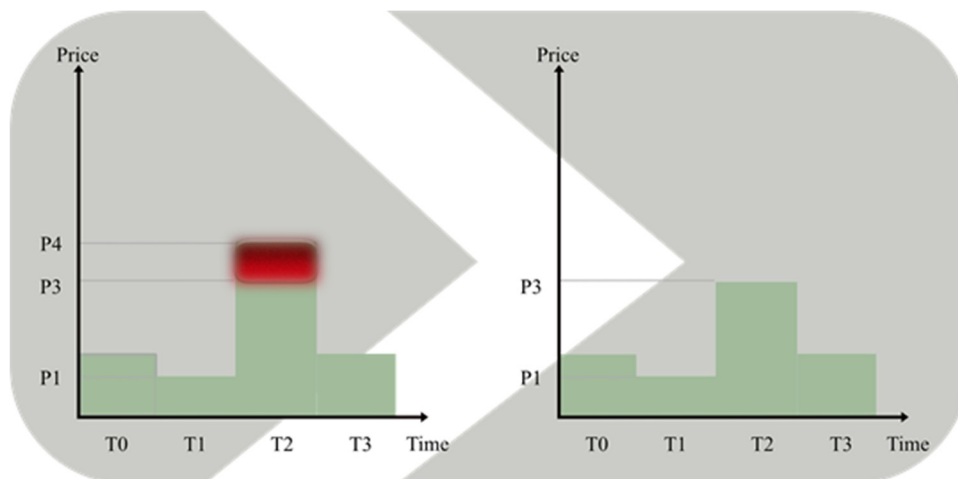
There are three mechanisms of changing the load profile of any customer on a short term: load shifting, load shedding and valley filling. Load shifting involves moving the electricity consumption

between periods. Figure 3 shows an example where energy consumption is shifted from peak load to off peak load by pre-heating the building.



**Figure 3 Load shifting**

Load shedding involves cutting the load and not using this energy at another point in time (either before or after). An example is to turn off lights, computers or television, or reduce the set-point temperature of the indoor air (and not increasing it later). Hence, load shedding may cause violation of comfort requirements in the building. Figure 4 shows how load shedding can affect the load profile. The last mechanism is valley filling, which involves increasing the load at times when electricity is cheap, without using electricity that would have been used later, i.e. the opposite of load shedding. The most relevant example of valley filling is in a building with two parallel heating sources, e.g. a thermal and an electric boiler, that can be used interchangeably. If electricity prices are low, the thermal pellet boiler is turned off, and the electric boiler can be turned on, increasing the electricity use in these hours.



**Figure 4 Load shedding**

## 2.2 How can building technologies provide DR-flexibility

Different solutions may be applied to building technologies to provide flexibility at the peak load hour. The energy demand for some technologies can be shifted using storage systems. Electrical heating

systems can offer load shedding when there is a separate alternative non-electric heating system installed in the building which can be accessed through substitution<sup>1</sup>.

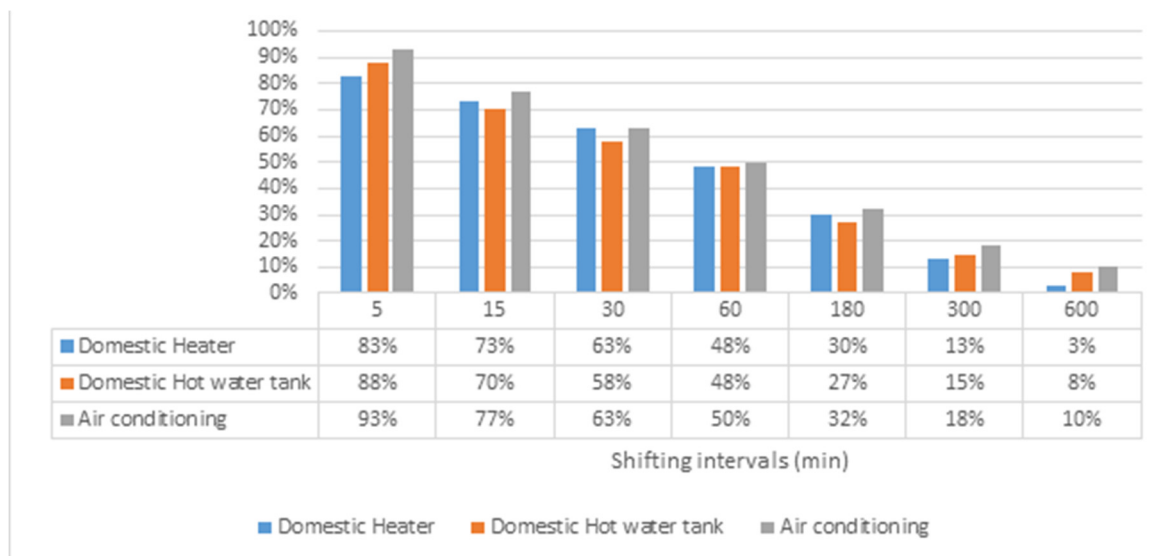
The following list describes how different energy purposes and building technologies can offer demand response flexibility through either load shedding or load shifting:

- 1) Space/ventilation heating: through reducing the indoor temperature, either within the set-point boundaries, or even below the comfort level for a short period of time if the users receive compensation. Space heating systems can offer flexibility using thermal storage or by using secondary non-electric heat sources when necessary. Well insulated buildings can be preheated to shift the peak in electricity for space and ventilation heating.
- 2) Hot water heaters: through delaying the heating of hot water in hot water heaters, or in combination with thermal storage.
- 3) Ventilation: Ventilation loads could be reduced for short amounts of time. The buildings are required to supply a certain level of air volumes, but it is likely that the air volumes of many buildings can be reduced and still fulfil these requirements due to unoptimized operation. The flexibility potential and technology readiness for flexibility through reduction of ventilation air loads is assumed to be high by [12], and the cost is expected to be low.
- 4) Charging of electric vehicles: electric vehicles charges at high power. There is flexibility in this charging in two ways – either the charging can be delayed/slowed down, or the battery in the electric vehicle can be used two-ways and offer electricity to the grid. The charging can be put on hold through the use of smart meters in accordance with price signals.
- 5) Emergency engine-generators can be used instead of electricity from the grid. In buildings which already have emergency generators installed (such as hospitals and industrial buildings), the generators need to be tested at regular intervals, and this could be done during peak load times, making the testing more profitable. Installations of new engines in buildings can be an alternative to grid investments when the installations reduce the costs and the life cycle emissions of the energy system don't increase.
- 6) Other electric loads: the use of electrical appliances might be able to shift - if the comfort of users are not affected or if the users are compensated.

In addition to the technologies, the flexibility potential also depends on the acceptance by the end-users. Safdar [13] investigates the willingness to shift energy demand in households. Figure 5 shows that the flexibility potential declines as shifting intervals increase.

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<sup>1</sup> This report has not considered the substitution effect.



**Figure 5 Willingness to shift energy demand for space heating, DHW and space cooling in households [13]**

### 2.3 Building automation systems

To release the flexibility potential in a building, the building and its technical systems need to have a technical infrastructure that makes it possible for the building to respond to its surroundings and to signals from the grid. There is not one definition on smartness of buildings; however, the Powerhouse project [14] has attempted to define different levels of smartness in buildings, as shown in Table 3.

**Table 3 Definition of 'smartness'- levels in buildings translated from [14]**

<b>Level 0: Automated</b>	The building satisfies the technical requirements for new buildings (TEK 17). These buildings are robust and energy efficient. Temperature, lighting, and ventilation air can be controlled based on pre-defines set points and timers.
<b>Level 1: Smart ready</b>	The building has technical infrastructure that makes it possible to upgrade the building to a higher ambition level at a later time.
<b>Level 2: Smart standard</b>	The building communicates with the users, and offers guidance and/or adjusts to the users' preferences and behaviour patterns (based on indoor climate preferences e.g.)
<b>Level 3: Smart predictive</b>	The building uses predictive control based on direct and indirect data from its surroundings to recommend and adjust the building and building loads.
<b>Level 4: Smart cognitive</b>	The building/the building system is self-learning and uses historical data and machine learning to improve its predictive control. The building communicates and adapts to its neighbourhood and surroundings.

According to this definition a building must be at a minimum level 2 to release its flexibility potential, as the building's technical systems must have the ability to respond to input signals. At level 2 the grid companies/other outside actors can send signals to a building about which loads the building should manage at which times. At level 3 or above the building can make its own predictions about when and how to manage its loads, according to price signals or other signals from the surroundings.

### 3. Case studies

This chapter identifies the days when the peak of the electricity price and the electricity load occurs in Norway in the years 2016-2020. These days are used as identifiers for hours when the power system is constrained. We investigate how the buildings may contribute to alleviate these constraints by reducing their load at these hours. Eight case studies are evaluated, investigating their hourly load profiles and which energy purposes that are contributing to the peak load. Detailed consumption data on electricity and district heating use are provided by GK Cloud (a control and surveillance system for buildings) and GK E-sight (an energy management system).

#### 3.1 Peak loads and electricity prices in the Norwegian power system

In the Nordic electricity market, the price of electricity varies between the different price zones. The system price is calculated based on sale and purchase orders disregarding available transmission capacity between bidding areas in the Nordic market. The number of Norwegian price zones can vary, today there are five price zones. The different price zones help indicate constraints in the transmission systems and ensure that regional market conditions are reflected in the price. Due to bottlenecks in the transmission system, price zones may get different prices called area prices[15]. The area price is the price "seen" by each building and is the price that should be used when calculating the cost and potential savings available through demand response In a building.

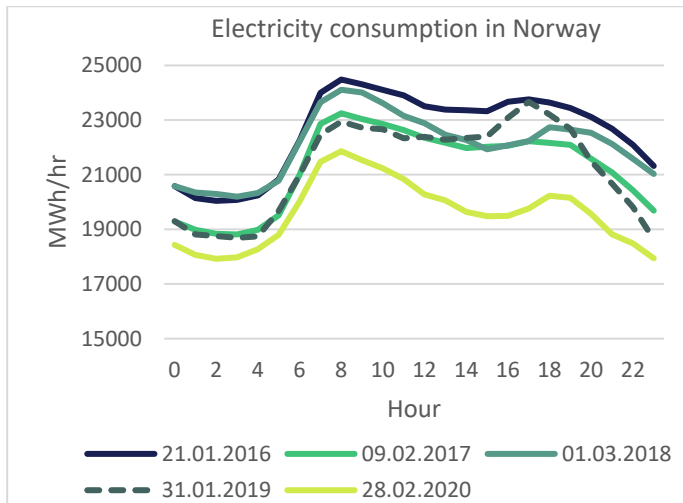
The hourly peak of the system price will often (but not always) coincide with the high/peak consumption in Norway; however, the peak prices in each region do not necessary coincide with the peak system price.

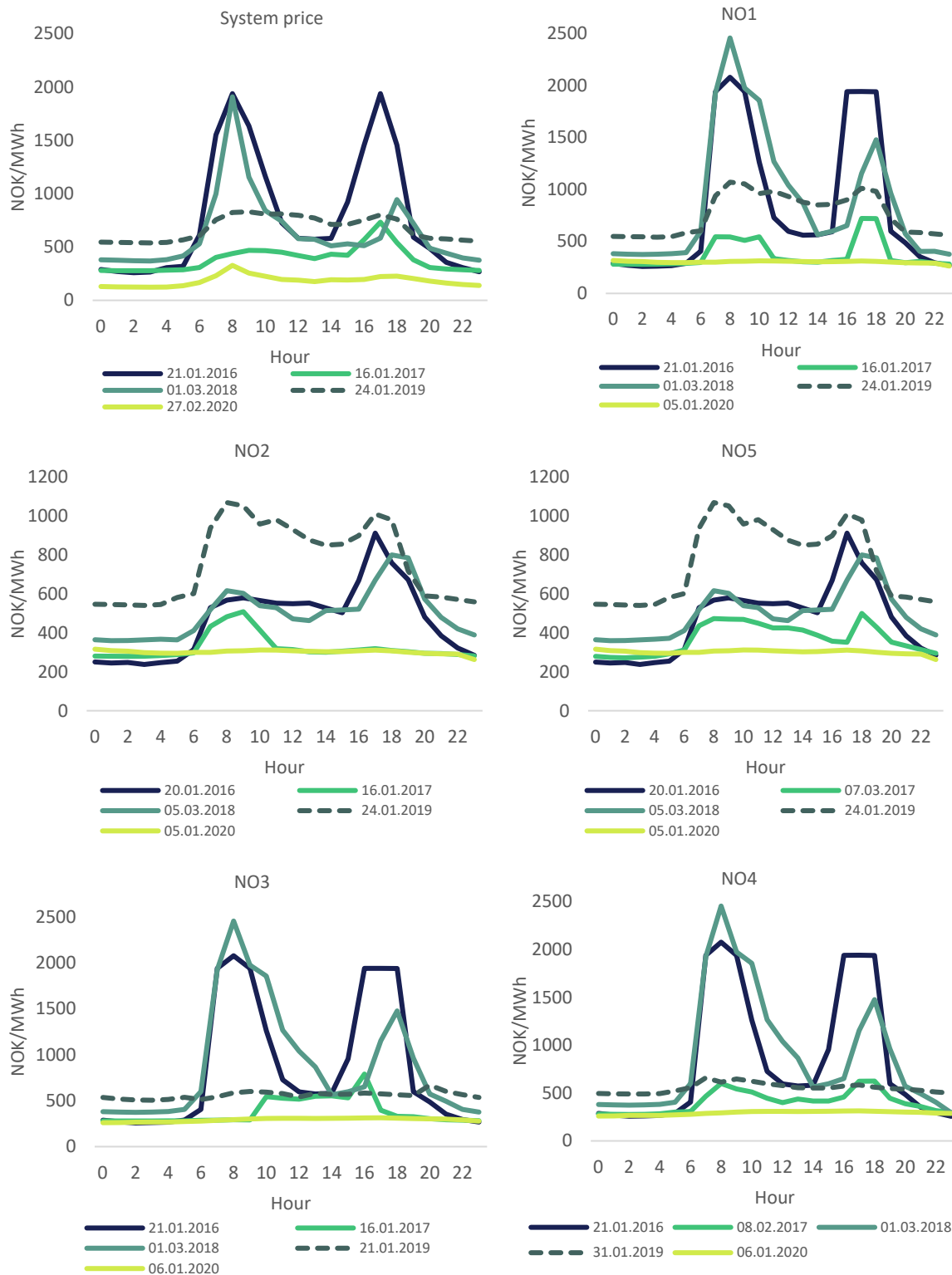
In this report, the scope is to evaluate the ability and potential for reducing the load of service buildings in the hours when the electricity grid is constrained, both in Norway and within each price zone. Both the electricity consumption and the electricity price reflect hours when the power system is constrained. Hence, Table 4 shows the days in the period 2016-2020 when the peak consumption occurs, and the peak price occurs, both for the system price and the area price (NO1 to NO5). We see that the peak consumption and the peak price coincide most of the years, however there are some discrepancies. It is therefore of interest to investigate this further. The hourly variation in area prices and system prices on the days when the peak prices occur are shown in Figure 7, and the peak day of Norway's electricity consumption is shown in Figure 6.

Due to the scarce availability of measurement data of the buildings (cf. Section 3.3 and 3.4), it was decided to evaluate the buildings on the day of the peak consumption in Norway in 2019 which occurred on 31<sup>st</sup> of January during the hours 07:00-09:00 and 16:00-18:00.

**Table 4 The date of the peak prices and peak Norwegian consumption for the years 2016-2020.**

	Day of peak				
	2016	2017	2018	2019	2020
<b>Consumption in Norway</b>	21.1.	9.2.	1.3.	31.1.	28.2.
<b>System price</b>	21.1.	16.1.	1.3.	24.1.	27.2.
<b>Area price NO1 (Østlandet)</b>	21.1.	16.1.	1.3.	24.1.	5.1.
<b>Area price NO2 (Nordvestlandet)</b>	20.1.	16.1.	5.3.	24.1.	5.1.
<b>Area price NO5 (Vestlandet)</b>	20.1.	7.3.	5.3.	24.1.	5.1.
<b>Area price NO3 (Midt-Norge)</b>	21.1.	16.1.	1.3.	21.1.	6.1.
<b>Area price NO4 (Nord-Norge)</b>	21.1.	8.2.	1.3.	31.1.	6.1.

**Figure 6 Load profile on the day of peak electricity consumption in Norway in 2016-2020.**



**Figure 7** The hourly variation of the electricity price (system price and area prices (NO1-NO5)) on the day of its annual peak in 2016-2020. [16]



### 3.2 GK Cloud and GK E-sight

GK Cloud is a cloud-based platform provided by GK, mainly as a service based control and surveillance system for buildings. The systems cover all basic functionality for buildings automation systems in addition to modern cloud and IoT functionality such as Big Data storage, ML algorithm, dashboarding and much more. These functionalities are added and configured according to each building owner's wishes and needs. As such - the number of data and details of information will vary from building to building. The system can collect data from any protocol or API available as a standardized information channel. This may also include all types of energy consumption meters, water consumption meters, temperature sensors, pressure sensors, run and alarm state from all type of equipment such as fans, pumps, compressors, heat pumps and so on.

Approximately 450 buildings are connected to GK Cloud today. The number and types of meters and controls varies with each building. In some buildings only the total electricity load is metered and logged, while other buildings use GK Cloud to control the ventilation air flow and temperatures in different zones.

Some of the buildings in GK Cloud also use a separate Energy management system – GK E-Sight. GK E-sight is an energy management system which allows for surveillance and analysis of historical energy use data for the building. GK E-Sight is also provided by GK, but this is a separate system which is not directly linked to GK Cloud.

### 3.3 Selection process – how were the cases selected

The goal of this work is to identify how service buildings can contribute to reducing the Norwegian peak load. To get the best possible approximation, it was important that the chosen cases are as representative of the service sector as possible. To achieve this, the following requirements for the selection process were defined (wish list):

- Minimum of 10 buildings
- Building types: at least offices, shops and schools (together they represent 70 % of the total service building area [17])
- Building age: both newer buildings (from after 2015) and older buildings
- Heating systems: different heating systems (cases with waterborne heating, and cases with direct electric heating).
- Metering data: Lastly it was a prerequisite that hourly metering of electricity (and district heating where this is relevant) are available separated on various energy purposes (often involving several sub-meters).

Despite the good intentions, the number of buildings in GK Cloud that met these requirements were limited. Finding cases with hourly data on energy consumption for separate energy purposes turned out to be the biggest barrier during the case selection process. The first challenge was the number of energy meters available within GK-Cloud. Although a building linked to GK Cloud may have several energy meters installed within the building, these energy meters were not necessarily available, connected to or logged within the cloud system. The second challenge was that the energy measurements within GK Cloud were logged by change-in-value, and not at regular time intervals, making it challenging to extract hourly time-series for energy consumption. GK E-sight – the energy management system – did however manage more energy meters per building and stored the energy consumption data at an hourly level. Due to these challenges, only buildings that were linked to both GK Cloud and GK E-sight were chosen as case studies.

### 3.4 Selected buildings

11 buildings were initially selected as case studies, however three of the buildings (a storage/office building, a school and a hotel) were left out of the study as they either had too few energy meters, or lacked data on the dates identified in Section 3.1. The eight remaining buildings selected as case studies are described in Table 5.

**Table 5 Selected buildings in the case study**

Building	Geography/ price region	Size	Age	Heating system	Energy Meters	Building automation level
Office 1	Oslo/ NO1	13650 m <sup>2</sup>	2012	District heating	El (main) El (ventilation) El (HP) EL (el.boiler) EL (EV) EL (heater)	Level 1
Storage/Office 1	Møre og Romsdal/ NO3	Unknown	Unknown	Heat pump + Electric boiler	El (Main) El (Electric unspecified) El (HP) EL (El. Boiler) EL (ventilation) EL (compressor)	Level 1
Storage/Office 2	Møre og Romsdal/ NO3	Unknown	Unknown	Heat pump + Electric boiler	El (Main) El (Electric equipment) El (HP) EL (El. Boiler) EL (ventilation)	Level 1
Storage/Office 3	Møre og Romsdal/ NO3	9350 m <sup>2</sup>	Unknown	Heat pump + Electric boiler	El (Main) El (Electric unspecified) El (HP) EL (El. boiler)	Level 1
School 1	Nordland/ NO4	Unknown	2016	Electric	El (main) El (water heater)	Level 1
Office 2	Møre og Romsdal/ NO3	9000/ 11000 m <sup>2</sup>	1970/ 2016	District heating	El (Main and zones) DH (main)	Level 1
Sports hall 1 and 2	Bodø NO4	12600 m <sup>2</sup>	1991/ 2007	District heating	El (Main and zones) DH (Main)	Level 1

The column "Energy Meters" describes the energy purposes/technologies being logged within GK Cloud and GK E-sight for each building. In addition to the energy meters listed here, values for ventilation air flows, indoor temperatures, heat flows and cooling flows are logged within GK-Cloud. The column "Building automation level" states the automation level of each building as defined in Section 2.3. All of the selected buildings are considered to be level 1 buildings, as they are all new or newly renovated buildings, and it is possible to control lighting, temperature and/or ventilation air flows through GK-cloud by defining set-point values, and through manual control in the control system.

## 4. Results - Building load profiles of the case studies

This chapter presents the hourly electricity consumption of the case study buildings on Thursday 31<sup>st</sup> of January 2019 when the peak load hours for electricity consumption in Norway in 2019 occurred.

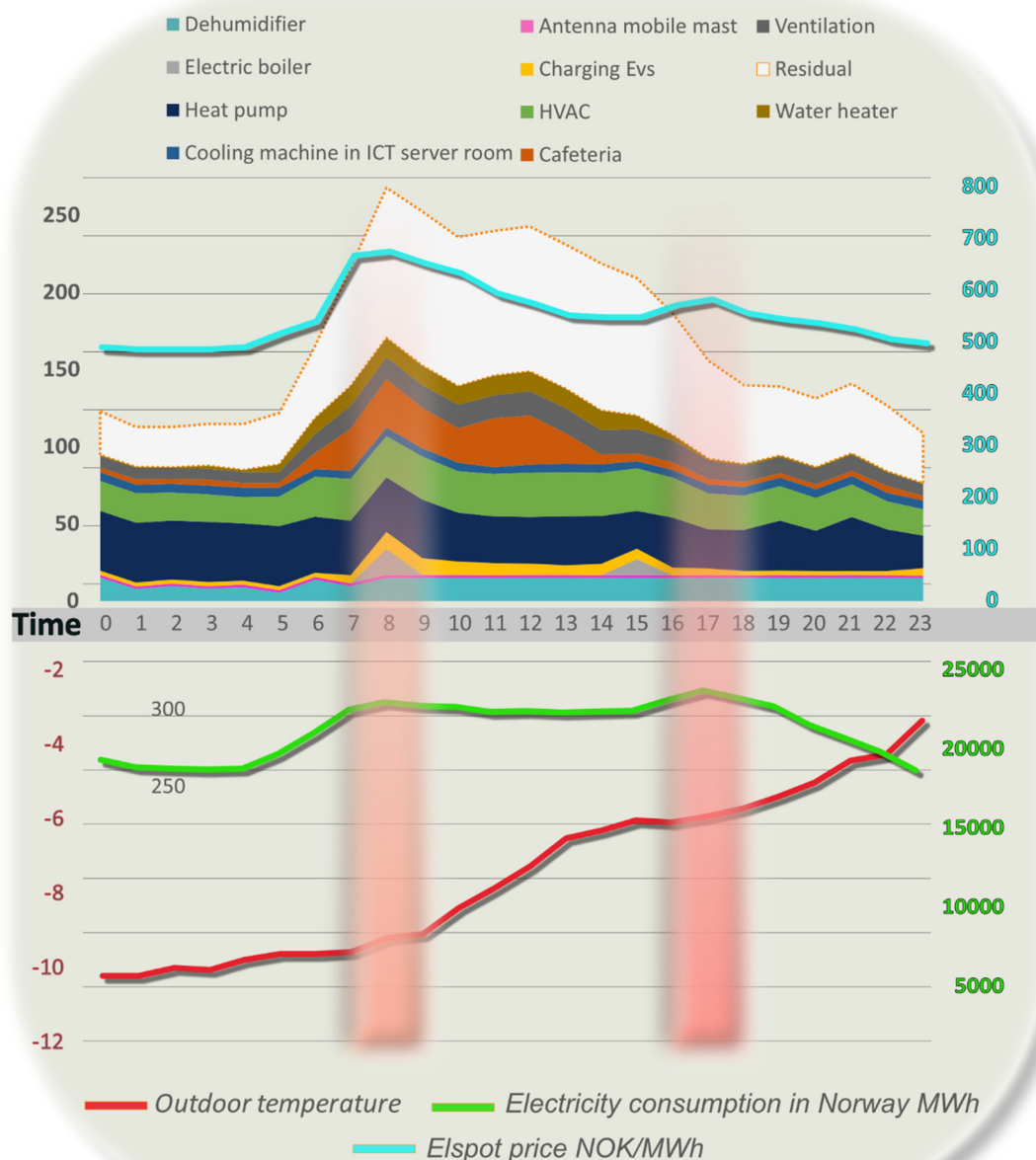
### Case: Office 1

Office 1 is a 5-story modern office building from 2012 of approximately 13 600 m<sup>2</sup> of heated area situated in Oslo. The office building is a passive house with energy label A. Energy efficiency and good indoor climate has been the focus of the construction of the building. The building is heated/cooled by two air-water heat pumps with a peak cooling power of 520 kW and peak heating power of 320 kW at -15 C through heating/cooling of ventilation air which covers 98 % of the buildings heating energy demand. The ventilation air is supplied to zones/rooms based on the ventilation demand defined by set point values for temperatures, air circulation speeds and CO<sub>2</sub>-concentration.

The electricity use in the building split by energy purposes (kWh), as well as the local energy price (Elspot price in NO1, NOK/MWh), the Norwegian electricity consumption (MWh) and the outdoor temperature on-site is shown in Figure 8. Office 1 is building with many energy meters for different zones/energy purposes, with different energy meters for ventilation/HVAC<sup>2</sup>, the heat pumps, cooling for servers/computers, electric vehicle chargers, the cafeteria ++. A large portion of the electricity use in the building ("Residual") is not linked to a specific purpose.

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<sup>2</sup> The building has a lot of energy meters, with 7 + different energy meters for electricity use for ventilation/HVAC. It is not certain how these meters are linked to one another, and whether some of the meters overlap. The electricity use for ventilation/HVAC in Figure 8 may be overestimated due to this.



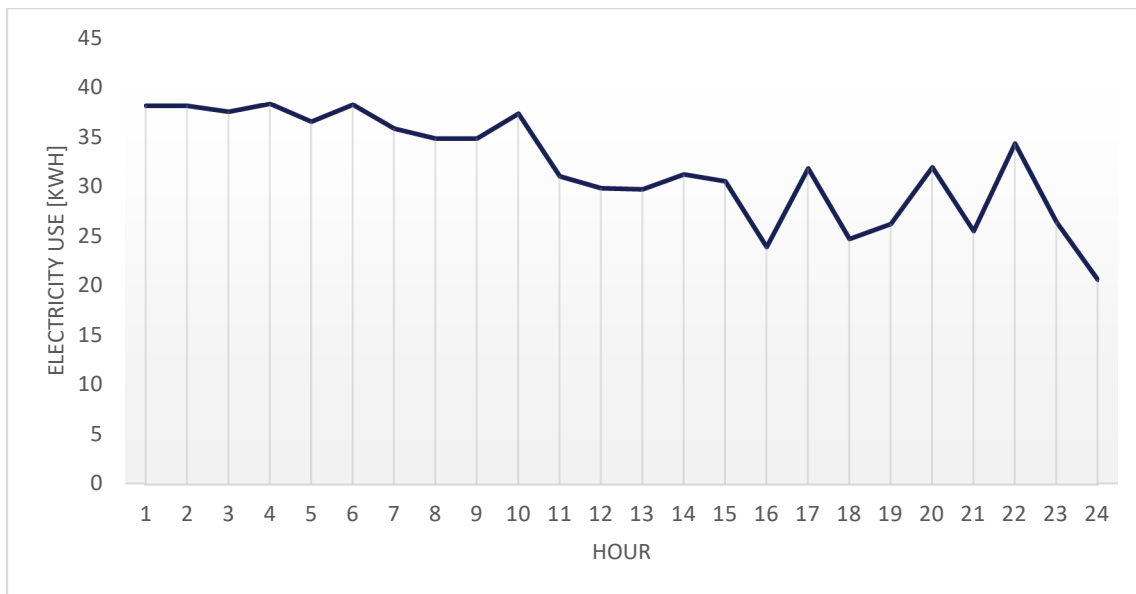
**Figure 8 Energy consumption in Office 1 situated in Oslo on 31.01.2019**

The total electricity demand in Norway peaks at 8 in the morning and between 16-18 in the afternoon, as marked with the pink lines in Figure 8 when there is expected to be a market for flexibility serviced from the demand side to reduce peak loads in electricity.

The hourly electricity demand at Office 1 peaks at 08:00. The electricity profile of Office 1 follows a typical office electricity consumption with a "bell-shaped curve" with high electricity consumption during the office hours 08:00-17:00 and reduced electricity consumption outside of office hours/during the night-time.

The outdoor temperature at the building location was below zero throughout the 31<sup>st</sup> January 2019, with a temperature of -10 C at midnight, which is steadily increasing to -3 C towards the following night. The outdoor temperature and the human activities are the most crucial reasons for fluctuation in energy use inside Office 1. The highest energy consumption for the heat pump occurs at 01:00 when

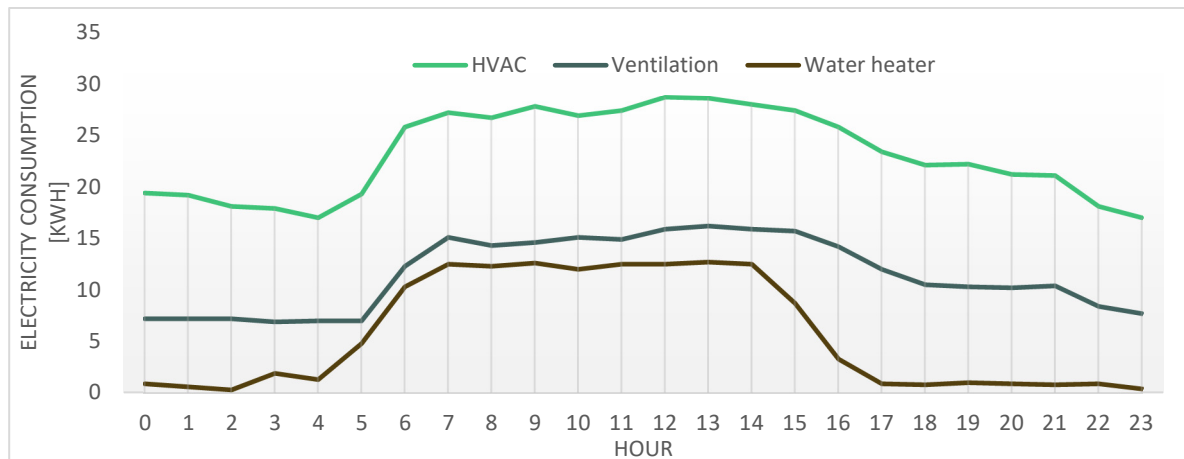
the temperature is at the minimum. The energy use for the heat pumps, as shown in Figure 9, seems to be more affected by the outdoor temperature than the activity inside the building. This is likely due to the 31.01.2019 being a particularly cold day in the Oslo-region, resulting in the heating of ventilation air to be mainly controlled based on the minimum set point temperatures for zones (as opposed to occupancy/CO2 concentration in the zones). The electric boiler is however only turned on at 08:00 and 15:00. The electric boiler is the peak load heating technology used for heating when the temperature is especially low, and the efficiency of the heat pumps is low. The temperature is not lower on the hourly level at these times compared to the neighbouring hours. One reason for the spike at 8 might be a need for increased heated ventilation air volumes (due to presence in more zones or due to set point volumes and temperatures changing before the employees arrive).



**Figure 9 Hourly electricity consumption for the heat pumps in Office 1 on 31.01.2019.**

The temperature in the Oslo region cannot explain the peak power demand in the building alone. The building peak electricity consumption in the morning coincides with the morning peak power demand in Norway - at 08:00, the other energy purposes need to be considered.

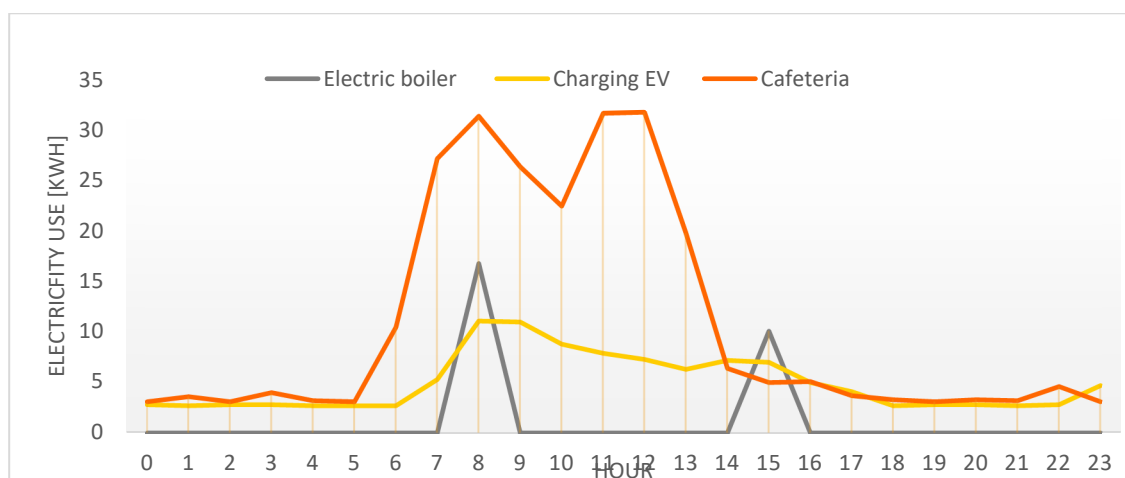
The mobile antenna and cooling of ICT systems seem to have steady energy use throughout the day. Electricity consumption for Ventilation/HVAC, the dehumidifier and the water heater seem to have steady energy use during the hours 06:00 to about 14:00-16:00 before the energy use is reduced. This is shown in Figure 10. This coincides with the office hours when there is expected to be human activity within the building.



**Figure 10 Electricity consumption for ventilation, HVAC and the water heater in Office on 31.01.2019.**

There seems to be a potential to shift energy consumption away from the morning peak to provide flexibility for the grid to some degree. The charging of electric vehicles might be possible to delay. The heating of ventilation air seems to be closely linked to the outdoor temperature, but it might be possible to preheat the office before 08:00, especially considering this building to be a passive house with some inertia. It is uncertain how much and if at all the heating energy and ventilation energy can be reduced during opening hours while fulfilling the set point requirements for indoor air quality and temperatures. The building owners might be more willing to reduce these loads after 16:00 before the peak load at 17, as the electricity consumption for other loads appear to be reduced after 16:00, suggesting less human activity in the building, but it uncertain how big the potential is.

The energy use for the electric boiler, the charging of electric vehicles and electricity use for the cafeteria appears to vary more throughout the working day, as shown in Figure 11. The cafeteria appears to have a peak at 8 (breakfast) and at 11-12 (lunch). The electric boiler only seems to be used at two times during the day – at 8 and 15. The charging of electric vehicles have a peak load at 8-9 – likely due to employees and guests connecting their electric cars to the on-site chargers after arriving at Office 1 in the morning.



**Figure 11 Electricity consumption the cafeteria, charging of electric vehicles and the electric boiler in Office on 31.01.2019.**

There might be a flexibility potential in delaying the charging of electric vehicles during the morning peak – either through reducing charging speeds, or through the use of smart meters.

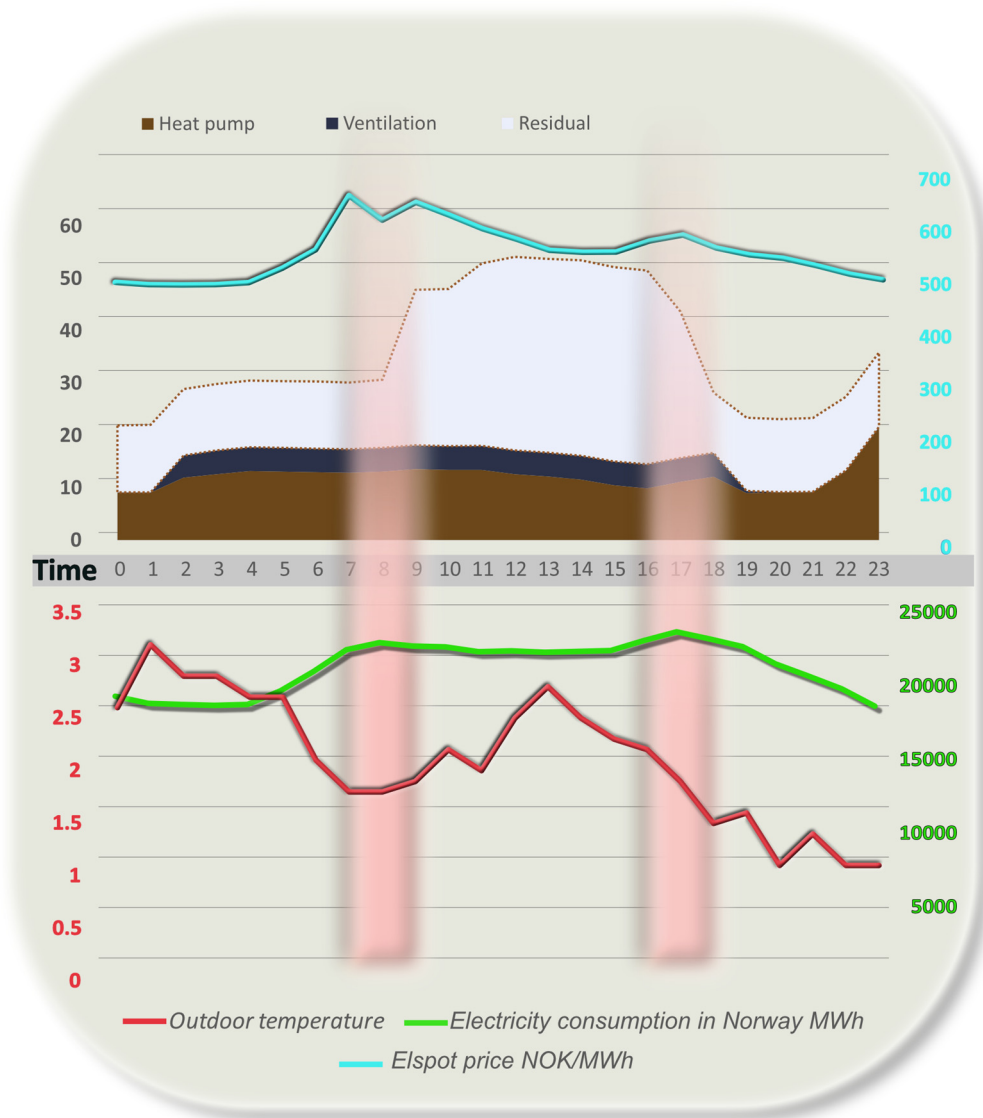
The infrastructure in Office 1 is currently not ready for interacting and responding to signals from the grid. With the needed infrastructure, flexibility might be available, but the grid must provide enough incentives to make Office 1 offer these flexibility services. The incentives could be financial or non-financial. In the case of Office 1, the peak price of electricity coincides with peak consumption, therefore shifting energy consumption may decrease the cost of energy for Office 1. Moreover, the owner might have a similar incentive release flexibility potential at 17:00, because the electricity price is higher at this hour compared to neighbouring points.

### **Case: Storage/office 1, 2 and 3**

Storage/office buildings 1, 2 and 3 are three buildings located in a large industrial area at the coast in Møre and Romsdal. The buildings are service buildings with storage halls and administrative offices linked to the oil and gas industry.

The buildings are all heated by electric heating – with heat pumps as the base load heater and an electric boiler for peak loads. On the 31<sup>st</sup> of January 2020, the temperature at the building site is above 0 for all hours of the day, with temperatures decreasing from 3 C at midnight before being reduced to about 1 C the following night. The buildings all have high energy use during the hours 9-10 and 16-17 (and even later for Storage/Office 3), and reduced energy use during the night-time.

Unfortunately, specific details about the buildings metadata, such as the area, industry activity and age, are not known.



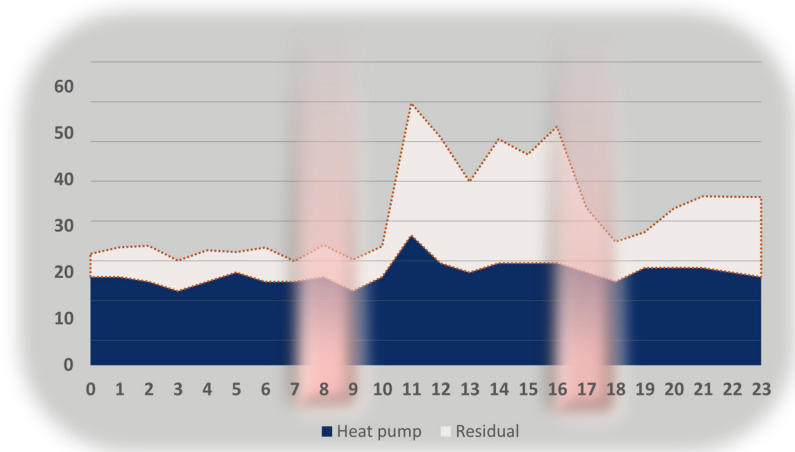
**Figure 12 Energy consumption in Office/Storage 1 in Møre og Romsdal on 31.01.2019**

The electricity consumption of Storage/office 1 as well as the local energy price (Elspot price in NO3, NOK/MWh), the Norwegian electricity consumption (MWh) and the outdoor temperature on-site is shown in Figure 12. The buildings Storage/Office 1,2 and 3 have few energy meters, but the buildings have separate meters for energy use for the heat pump, ventilation and the main meter of electricity.

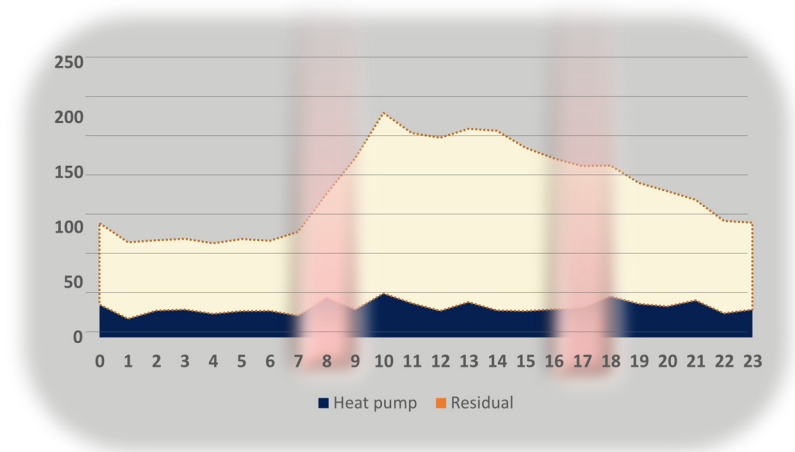
In Office/storage 1 it seems to be some link between the heating demand, as the electricity use for heating increases drastically during the hours 21-23, likely due to a large production hall reaching the minimum set-point temperature, resulting in a sudden heating demand. The energy use for heating appears to be quite constant throughout the work hours. The peak load of the building does not occur during the hours of the morning peak and afternoon peak in Norway.

Office/Storage buildings 2 and 3 also seem to have a steady consumption for the heat pump, as shown in Figure 13 and Figure 14. It is unknown whether there is a potential for flexibility services through the reduction of electricity use for the heat pump/preheating, as the set point temperatures and sizes of the storage units are unknown, or what the residual electric load is used for. As the peak load in the building occurs outside of the Norwegian peak load, one can assume that the flexibility potential and the willingness to shift of the three buildings is limited.





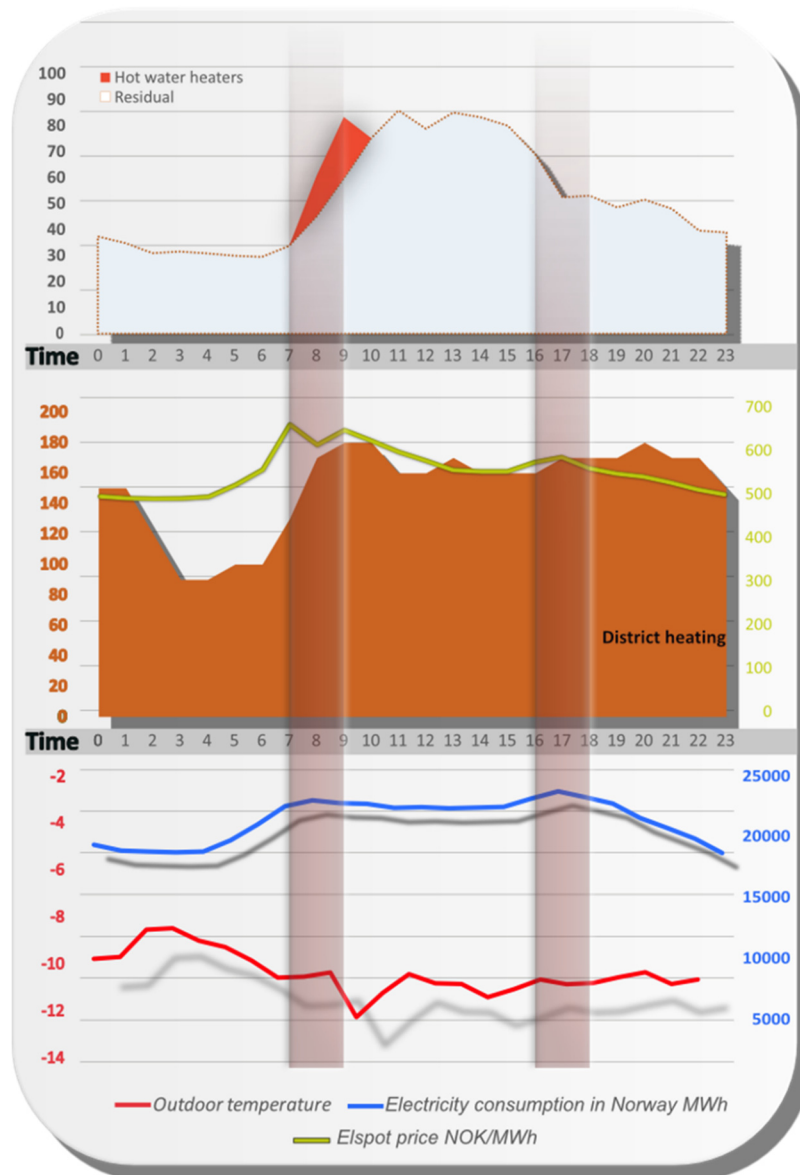
**Figure 13 Energy consumption in Office/Storage 2 in Møre og Romsdal on 31.01.2019**



**Figure 14 Energy consumption in Office/Storage 2 in Møre og Romsdal on 31.01.2019**

### Case: School 1

School 1 is a new/renovated primary and secondary school situated in a small town in Nordland. The school was finished in 2016/2017 with 600 + pupils. The school uses district heating and electric hot water heaters for heating. The electricity consumption of School 1, the district heating energy consumption of school 1, as well as the electricity use, the local energy price (Elspot price in NO4, NOK/MWh), the Norwegian electricity consumption (MWh) and the outdoor temperature on-site is shown in Figure 15.



**Figure 15 Energy consumption of school 1 on 31.01.2019**

The peak load of electricity in the school occurs at 09:00, when the electricity consumption in Norway is high. The building has the possibility to use hot water tanks for shifting electricity consumption from 8 am to early morning. As the school uses both electric heating and district heating, it is theoretically possible to switch between the different heating alternatives according to different signals. A price signal can provide enough incentive to switch between the alternatives. The building uses balanced ventilation, and there might be possibilities in reducing the ventilation air flows during the morning and afternoon peaks, but the potential is unclear as the ventilation energy use is not measured separately.

**Case: Office 2**

Office 2 is a new office building situated on the coast in Møre og Romsdal. The office building is approximately 10 000 m<sup>2</sup>. The building was constructed in the 1970's and was renovated in 2016. The office is connected to a neighbouring production hall/factory which produces equipment for the shipping industry. Approximately 300 people work in the office or at the factory. After the renovation, the office building has become a low energy building with energy label B.

Office 2 uses district heating and has balanced ventilation. The heating and ventilation air loads are controlled based on set point values and through presence sensors in the zones. The ventilation air flows are reduced in the zones without human presence. There is a cafeteria in the building.

The main electricity consumption and the electricity consumption for Office 2, the district heating energy consumption of Office 2, the local energy price (Elsport price in NO3, NOK/MWh), the Norwegian electricity consumption (MWh) and the outdoor temperature on-site is shown in Figure 16.

The peak load of electricity occurs at 10:00. Ventilation is the only known electric load in the building. As the ventilation is already controlled by presence and set point values, there may be little willingness to shift energy use for ventilation at these hours. The electricity consumption of the building is largely unknown, and little is known about the electrical appliances within the building, but there are approximately 100 parking spaces in the parking garage in the office buildings. If electric charging is offered for some of these parking spaces, there might be a flexibility potential in delaying the charging of electric vehicles during the morning peak – either through reducing charging speeds or through the use of smart meters.

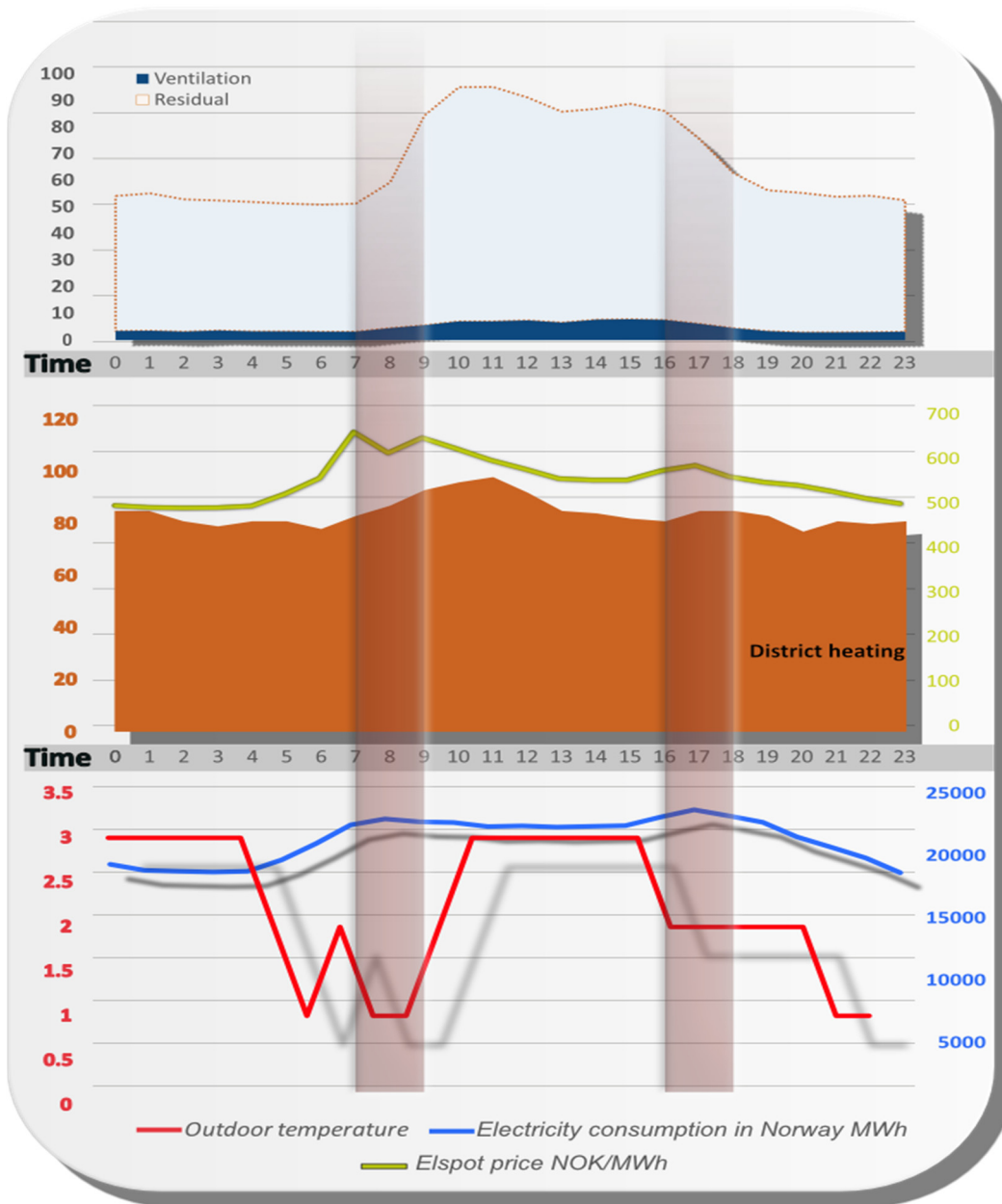
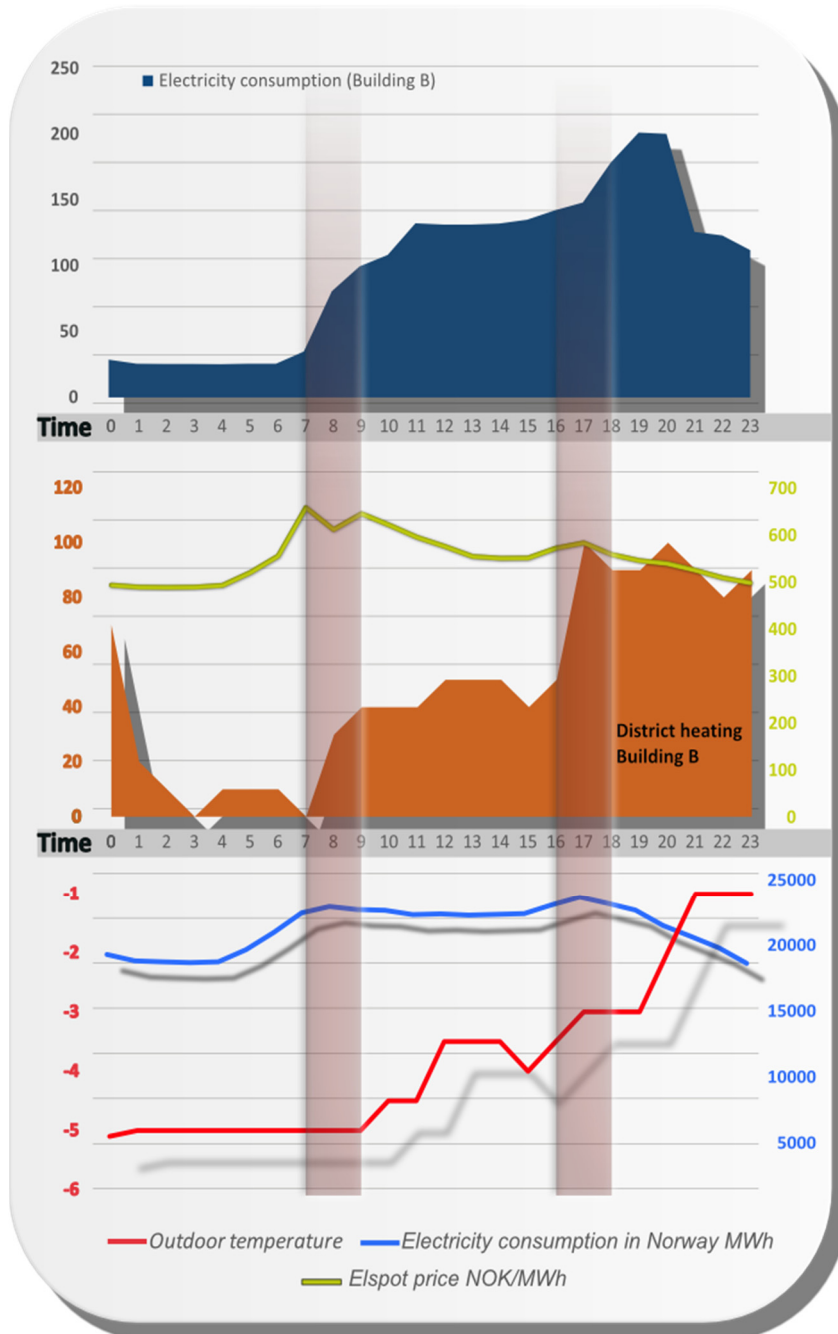


Figure 16 Energy consumption of Office 2 on 31.01.2019

### Case: Sports hall 1 and 2

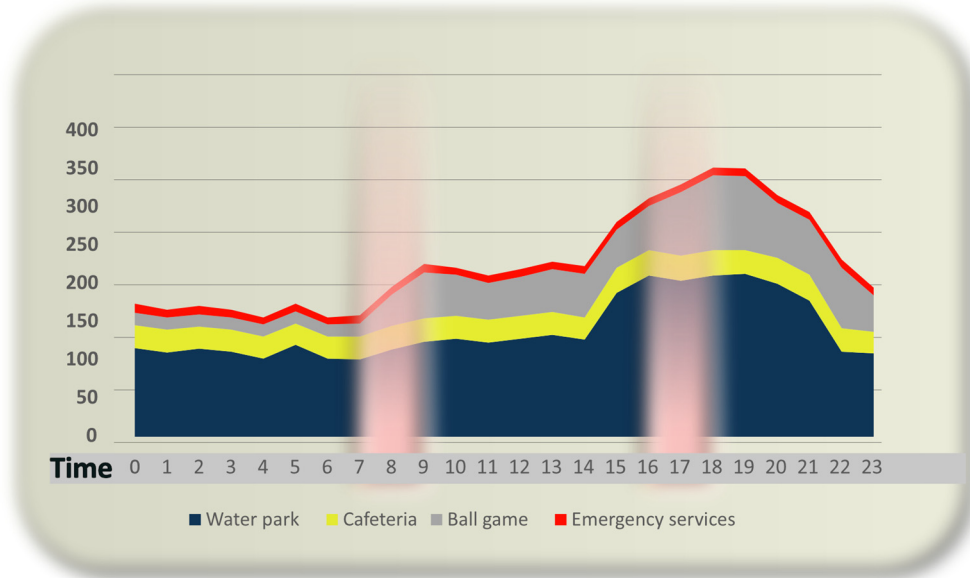
Sports hall 1 and 2 are two large sports halls located near the coast in a city in Nordland. One of the halls was built in 1991, while the other was built in 2007. The sports halls have more than 500 000 visitors each year. The electricity consumption of Sports hall 1, the district heating energy consumption of sports hall 1, the local energy price (Elspot price in NO4, NOK/MWh), the Norwegian electricity consumption (MWh) and the outdoor temperature on-site is shown in Figure 17. The energy consumption in sports hall 2 is shown in Figure 18.



**Figure 17 Energy consumption in Sports Hall 1 on 31.01.2019**

The peak energy consumption of the sports halls does not coincide with the peak electricity consumption in Norway, however the electricity consumption of both buildings is high at 17:00 – during the national peak. In both buildings there seem to be no negative correlation between the outdoor temperature and the energy use for heating. This is likely due to the nature of the building.

The building provides indoor sport facilities, which are affected by the activity, such as guests showering, halls being used for different sport activities, which increases the demand for ventilation, lighting and heating/cooling. In such a building there might be a small willingness to shift energy loads for both heating and other purposes, and price signals from the market may not give enough incentives to increase the willingness of shift, but there might be a potential for reduction in loads that were not metered separately within the buildings.



**Figure 18 Energy consumption in Sports hall 2 on 31.01.2019**

## Summary of flexibility potential

A summary of the results for the case studies on the load profiles of the seven buildings on the 31<sup>st</sup> of January 2019 is shown in Table 6. The table lists all available electric loads that are assumed to have a flexibility potential for shorter time periods, based on the listed flexibility resources in 2.2.

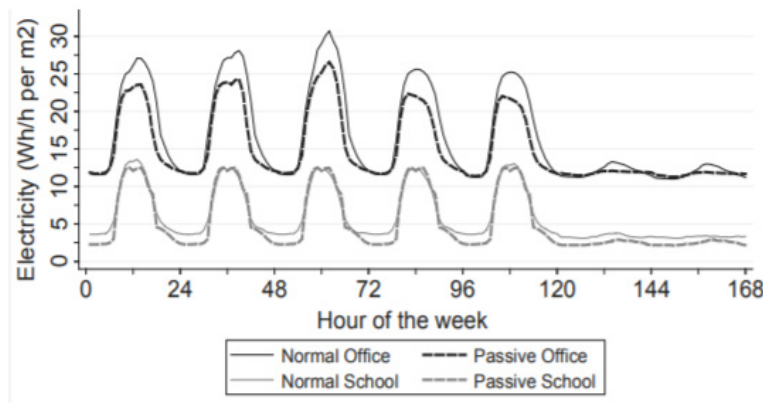
The table also lists the share of the electric loads that is used for the technologies that are defined as possible flexibility resources. For the buildings with electrical heating - office 1 and storage/office 1-3 - this share is at least 28 % at 8, 16- 20 % at 9 to 10, and at least 17-24 % at 16 to 20. The share is somewhat lower at school 1 and office 2 due to few possible flexibility resources being known in these buildings. The results show a large flexibility potential in the buildings with detailed energy measurements. This suggests that there may also be a flexibility potential in all of case studies. There was not enough information about sports halls 1-2 to make any conclusions about the flexibility potential of these buildings.

**Table 6 Summary of the flexibility potential in the case studies.**

Building	Building Peak load occurs at	Peak of electricity grid	Peak of area electricity price	Possible flex resources (known)	Assumed share of total load that is flexible (load of flex resources/total load)	Heating source
Office 1 NO1	8 hrs	8-10 hrs and 16 to 18	9 hrs	HP, hot tap water (electric boiler), EV chargers, ventilation	33 % throughout the day. Ca 30 % at 8-10 and 16-18 hrs.	HP through ventilation air. Electric boiler for DHW,
Storage/office 1 NO3	11-16 hrs	(same as above)	7-9 hrs	Ventilation, heat pump, electric boiler	42 % throughout the day. 58 % at 8, 38 % at 9-10 28 % at 16 36 % at 17	HP (base load) and Electric boiler (Peak load)
Storage/office 2 NO3	11 hrs	(same as above)	7-9 hrs	Ventilation, heat pump, electric boiler	61 % throughout the day. 70-75 % at 8-10. 44-67 % at 16-18.	HP (base load) and Electric boiler (Peak load)
Storage/office 3 NO3	10 hrs	(same as above)	7-9 hrs	Ventilation, heat pump, electric boiler	20 % throughout the day. 28 % at 8. 16-20 % at 9-10 17-24 % at 16-18	HP (base load) and Electric boiler (Peak load)
School 1 NO4	9 hrs	(same as above)	7-9 hrs	Hot water heater	3 % throughout the day. 26-28 % at 8-9 hrs.	District heating
Office 2 NO3		(same as above)	7-9 hrs	Ventilation	7-9 % during the hours 8-10 and 16-18.	District heating
Sportshall 1 NO4	19-20 hrs	(same as above)	7-9 hrs	Unknown	Unknown	District heating
Sportshall 2 NO4	18-19 hrs	(same as above)	7-9 hrs	Unknown	Unknown	District heating

The reader should note that most of the buildings analysed here do not have typical load profiles for service buildings. Typical load profiles for schools and offices (which make up approximately 40 % of service building area) from measurements have a high consumption during the middle of the day

(from about 7-16) during workdays, with reduced energy used during the evening, night-time and on the weekends, as shown in Figure 19 [18]. This pattern is observed in office 1, and slightly shifted compared to the typical profile in school 1, office 2 and in storage/office 1. The remaining case studies show buildings with load profiles that differ from the typical load profiles observed in most service buildings.



**Figure 19 Typical load profiles for schools and offices [18].**



## 5. Results - Unlocking the flexibility potential in service buildings

This chapter presents a qualitative evaluation of the flexibility potential in service buildings in Norway and investigates the barriers for unlocking this potential.

### 5.1 Aggregate flexibility potential of service buildings

In this work, the idea was to evaluate the aggregate flexibility potential of service buildings in Norway by investigating the building's smartness level using the building portfolio of GK as a proxy for the Norwegian non-residential building stock.

To release the flexibility potential in a building at the peak load hour, the building and its technical systems need to have a technical infrastructure that makes it possible for the building to respond to its surroundings and signals from the grid. In section 2.3 [14], we defined that a building must at least be of level 2 to be able to utilise its energy flexibility potential.

The buildings in this study – even the building with the most complex system for metering and control - are all considered to be at Level 1. This means that they can control temperature, lighting and ventilation air based on pre-defined set points and timers. They also have the technical infrastructure that makes it possible to upgrade the buildings to higher flexibility levels at a later time. The data supplier (GK) assumes that most (if not all) of the buildings that are being monitored and controlled through their database – hence, approximately 450 buildings - are at Level 0 or Level 1. The buildings analysed in this report are all new/newly renovated buildings. Older buildings may have even less developed control systems, making them below Level 0. This indicates that there are currently very few service buildings in Norway that are advanced enough to unlock the flexibility potential at the peak load hour.

### 5.2 Barriers for unlocking the flexibility potential in service buildings

The flexibility potential of a building at Level 2/ Level 3 can be released if the building can respond to model predictive control (MPC) or other rule based control signals. MPC is a control strategy that calculates an optimal sequence of control inputs for a prediction horizon, based on inputs of predicted external effects, such as weather, prices and user behaviour, and subject to a set of constraints, such as user comfort and system limits. At Level 3, the model predictive control is done within the building's own control system. But a building could also be controlled through MPC if the MPC is done at a higher level – for instance if the building is linked to a cloud based control system, where MPC works as a high-level controller, giving setpoints and signals to existing low-level controllers in the building. For instance, the MPC could give temperature setpoints to shunt-valves that control the supply temperature to the radiators, or room temperature setpoints for thermostat-controlled valves.

Even though there is a potential for flexibility, there are two main barriers for unlocking this potential: 1) there are few marketplaces or DR programmes available for building owners in Norway (cf. Table 1 and

Table 2) , and 2) most service buildings lack the technical infrastructure needed to unlock the potential. As there is currently no legal requirement for buildings to be flexibility ready<sup>3</sup>, economics is most important incentive for building owners. Service buildings require sophisticated control systems to release the flexibility potential in the heating, ventilation, and electrical systems, and this is expensive. By this – we mean open control system which have the possibilities for integrating with third party systems through APIs. The control system and sales of flexibility must be profitable for the for the user, where the investments, loss of thermal comfort and inconvenience is sufficiently compensated. The cost for the required upgrades is unknown. This means there is not a standard price or solution for making a building ready for offering flexibility services to the grid. Depending on the technological system in the building today, and the desired functions/flexibility services, the price depends on the numbers of new sensors and the reprogramming of the control system. Reprogramming will also be needed as the control systems are programmed to detect errors and to activate functions when any value is outside the setpoints, to ensure the systems are coupled without causing any more errors. To increase the smartness levels in new/renovated buildings, the decisions about investment for the desired smartness level should be decided early in the planning phase of the project to include it in the requirement analysis before a contractor is chosen. In older buildings with smartness Level 0 or lower, the price might be a lot higher, and the functions available are more limited as they have no or less sophisticated control systems.

## 6. Discussion and further research

The purpose of this case study was to 1) study if and to quantify how much service buildings can reduce their peak loads during the Norwegian peak load hour based on actual measured electricity consumption data, and 2) examine what is needed to unlock this potential. As the number of buildings with measurements separated on energy purposes was limited (N=8), and did not meet the requirement list for making a representative sample of service buildings (Section 3.3), it has not been possible to quantify the aggregate potential for service buildings to reduce their peak loads. However, the few buildings studied in this case study suggest that there is a potential for reducing peak loads in the investigated buildings, but that there are several barriers linked to unlocking this potential.

Buildings registered within the control and surveillance system GK Cloud and the energy management system GK E-sight have been the focus of this ZEN Case. There was limited access to energy meters for different energy purposes of the case studies in this analysis. The main purpose of GK Cloud and E-sight is to detect errors and secure a comfortable indoor climate. Due to this, a building linked to GK Cloud may have several energy meters installed within the building, but these energy meters are not necessarily available within the cloud system. Another issue is that the energy meters are not logged and stored at regular time intervals – making it challenging to make an analysis of hourly energy use.

The case study analysis in this report has been limited to a qualitative review on the possibility for reducing the energy consumption in the case study buildings on the 31<sup>st</sup> of January 2019 during the hours 07:00-09:00 and 16:00-18:00 when the peak load hours for electricity consumption in Norway in 2019 occurred. However, these hours do not necessarily represent the hours with the highest demand for flexibility services. The peak load of the different price areas or local areas do not all

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<sup>3</sup> Although a smart readiness indicator in the EPBD is in the making, it is uncertain whether this will improve the energy flexibility of buildings.

necessary occur during these hours or even on this date. Due to i.e. local variations in weather, mix of end-use sectors or bottlenecks in the grid, the need for flexibility may occur at completely different times in the local distribution grid than in the high voltage transmission grid. When dimensioning the grid, the outdoor temperatures of particularly cold years are considered, and although 2019 had a high consumption nationally compared to the past 5 years, this is not true for all regions, or in all areas of the distribution grid.

This study has focused on hourly electricity consumption, but the peaks in electricity demand may vary greatly within each hour, which may affect the dimensioning electric load of the grid.

### **6.1 Further research on how to estimate the flexibility potential in buildings**

To make a more quantified analysis of the flexibility potential in Norwegian service buildings, more research is needed, both with regards to gathering data measurements divided on energy purposes, and how the peak load of grid can be alleviated by service buildings. With regards to the latter, there is both need for more research on the quantification of the flexibility potential, and how to overcome the barriers to unlock it.

Several studies have created models for estimating the flexibility potential of service buildings [12], [19]. An extended study with the focus on estimating the potential from measurements in buildings could be a valuable supplement to these models as there is often a mismatch between measured and simulated energy use. An extended study on the flexibility from energy use measurements should examine the energy measurements from an energy management system with a bigger portfolio of buildings where the building energy use for different energy purposes is logged.

Analysing the flexibility potential at the hour of the national peak load is a simplified method. In addition to identifying the flexibility potential of the buildings at the peak load hour in Norway, it would also be valuable to identify the flexibility potential of the buildings during the peak load hour of the local distribution grid.

## **7. Conclusion**

The purpose of this case study was to examine 1) if and quantify how much service buildings can reduce their peak loads during the Norwegian peak load hour based on actual measured electricity consumption data, and 2) examine what is needed to unlock this potential.

The work is based on detailed building measurements from GK Cloud and GK E-sight. The intention was to study at least ten buildings with the requirements listed in Chapter 3.3, with a variety of offices, shops/malls and school buildings. Due to a limited number of buildings that met the requirements, especially regarding energy measurements divided on energy purposes, only eight buildings were investigated: 2 office buildings, 1 school, 3 storage buildings and 1 sports hall. As these buildings do not meet the requirements of representativeness of the non-residential building stock in Norway (office, shops/malls and schools), it has not been possible to quantify the potential for service buildings on a national level.

However, the analysis of the eight buildings studied suggest that there is a potential in reducing the building loads during the peak load hours. In the 4 buildings with electric heating, the share is at least

28 % at 8 hrs, 16- 20 % at 9 to 10 hrs and at least 17-24 % at 16-20 hrs. The share is somewhat lower at the remaining buildings due to few possible flexibility resources being known in these buildings. The results show a large flexibility potential in the buildings with detailed energy measurements. This suggests that there may also be a flexibility potential in all of case studies, but there are several barriers linked to unlocking this potential.

To evaluate the smartness level of the non-residential buildings, GK Cloud's database was used as a proxy for the non-residential building stock. Based on GKs database, the new or newly renovated buildings show a smartness level of 0 or 1 (cf. Table 3 in Chapter 2.3), indicating that they have an automatic control system installed for comfort purposes, however they do not have an optimisation algorithm to operate the buildings in a smart and energy flexible way. Although the available information of the older buildings is scarce, they are expected to have a smartness level that is below 0, indicating that advanced control systems are not present in these buildings. Hence, the cost associated with upgrading the buildings to higher smartness levels will be higher for old buildings than newer buildings. This suggests that of none the buildings studied in this report are currently at a building automation level where flexibility can be sold and/or utilized, although all of them are new or newly renovated buildings. To release the flexibility potential in a building at the peak load hour, the building and its technical systems needs to have a technical infrastructure that makes it possible for the building to respond to its surroundings and signals from the grid, and respond to signals based on model predictive control (MPC). This study has showed that even fewer buildings than expected have the necessary smartness level and large investments are required to release the full flexibility potential. The control system and sales of flexibility must be profitable for the user, where the investments, loss of thermal comfort and inconvenience is sufficiently compensated.

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