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RUGGEDISED
Designing smart, resilient cities for all

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Executive summary

RUGGEDISED is a smart city project funded under the European Union's Horizon 2020 program. Several subprojects are performed in the cities of Umeå, Glasgow and Rotterdam. This report describes the RUGGEDISED smart city solution U9 in Umeå that is focused on developing a demand side management analysis tool to be used for the buildings of Umeå University. The university was established in 1965, and this area is now the main campus for two universities with research facilities, along with the regional hospital, serving all northern Sweden´s 876 000 inhabitants. All in all, with recreational and commercial buildings there are approx. 40 000 daily visitors in the University City area. The two largest property owners in the area are Västerbotten County Council (VCC) who manage the hospital buildings (350 000 m^2) and Akademiska Hus AB (AHAB) who manage the university buildings.

Umeå University faces the challenge to be able to meet a growing number of student and staff, without constructing or buying new properties and thereby increasing the resource use and demand for building-related energy. This project aims to develop an analysis tool on energy consumption and demand side management with the primary objectives:

- Mapping the utilization of buildings and flows of people and study how the occupancy correlates to indoor CO_2-levels, humidity, temperature, light, heating and electricity use (indoor climate)
- Study differences between conventional and smart HVAC systems in both north- and south-faced rooms
- Verify the occupancy in bookable lecture halls and study rooms
- Investigate possibilities to optimize the energy usage, technical and cleaning services as well as improve safety and security
- Integrate different monitoring and control systems to one platform in order to do more complex analyses and thereby improve the energy efficiency and facility usage beyond the existing systems.

The purpose of the analysis tool is to collect and aggregate data to visualize utilization of facilities, energy use and parameters detecting indoor comfort and heat supply as they are today and provide a basis for optimization potential through demand side management and further studies.

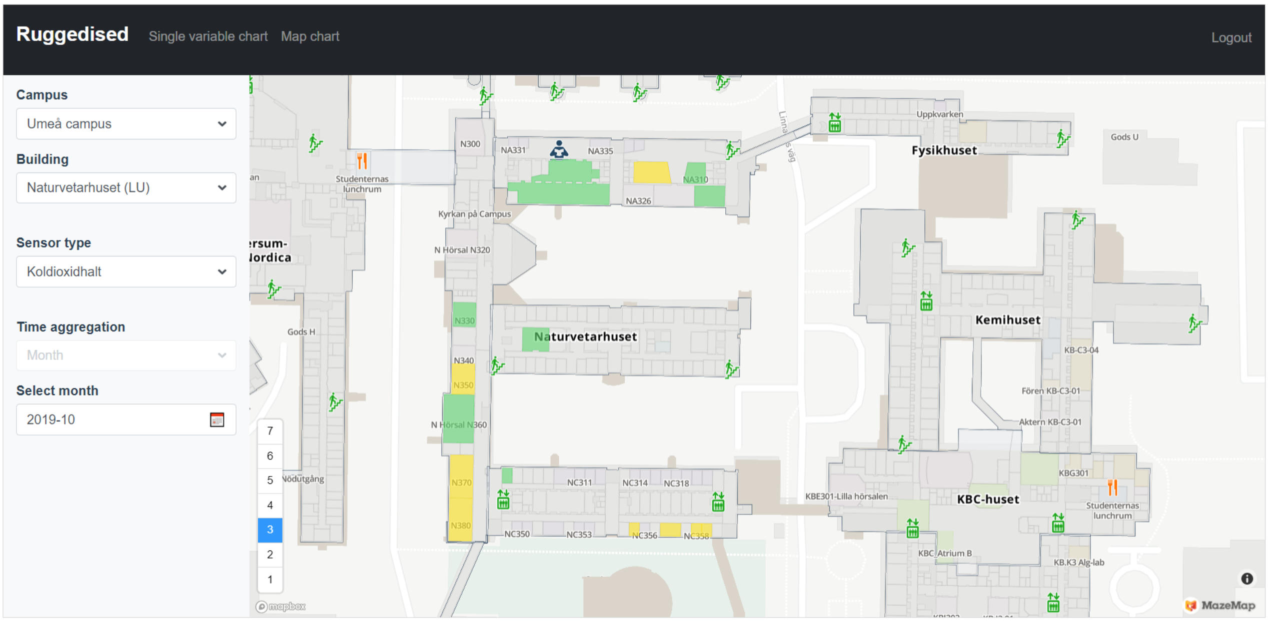
The Natural Sciences Building (Naturvetarhuset) was chosen as a study object for the pilot in order to develop the demand side management analysis tool. This building was already largely equipped with smart HVAC systems (Lindinvent) which would simplify the project preparations. In rooms without Lindinvent, where conventional HVAC systems are being used, sensors (LoRa) were installed. The investigation was conducted in offices, lecture halls, study rooms and long corridors with temporary workplaces.

To create the analysis tool, several data sources were installed and connected to one platform. The sources for the platform was the Lindinspect database that collects and stores data from Lindinvent sensors, along with a database that collects and stores data from LoRa sensors. The booking system TimeEdit was also included, as it contains information about what times rooms are booked. Additionally, maps from the indoor navigation system MazeMap was used as a basis for visual presentation of the results. Weather data was collected from the on-campus weather station at the department of Applied Physics and Electronics (TFE). The input from different sources could then be processed and converted into five key quality indicators to support the evaluation of the potential for energy use reduction and working environment improvements at the university.

Quality indicator	Scope	Purpose
Utilization	Comparing the actual hours (rooms were used with a desirable number of hours of use per day)and cross check of actual use of rooms with scheduled bookings	Optimize energy efficiency, scheduled bookings, service and off-peak management
Indoor climate	Monitoring indoor temperature and CO_2 levels to ensure that both parameters meet the regulation requirements of the Swedish Work Environment Authority regulation, *AFS 2009:2*	Ensure a good indoor climate by monitoring CO_2 and indoor temperature. Optimize energy use during occupancy and peak-off
Unnecessary electricity use	Monitor electricity load during non-occupancy	Optimize electricity use during peak-off and keeping the electricity as low as possible
Heat supply	Estimate supplied space heat and indoor temperature and compare results with a predictive model based on historical data	Optimize use of energy for space heating.
Noise level	Monitor noise levels in corridors and lecture halls	Map noise levels to find out if the rooms and corridors should be designed differently.

Early results

The figure below shows an example of a screenshot from the demand side management analysis tool, visualizing CO_2-levels during October 2019 on floor 3 in the Natural sciences building. Monitored rooms are highlighted in green, yellow or red illustrating the CO_2 level. Green indicates a CO_2 level under 500 ppm, yellow 500-1000 ppm and red over 1000 ppm.



CO_2 level on the third floor in the Natural sciences building during October 2019, presented in the analysis tool.

The data collected and processed in the analysis tool has been used to visualize energy use and actual indicators related to the activities of the occupants. The results provide a basis for optimization potential through demand side management as well as further studies. The tool will also be used for monitoring the effect of changes in demand side management on energy use and utilization. Multivariate analysis KPIs have been used to gain an in-depth understanding of both the buildings energy systems, but also the correlation between occupancy and other parameters. The early results from the analysis are:

- Occupancy is rarely greater than 70 % in offices and 40 - 50 % in lecture halls and study rooms
- The monitored parameters are more correlated for the north-faced offices than south-faced offices, since the latter are more affected by solar radiation
- The CO_2 level in offices is affected by the CO_2 concentration of corridors

- Indoor parameters such as temperature and CO_2 are highly correlated to occupancy in lecture halls and seminar rooms (except light)
- Temperature control could be improved
- Conventional HVAC system perform comfort all day, thus there is energy saving potential at no occupancy and at non-working hours

The direct improvement in working methods is an increased focus on densification for the buildings in-use rather than a traditional focus on construction of new buildings. Additional expected improvements are:

- Optimized service for cleaning in response to the actual use
- More accurate bookings of lecture halls and seminar rooms, by making awareness of actual utilization
- The supplied space heat can be reduced outside of normal working hours and at non-occupancy
- Optimized energy use and utilization of facilities by using a modification of access permission and locking redundant lecture halls
- More accurate measurements methods of occupancy and indoor climate
- Sensitivity analysis of the demand-controlled energy systems by using the real-world data, to estimate a more precise and true energy efficiency potential that bases on real occupancy
- Energy savings in other University buildings in other cities and in facilities with similar energy systems in other regions

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1 Introduction

1.1 Background

RUGGEDISED is a smart city project funded under the European Union's Horizon 2020 research and innovation program. It brings together three lighthouse cities: Rotterdam, Glasgow and Umeå and three follower cities: Brno, Gdansk and Parma to test, implement and accelerate smart city solutions across Europe.

The three overall aims of RUGGEDISED are:

1. **Improving the quality of life of the citizens,** by offering the citizens a clean, safe, attractive, inclusive and affordable living environment.

2. **Reducing the environmental impacts of activities**, amongst others by achieving a significant reduction of CO_2 emissions, a major increase in the investment and usage of renewable energy sources and an increase in the deployment of electric vehicles, not only to reduce emissions, but also to enable smart grid balancing.

3. **Creating a stimulating environment for sustainable economic development,** by generating more sustainable jobs, stimulating community involvement in smart solutions and to boost start-up and existing companies to exploit the opportunities of the green digital economy and Internet of Things.

To achieve these aims, all three lighthouse cities of RUGGEDISED will demonstrate combinations of integrated smart solutions for energy and e-mobility and appropriate business models with the right incentives for stakeholders to invest and participate in a smart society. This report describes the work done in one of the nine Smart solution sub projects included in Umeå, called U9.

1.1.1 The University City area

Umeå is a city in Northern Sweden, located 600 km north of Stockholm. With 128 000 inhabitants it is the 11th largest city in Sweden. The climate of Umeå is subarctic, with short and fairly warm summers. Winters are lengthy and freezing but considering the latitude very mild due to the influence of the Gulf Stream.

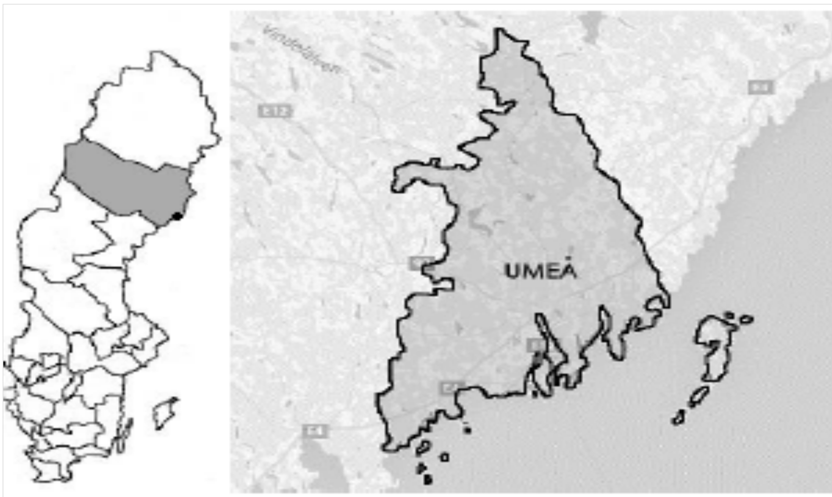

Figure 1. Umeå's location in Sweden and in the County of Västerbotten.

The unemployment rate is 5% and the employment rate of people between 20 to 64 years old is 76%. Umeå is a center of education and technical and medical research. The public sector (municipality, county council/hospital and Umeå University) is the main employer. The private sector in Umeå is quite diversified with IT, research based on biotechnology and forestry and the engineering industry well-represented. Six of Umeå's export companies have turnovers higher than 100 M€/year.

Within RUGGEDISED, Umeå will focus on the University City area situated immediately to the east of Umeå city center. The university was established in 1965, and this area is now the main campus for two universities with education and research facilities and the regional hospital, serving all northern Sweden´s 876 000 inhabitants. There are also apartment buildings with more than 1000 on-campus residents, and a sports center which is the largest training facility in Scandinavia. All in all, with recreational and commercial buildings there are approx. 40 000 daily visitors in the University City area. The area is shown in Figure 2.

Figure 2. The University City area with mainly university and hospital buildings.

The two largest property owners in the area is Västerbotten County Council (VCC) who manage the hospital buildings and Akademiska Hus AB (AHAB) who manage the university buildings.

1.2 The "RUGGEDISED building"

Several of the RUGGEDISED smart solutions in Umeå (U1-U9) relate to energy efficiency within, and connected to, buildings. This is illustrated by combining them in a picture of the "RUGGEDISED building", see Figure 3. The projects focus on energy savings and energy efficient solutions connected to building technology, e-charging and new business models to provide the university city with 100% renewable energy. The U9 project presented in this report has the focus area of demand side management and utilization of existing buildings.

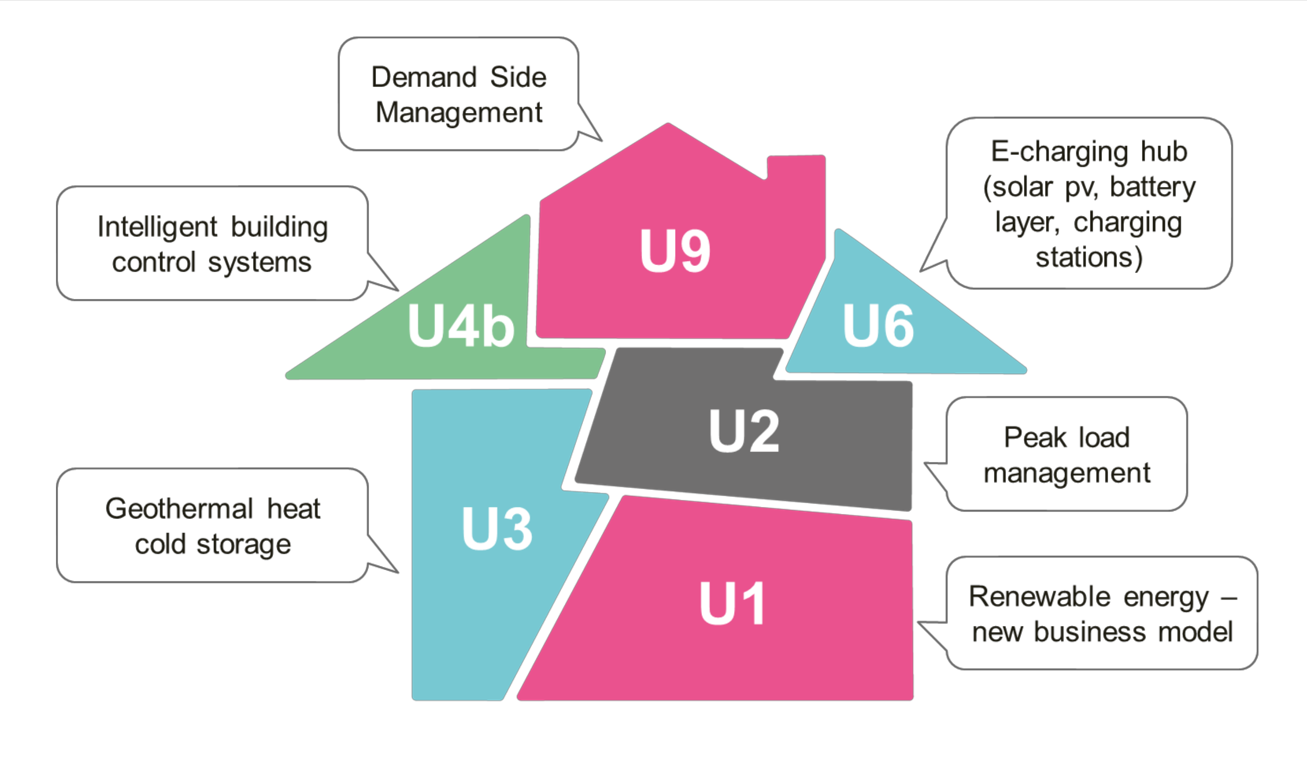

Figure 3. The RUGGEDISED building, a way of illustrating six of the RUGGEDISED smart City Solutions of Umeå

The projects in the "RUGGEDISED building" are all conducted in buildings on the campus area and complement each other with their different focus areas. The projects U2, U4b and U9 are most strongly connected as they all cover energy use in buildings. The scope of U2 is to reduce the peak load demand by using buildings as thermal energy storage and has a potential to reduce energy demand by 2-8%. The scope of U4b is to reduce energy use through intelligent building control, and Akademiska Hus AB will install automatic smart control equipment to control air volumes, room climate and lighting. The demand side management project, U9, takes the effects of U2 and U4b one step further, as it aims to streamline the utilization of space and possibly gather people in certain buildings at peak-off times, and thereby reduce energy demand even more. Other possible benefits with the U9 solution is improved cleaning schedules and gaining a higher sense of safety and security.

The scope of remaining projects U1, U3 and U6, is to supply the University city with 100% renewable energy, decrease total demand in the area by a decentralized energy market place, including distributed energy through geothermal heat/cold storage and testing smart solutions for e-charged vehicles, where charging stations are installed along with solar panels and energy storages.

1.3 Energy efficiency and sustainability in commercial buildings

For buildings in cold climate, such as in Umeå, the supplied heat can be reduced significantly by constructing airtight building envelopes with a low heat transfer coefficient and controlled ventilation with efficient heat recovery in ventilation units. The main objective is constructing buildings that in the best way minimize the heat losses through walls, roof, floor, windows and ventilation air. In a combination with efficient heating- and domestic hot water systems, as well as low-energy lighting- and electrical systems, the supply of heat and electricity can be minimized.

The building control system, connected to room sensors, can be integrated to make sure that added heat, air and electricity is synchronized with the demand side, i.e. the room is warm, and lights and ventilation systems are turned on only while rooms are being used. During summer, there are over temperatures due to large heat loads. As a consequence, the need for air conditioning increases. At such times the control parameters should switch from heating a room, to cooling through ventilation air or chilled beams.

Energy savings and thereby increased sustainability can also be achieved through other means than technical solutions. An important one is to make sure that existing buildings and rooms are being used as often as possible. If not, they are being heated, ventilated and lit unnecessarily. During off-peak times, it is efficient to use all the space in one building and then being able to close others, and thereby reducing energy use. Another aspect is making sure existing buildings are used to their full potential before constructing or buying additional properties that drive energy use and cost. To be able to keep track of the utilization of rooms, sensors that indicate occupancy can be installed.

Sensors that indicate occupancy can also be used to connect cleaning and waste management schedules with actual room use. A room that is not used will simply not be cleaned, which can lead to a reduced use of cleaning detergents, but also generate time and economic savings since unnecessary work will be avoided.

1.4 Facility usage and services

Umeå University´s under-utilized space together with some existing features for booking, logging and control gave the idea of combining these to steer utilization and energy use even more. The university faces a challenge to be able to meet a growing number of student and staff, without constructing or buying new properties.

The university facilities include lecture halls, offices, seminar rooms and corridors. Lecture halls and seminar rooms can be booked by lecturers and students through a booking system called TimeEdit. The university also has a digital map system with indoor navigation that shows the university's buildings and rooms, called MazeMap. Normal working and studying hours are 08:00-17:00 Monday – Friday.

The department of Applied Physics and Electronics (TFE) has a weather station at the campus that has operated since 1996 and is collecting data every 10 minutes and saving data every hour. The weather station measures and logs temperature, humidity, air pressure, wind speed, precipitation and insolation outside the TFE building.

The smart HVAC system Lindinvent is installed in some of the facilities at Umeå University. The concept of Lindinvent is that the air flow, heat supply and the lighting adjust depending on the degree of occupancy- both current and expected in the rooms. The occupancy-rate will be decisive for the total cooling effect and the heating power needed to maintain the desired indoor climate. Facilities without Lindinvent are equipped with conventional HVAC systems.

By using the above-mentioned systems and installations, a demand side management tool could be developed by Umeå University in cooperation with Akademiska Hus AB.

2 The Demand Side Management Analysis Tool

The Umeå University with its 250,000 m² of area, is most aware that floor space drives energy use. Developing a multivariate analysis tool for predictive analytics which will support the decision process concerning tenant area use is a most powerful way to reduce energy use by the end user. Based on predictions of actual flows of students and staff, the university can lower energy use during the hours when facilities are off-peak. Facility services such as cleaning of floors, technical standby and waste management traditionally operates on schedules and contracts but can also be optimized by using predictive analysis.

The initial idea was to estimate attendance and base the analysis tool on radio traffic from mobile devices, by assuming that the number of Wi-Fi connections are close to the actual number of people in the buildings. However, an early study showed a few non-negligible issues with this approach, and it was therefore decided to use sensors to estimate attendance instead.

The purpose of the analysis tool is to collect and aggregate data to visualize utilization of facilities, energy use and parameters such as indoor climate and heat supply as they are today and provide a basis for optimization potential through demand side management and further studies.

The Natural sciences building (Naturvetarhuset) was chosen as a study object for the pilot project of developing a demand side management analysis tool. This building was already fully equipped with Lindinvent systems, which would simplify the project preparations. In rooms without Lindinvent, where conventional HVAC systems are being used, LoRa sensors were installed. Offices, lecture halls, seminar rooms and long corridors with small groups of workplaces were included. In total, 529 Lindinvent devices and 450 LoRa sensors have been included in the project.

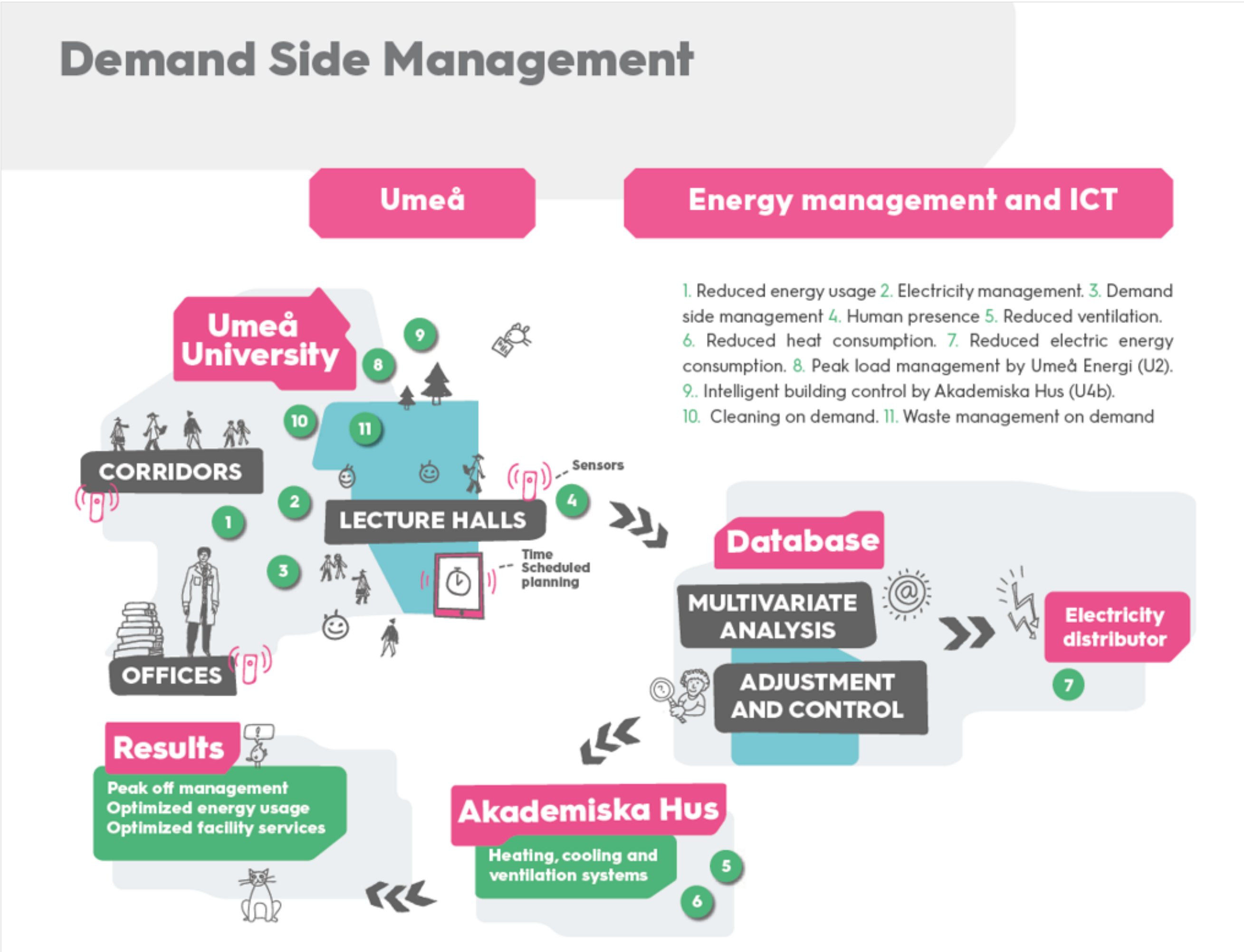

Figure 4. Visualization of the methodology with installed sensors at the university, multivariate analysis and resulting adjustments.

The scope of the project is to:

- Map the utilization of buildings and the flows of people
- Study how the occupancy is correlated to indoor climate (CO_2, humidity, temperature, light, heating and electricity use)
- Study differences between conventional and smart HVAC systems in both north- and south-faced rooms
- Verify the occupancy from the registered booking of lecture halls and seminar rooms
- Investigate possibilities to optimize the energy usage, technical and cleaning services as well as improve safety and security
- Integrate different monitoring and control systems to one platform in order to do more complex analyses and thereby improve the energy efficiency and facility usage beyond the existing systems.

2.1 Sources and sensors

In seminar rooms, lecture halls and corridors with conventional HVAC systems, LoRa sensors were installed. The sensors measure multiple parameters, and those used in the project are occupancy (PIR[1]), humidity, sound, temperature, CO_2, electric pulses (electricity use) and radiator heating. Measurements are uploaded and logged to a database, where data for each room can be extracted and used in the analysis tool.

The LoRa sensors are similar to Lindinvent sensors, although the Lindinvent sensors are built in in the supply air device and the LoRa sensors are installed in various places in the rooms. The Lindinvent system Lindinspect logs sensor data regarding occupancy, room temperature and CO_2 as well as supply and exhaust temperatures of ventilation air.

To create the demand side management analysis tool, a database with useful data was set up. The sources for the database was the Lindinspect database that collects and stores data from Lindinvent sensors, along with a database that collects and stores data from LoRa sensors. The booking system TimeEdit was also included, as it contains information about scheduled bookings. Maps from MazeMap was used as a basis for visual presentation. Weather data was collected from the on-campus weather station at the department of Applied Physics and Electronics, TFE.

The input from different sources could then be processed and converted into five key quality indicators to help evaluate the potential for energy reduction at the university. The analysis tool database and data processing were structured according to Figure 5.

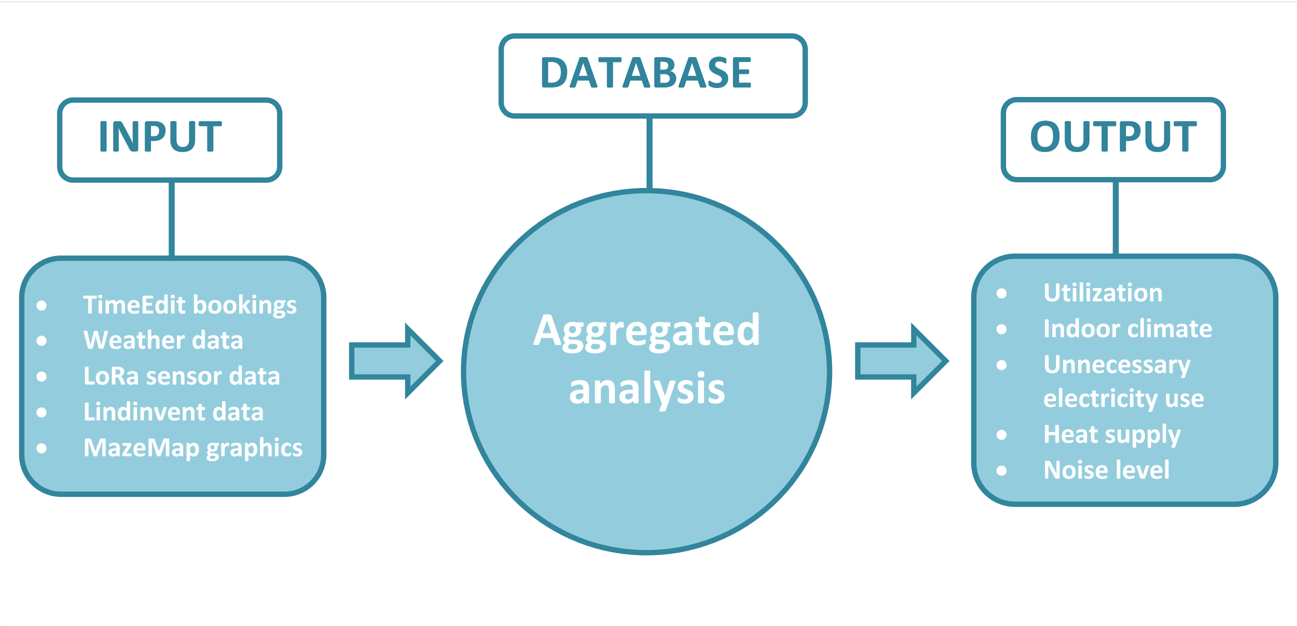

Figure 5. Flow chart of the analysis tools inputs and outputs

2.3 Quality indicators

The demand side management analysis tool is designed to present five key indicators; Utilization, Indoor climate, Unnecessary electricity use, Heat supply and Noise level. A description of each indicator is presented below. The tool will use a color system to indicate acceptance levels of the results, and below the desirable, acceptable and non-acceptable levels of all indicators are presented.

[1] PIR stands for Passive infrared sensor, a motion detector that gives an indicator of how much movement is detected per hour

2.3.1 Utilization

The use of offices, lecture halls and seminar rooms, and presence in corridors was summarized and evaluated with two different methods. The first method was to compare actual use of rooms, by using PIR-sensors, with a desirable number of hours of use per day, see Table 1. Corridors were evaluated based on detected motion from PIR-sensors. The second method was to cross check actual use of rooms with scheduled bookings. The combinations were evaluated according to Table 2.

Table 1. Evaluation criteria for office utilization and movement in corridors.

Hours of use, offices and lecture halls	> 6 h	Green	Good
	2-6 h	Yellow	Acceptable
	< 2 h	Red	Not acceptable
Real time use, offices and lecture halls	Used	Green	Good
	Not used	Red	Potential for improvement
Movement in corridors (PIR)	> 4/h	Green	Good
	1-4/h	Yellow	Acceptable
	< 1/h	Red	Not acceptable

Table 2. Evaluation criteria for cross-checking bookable rooms.

	Used	Not used
Booked	Scheduled (good)	Cancelled (Not acceptable)
Not booked	Spontaneous (acceptable)	Empty (utilization potential)

The aim of this indicator is to collect information on the number of hours the rooms are booked and used, and to what extent booked rooms are left unused. The utilization indicator was evaluated as presented in Table 3.

Table 3. Visualization factors for Utilization in the demand side management analysis tool.

Room type	Analysis	Evaluation	Parameters	Time	Sensor	Purpose
Offices (non-bookable)	Real time use 08-17 weekdays	Green/Red	Occupancy	Real time	LoRa/ Lindinvent	Optimize energy efficiency, service & facility use
	Hours of use 08-17 weekdays	Green/Yellow/ Red	Occupancy	Historic data	LoRa/ Lindinvent	Optimize energy efficiency, service & facility use
Lecture halls & seminar rooms (bookable)	Real time use 08-17 weekdays	Blue/Yellow	Occupancy	Real time	LoRa/ Lindinvent	Optimize energy efficiency, service & facility use
	Hours of use 08-17 weekdays	Blue/Green/ Yellow	Occupancy	Historic data	LoRa/ Lindinvent	Optimize energy efficiency, service & facility use
	Used/Booked 08-17 weekdays	Blue/Green/ yellow/Red	Occupancy Bookings	Real time	LoRa/ Lindinvent	Optimize energy efficiency, service & facility use
	Used/Booked 08-17 weekdays	Blue/Green/ yellow/Red	Occupancy Bookings	Historic data	LoRa/ Lindinvent	Optimize energy efficiency, service & facility use
Corridors	Movement (PIR) 00-24 all days	Green/Yellow/ Red	Occupancy	Real time	LoRa/ Lindinvent	Optimize service & peak-off management
	Movement (PIR) 00-24 all days	Green/Yellow/ Red	Occupancy	Historic data	LoRa/ Lindinvent	Optimize service & peak-off management

2.3.2 Indoor climate

The indoor climate in offices, lecture halls, seminar rooms and corridors were evaluated both during occupancy and while the rooms were empty. According to the Swedish Work Environment Authority regulation *AFS 2009:2*, the CO_2-level in these types of rooms should not durably exceed 1 000 ppm and the temperature shall not durably exceed 24°C in winter and 26°C in summer, nor drop below 20°C in either case while the room is being used. The outdoor air CO_2-level is normally 400 ppm.

The indoor temperature and CO_2-level are evaluated both individually but also combined. Both parameters should meet the regulation requirements at the same time for the indoor climate in order to be considered "good". The evaluation levels are presented in colors depending on the level of acceptance during occupancy, as presented in Table 4.

Table 4. Evaluation criteria for CO_2 and Temperature while rooms are occupied

CO_2-level	< 500 ppm	**Green**	Good
	500-1000 ppm	**Yellow**	Acceptable
	> 1000 ppm	**Red**	Not acceptable
Indoor Temperature	20-24°C	**Green**	Good
	19-20 or 24-25°C	**Yellow**	Acceptable
	< 19 or >25°C	**Red**	Not acceptable
Indoor climate (CO_2 & Temperature)	< 500 ppm & 20-24°C	**Green**	Good
	500-1000 ppm and/or 19-20, 24-25°C	**Yellow**	Acceptable
	> 1000 ppm and/or <19, >25°C	**Red**	Not acceptable

The indoor climate indicator was evaluated as presented in Table 5.

Table 5. Visualization factors for Indoor climate in the demand side management analysis tool

Room type	Analysis	Evaluation	Parameters	Time	Sensor	Purpose
Offices	Indoor climate (CO_2-level & temp)	Green/ yellow/red	Occupancy Temp CO_2	Real time & Historic data	LoRa/ Lindinvent	Ensure a good indoor climate & optimize energy use during occupancy and peak-off
	CO_2-level	Green/ yellow/red	Occupancy CO_2	Real time & Historic data	LoRa/ Lindinvent	Monitor CO_2 over time to ensure a good indoor climate
	Temperature	Green/ yellow/red	Occupancy Temp	Real time & Historic data	LoRa/ Lindinvent	Monitor the temperature over time to ensure a good indoor climate
Lecture halls & seminar rooms	Indoor climate (CO_2-level & temp)	Green/ yellow/red	Occupancy Temp CO_2	Real time & Historic data	LoRa/ Lindinvent	Ensure a good indoor climate & optimize energy use during occupancy and peak-off
	CO_2-level	Green/ yellow/red	Occupancy CO_2	Real time & Historic data	LoRa/ Lindinvent	Monitor CO_2 over time to ensure a good indoor climate
	Temperature	Green/ yellow/red	Occupancy Temp	Real time & Historic data	LoRa/ Lindinvent	Monitor the temperature over time to ensure a good indoor climate
Corridors	Temperature	Green/ yellow/red	Occupancy Temp	Real time & Historic data	LoRa/ Lindinvent	Ensure a good indoor climate & optimize energy use during occupancy and peak-off

2.3.3 Unnecessary electricity use

With the purpose of optimizing electricity use during peak-off and keeping it as low as possible, the use of electricity when rooms are not being used was evaluated. The evaluation levels are presented in colors depending on the level of acceptance during non-occupancy, as presented in Table 6.

Table 6. Evaluation criteria for unnecessary electricity use

Electrical power when empty	0-10 Watt	**Green**	Good
	10-100 Watt	**Yellow**	Acceptable
	> 100 Watt	**Red**	Not acceptable

The unnecessary electricity use was evaluated as presented in Table 7.

Table 7. Visualization factors for unnecessary electricity use in the demand side management analysis tool

Room type	Analysis	Evaluation	Parameters	Time	Sensor	Purpose
Offices	Electrical power when empty	Green/ yellow/red	Occupancy Electric pulse	Real time & Historic data	LoRa/ Lindinvent	Optimize electricity use during peak-off
Lecture halls & seminar rooms	Electrical power when empty	Green/ yellow/red	Occupancy Electric pulse	Real time & Historic data	LoRa/ Lindinvent	Optimize electricity use during peak-off

2.3.4 Heat supply

To investigate possibilities to optimize the energy use further, the supplied space heat is studied through the demand side management analysis tool. The supplied space heat is monitored based on the indoor temperature, T_{In}, and the radiator temperature, T_{Rad}. It is compared to a predicted radiator temperature, $T_{Rad, predicted}$. The model for $T_{Rad, predicted}$ is based on a linear regression of historical data for T_{Rad} and the outdoor temperature. The idea is to monitor if the actual radiator temperature exceeds historical radiator temperatures at a certain outdoor temperature, as the supply temperature to the radiator increases with lower outdoor temperatures. The evaluation criteria are presented in colors depending on the level of acceptance in Table 8.

Table 8. Evaluation criteria for heat supply

Indoor temperature & Radiator temperature	T_{In}< 21°C and T_{Rad} < 0,9*$T_{Rad, predicted}$	**Green**	Good
	T_{In} = 21-22,5°C and 0,9* $T_{Rad, predicted}$ ≤ T_{Rad} ≤ 1,0* $T_{Rad, predicted}$	**Yellow**	Acceptable
	T_{In} > 22,5°C and T_{Rad} > $T_{Rad, predicted}$	**Red**	Not acceptable

The heat supply indicator was evaluated as presented in Table 9.

Table 9. Visualization factors for Heat supply in the demand side management analysis tool

Room type	Analysis	Evaluation	Parameters	Time	Sensor	Purpose
Offices	Supplied heat at given outdoor temperature	Green/ yellow/red	Indoor temp Outdoor temp Delta T_{Rad}[2]	Real time & Historic data	LoRa/ Lindinvent TFE weather	Optimize energy use during use and peak-off
Lecture halls & seminar rooms	Supplied heat at given outdoor temperature	Green/ yellow/red	Indoor temp Outdoor temp Delta T_{Rad}	Real time & Historic data	LoRa/ Lindinvent TFE weather	Optimize energy use, and during peak-off possibly "close" lecture halls and seminar rooms.

[2] Delta T_{Rad} is the temperature difference between the inlet and outlet temperature of a radiator

2.3.5 Noise level

Noise can be a major problem on the work environment, being disruptive and tiring and in the worst-case cause persistent hearing problems. It can contribute to mental strain and disturb the concentration, having a negative effect on the quality of work. According to the Swedish Work Environment Authority regulation *AFS 2005:16*, actions should be taken when the daily level exceeds 80 dB. Furthermore, 40 dB corresponds to an environment that meets average requirements for secure speech intelligibility up close, also for hearing impaired and elderly listeners as well as in communication in languages that are not the listener's native language.

In order to map noise levels, sound measuring LoRa sensors were used in lecture halls and corridors. The evaluation levels for noise is presented in Table 10.

Table 10. Evaluation criteria for noise level

Noise level	< 40 dB	**Green**	Good
	40-80 dB	**Yellow**	Acceptable
	> 80 dB	**Red**	Not acceptable

The noise level indicator was evaluated as presented in Table 11.

Table 11. Visualization factors for Noise level in the demand side management analysis tool

Room type	Analysis	Evaluation	Parameters	Time	Sensor	Purpose
Lecture halls	Noise during occupancy	Green/ yellow/red	Occupancy Average noise level	Real time & Historic data	LoRa	Mapping noise
Corridors	Noise during occupancy	Green/ yellow/red	Occupancy Average noise level	Real time & Historic data	LoRa	Mapping noise

2.4 Analysis tool

The demand side management analysis tool can be used to display results from the quality indicators, in real time or for historic data. A building and floor level, single room or a room type are chosen, along with a single variable or quality indicator and the desired time interval. The results can be visualized as a graph or on a map chart. Screenshots from the analysis tool is presented in this chapter, with examples from the 5 quality indicators.

Figure 7 shows a screenshot visualizing utilization of bookable lecture halls during January and February 2020 on floor 3 in the Natural sciences building. Studied rooms are highlighted in blue, green, yellow and red, where blue indicates that the rooms is booked and occupied, green that the rooms are spontaneously occupied, yellow that they are booked but cancelled and red that they are empty during the workday (8-17).

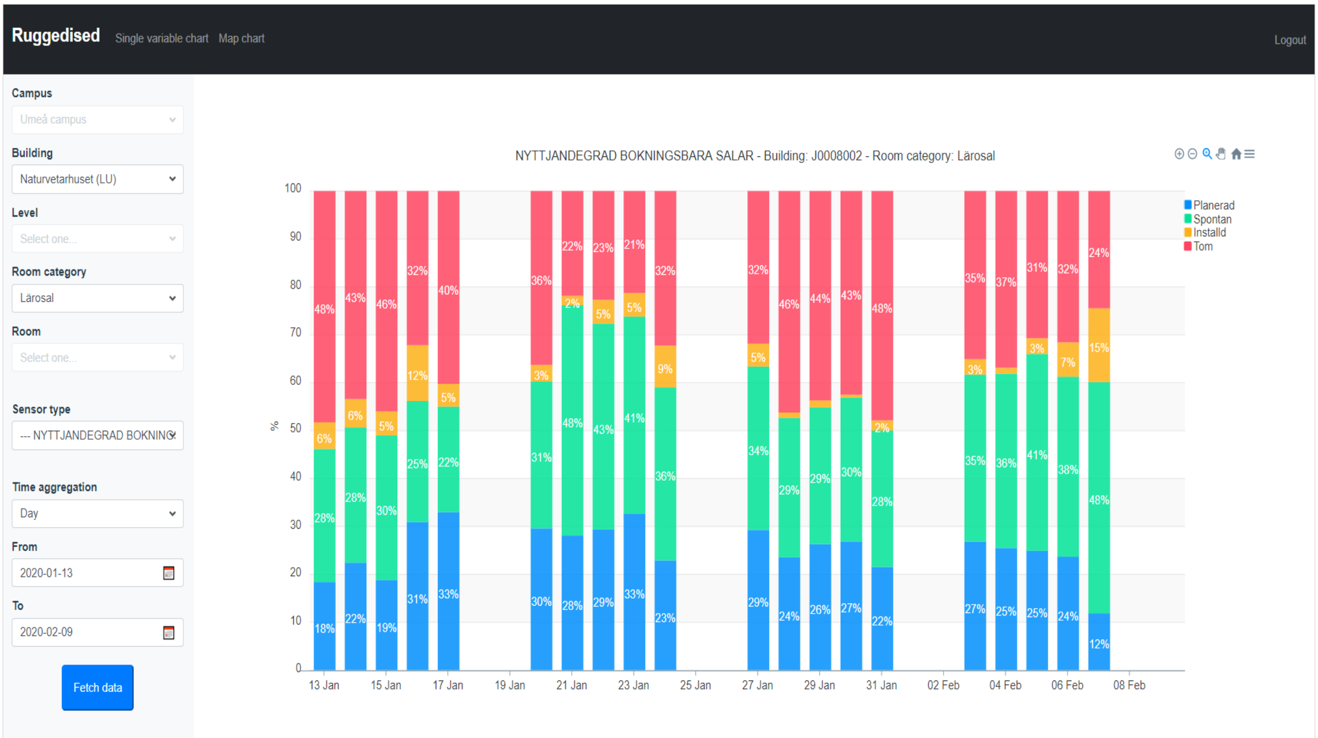

Figure 6. Utilization of bookable lecture halls during normal working/studying hours of the Natural sciences building from the 13th of January to the 9th of February 2020.

Figure 7 shows a screenshot visualizing a single variable, occupancy, in offices and seminar rooms during January 2020 on floor 3 in the Natural sciences building. Studied rooms are highlighted in green, yellow and red, where green indicates that the rooms is occupied more than 6 hours per day, yellow 2-6 hours and red less than 2 hours.

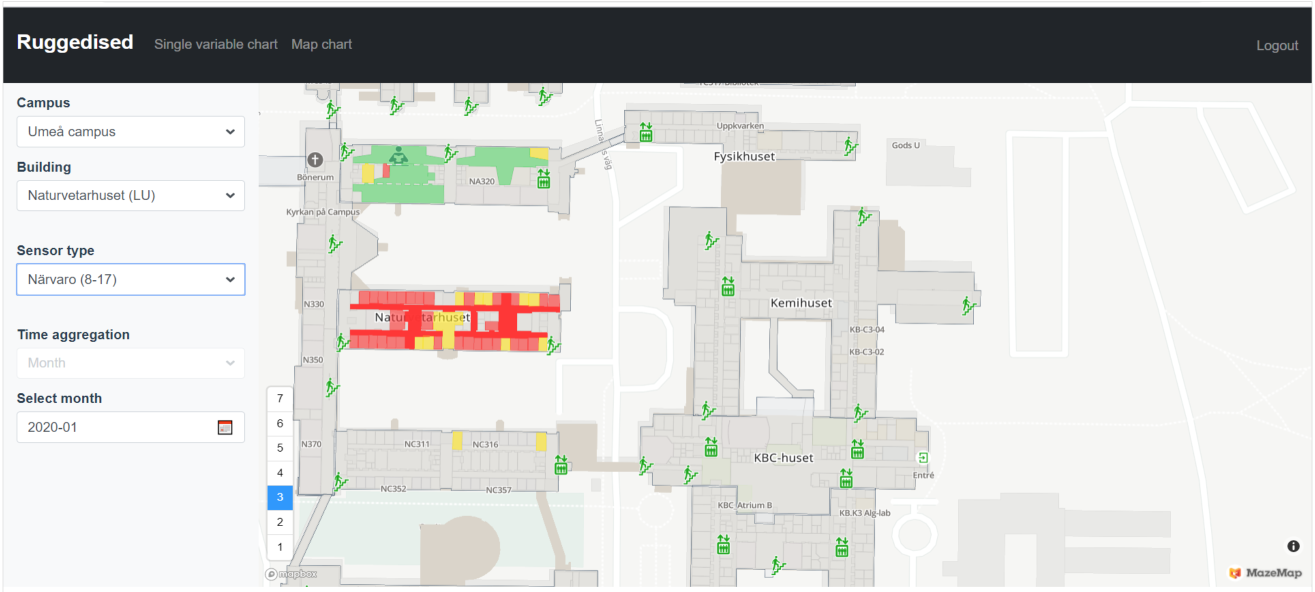

Figure 7. Utilization during normal working/studying hours on the third floor of the Natural sciences building during January 2020.

Figure 8 shows another screenshot, visualizing the single variable CO_2-level from October 2019 on floor 3 in the Natural sciences building. Rooms with CO_2 sensors included in the analysis tool are highlighted in green, yellow or red depending on the CO_2-level. Green indicates a CO_2-level under 500 ppm, yellow 500-1000 ppm and red over 1000 ppm.

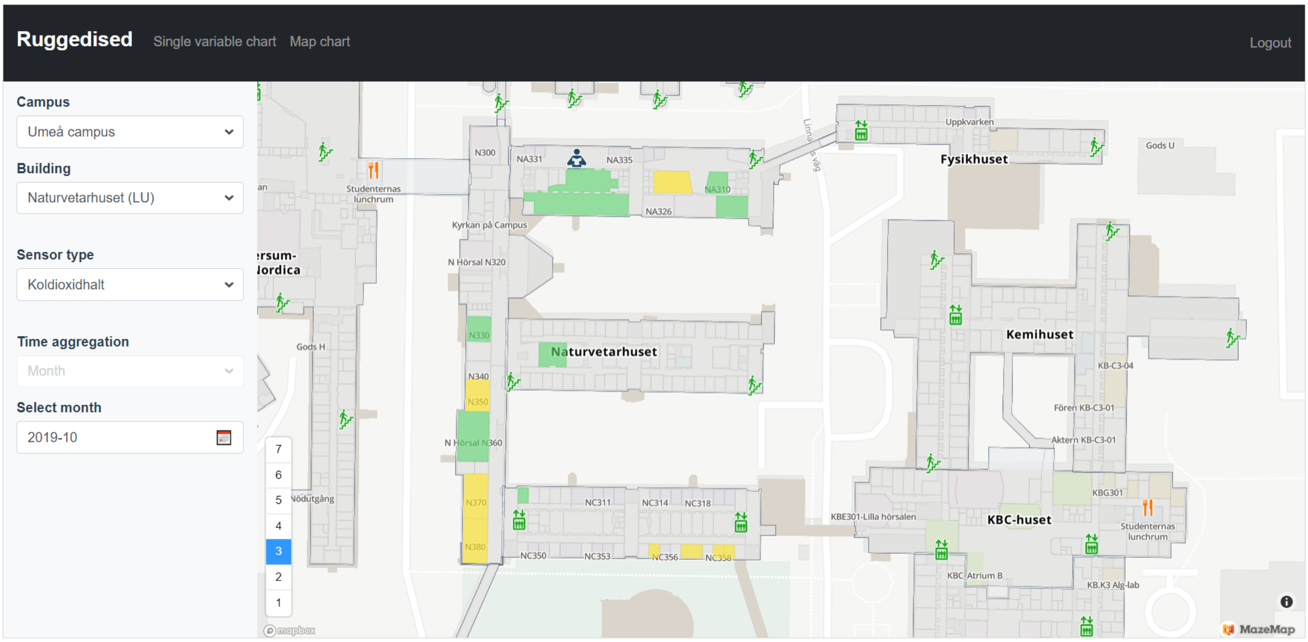

Figure 8. CO2 level on the third floor in the Natural sciences building during October 2019, presented in the analysis tool as a map chart.

The CO_2-level can also be presented in a graph. In Figure 9 the actual CO_2-level in parts per million is presented for lecture halls during a week in December 2019. The time aggregation is 10 minutes and the yellow line shows the limit for when the CO_2-level goes from good to acceptable.

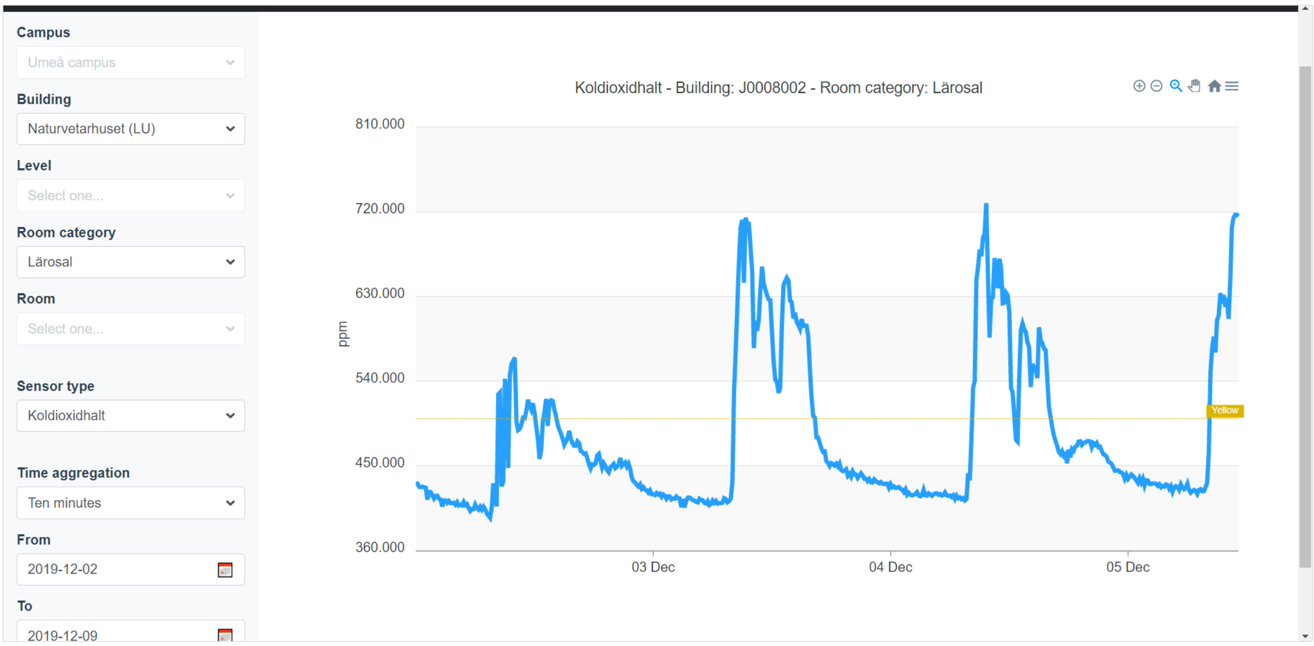

Figure 9. The blue line shows CO2 levels (ppm) in lecture halls during a week in December 2019.

The indoor climate is evaluated as a combination of CO_2-level and temperature. Figure 10 presents the indoor climate in an office during three days in February 2020. Green indicates a good indoor climate, yellow indicates an acceptable indoor climate with a smaller deviation in CO_2-level or temperature. Red indicates a non-acceptable indoor climate in accordance with the Swedish Work Environment Authority regulation *AFS 2009:2*.

Figure 10. Indoor climate, i.e. temperature and CO2-level, in lecture halls between the 13th of January and 9th of February 2020.

Figure 11 shows a screenshot of electricity use in an office during January 2020. The blue line shows electricity use in watts. The red line indicates the evaluation criteria that the electricity use during non-occupancy is over 100 watts and the yellow line indicates the evaluation criteria that electricity use is over 10 watts. The figure shows that electricity use is high even during non-office hours.

The electricity use in a selected number of offices will be monitored to establish a baseline for electricity uses in typical offices with and without occupants. This information will be an input to the tool which provides a more representative view of the scenario.

Figure 11. Electricity use (watt) in an office between 7th of January and 9th of February 2020.

The quality indicator Heat supply evaluates added heat in a room compared to a theoretical model based on historical data, in a combination with the actual indoor temperature. Figure 12 visualizes the heat supply in a room with the smart HVAC system Lindinvent, and Figure 13 a room with a conventional fixed flow HVAC system. Green bars indicate a low heat supply while keeping the room temperature under a desired level, yellow bars show that heat supply and indoor temperature are acceptable with a smaller deviation, and red bars indicate a non-acceptable heat supply.

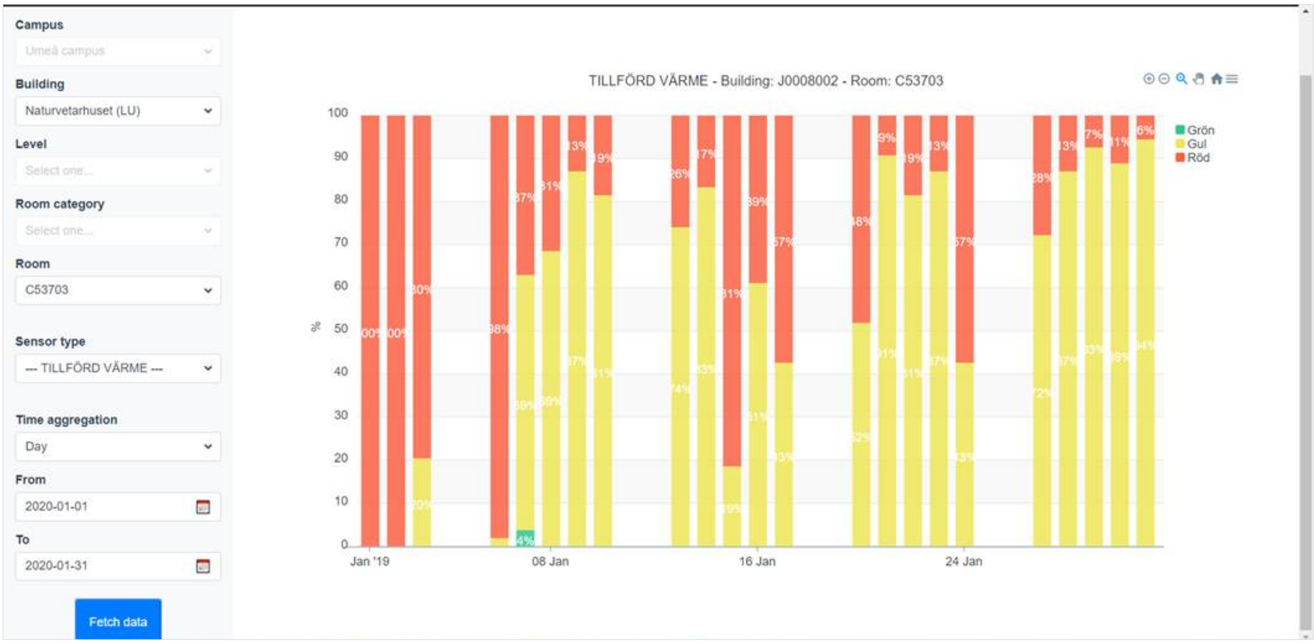

Figure 12. Heat supply in an office with variable air supply through Lindinvent, during January 2020.

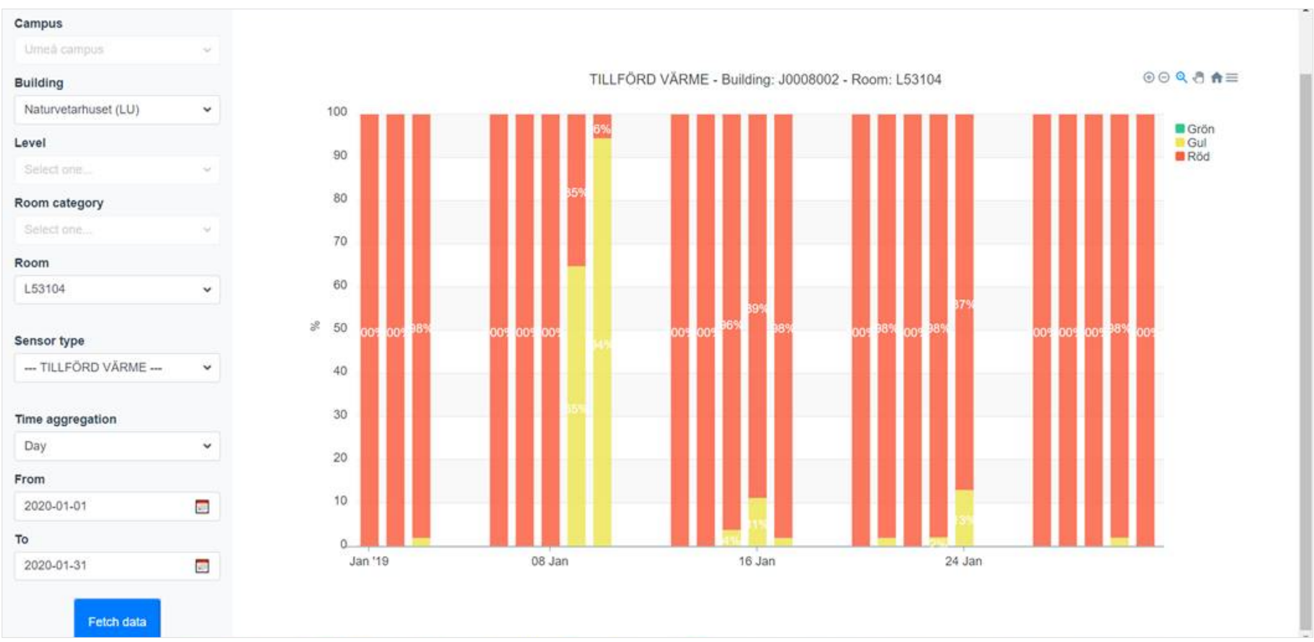

Figure 13. Heat supply in an office with a conventional HVAC system, during January 2020.

Figure 14 shows a screenshot of the average noise level in lecture halls during January 2020. The blue line shows the noise level in dB. The yellow line indicates the evaluation criteria level where the noise goes from good to acceptable.

Figure 14. Average noise level in lecture halls during January 2020 with the time aggregation one day.

3 KPIs for follow up

Beside the quality indicators in the analysis tool some other KPIs will be used to strengthen the follow up and to show and measure possible interventions.

3.1.1 Utilization

Intensity of space use: This KPI can reveal space efficiency by interventions such as limiting access or closing down redundant lecture rooms. It can be measured by "percentage of booked-occupied status to total available time" in the lecture rooms.

Accuracy of occupancy detection: This KPI can be measured considering different sensor installation aspects. Higher values for this KPI show the efficiency of occupancy detection and thus the efficiency of demand-controlled energy system. This KPI can be measured by "percentage of correct detection to total detected instances".

3.1.2 Indoor climate

Correlation of occupancy with CO_2 concentration: As CO_2 concentration in built environments rises with presence of occupants, the ventilation systems are responsible to mitigate the change. This KPI indicates indoor air quality in the investigated areas. Stronger correlation between CO_2 concentration and occupancy can indicate a relatively lower air quality and/or an inefficient ventilation system.

3.1.3 Unnecessary electricity use

Correlation of occupancy with electricity load: Electricity load is mainly related to lighting and appliances which are supposed to operate during presence of occupants. This KPI can be measured in offices and lecture rooms and indicates the efficiency of electricity use. Stronger correlation can indicate unnecessary use of electricity is relatively less during the time that occupants are not present.

3.1.4 Space heat supply

Correlation of occupancy with temperature: The space heat supplied to the built environment is supposed to maintain a desirable temperature required for comfort of occupants. The temperature can be lowered during times when occupants are not present, in order to reduce the space heat demand. This KPI can be measured in offices to show the efficiency of heat use. Stronger correlation indicates that the heat supply is relatively less during the time without presence of occupants.

Heat use in offices: This KPI can reveal the energy efficiency by replacing the conventional building control with demand-controlled heating and ventilation. The KPI can be measured in kWh/m^2.yr.

3.1.5 Noise level

Detection of noise levels: Noise level is measured by sound sensors. For every 5 minutes period, an average of noise level in dBA is calculated. Additionally, the peak level is registered in dBA for every 5 minutes period. The KPI can be defined as maximum 40 dBA as average for the 5 min period and maximum 80 dBA as peak noise level.

4 Early results

The data collected and processed in the analysis tool has been used to visualize energy use and actual indicators related to the activities of the occupants. The results provide a basis for optimization potential through demand side management as well as further studies. The tool will also be used for monitoring the effect of changes in demand side management on energy use and utilization. Multivariate analysis KPIs have been used to gain an in-depth understanding of both the buildings energy systems, but also the correlation between occupancy and other parameters. The early results from the analysis are:

- Occupancy is rarely greater than 70 % in offices and 40 - 50 % in lecture halls and study rooms
- The monitored parameters are more correlated for the north-faced offices than south-faced offices, since the latter are more affected by solar radiation
- The CO_2 level in offices is affected by the CO_2 concentration of corridors
- Indoor parameters such as temperature and CO_2 are highly correlated to occupancy in lecture halls and seminar rooms (except light)
- Temperature control could be improved
- Conventional HVAC system perform comfort all day, thus there is energy saving potential at no occupancy and at non-working hours

The direct improvement in working methods is an increased focus on densification for the buildings in-use rather than a traditional focus on construction of new buildings. Additional expected improvements are:

- Optimized service for cleaning in response to the actual use
- More accurate bookings of lecture halls and seminar rooms, by making awareness of actual utilization
- The supplied space heat can be reduced outside of normal working hours and at non-occupancy
- Optimized energy use and utilization of facilities by using a modification of access permission and locking redundant lecture halls and seminar rooms. In the future even locking buildings could be an option during nights, weekends and vacations.

4.1.1 Utilization

As part of the quality indicator Utilization, the room bookings in TimeEdit were compared with actual use of rooms. The results show that for a third of the week, seminar rooms remain unused even when they are booked. Spontaneous use occurs 5% of the time, and scheduled use amounts to 42%, see Figure 15.

Figure 15 also shows that lecture halls that are not booked remain unused during 51% of normal working and studying hours, and scheduled use amounts to 20%. For 15% of the weekdays, lecture halls remain unused even though they are booked, and halls are used spontaneously 14% of the week.

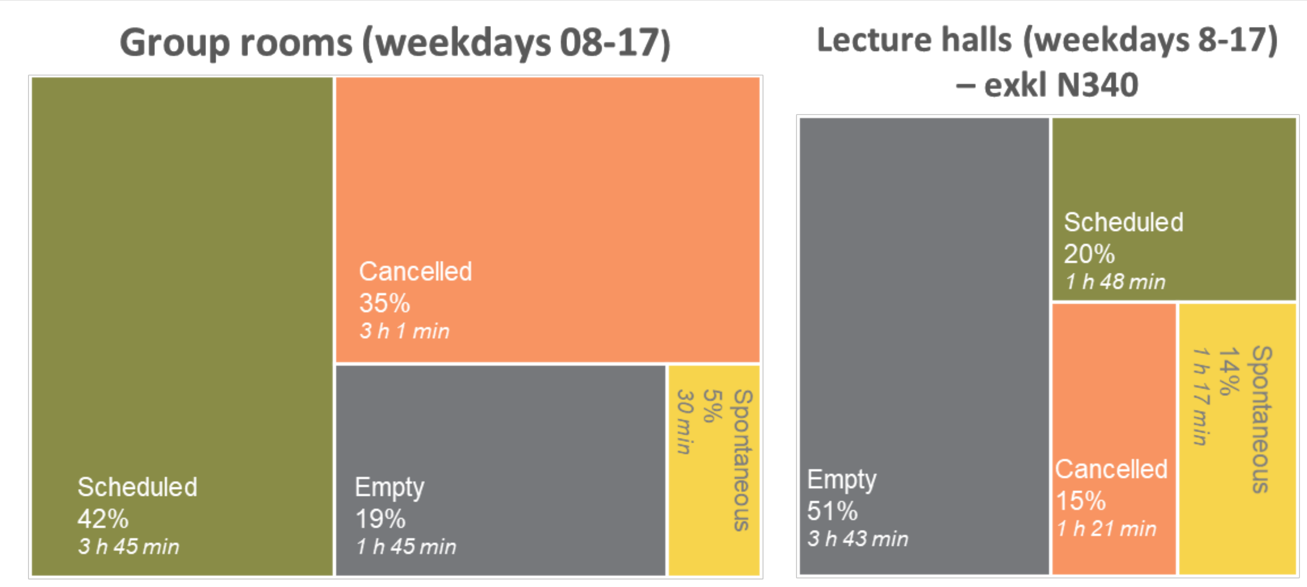

Figure 15. Results from the analysis tool, comparing booking schedules to actual use. The result for seminar rooms (seminar rooms) is presented to the left, and lecture halls to the right.

4.1.2 Indoor climate

In the quality indicator Indoor climate, the air quality in offices and lectures halls are shown and compared to Swedish work environment regulation. In Figure 16 indoor climate in offices during normal working hours is shown.

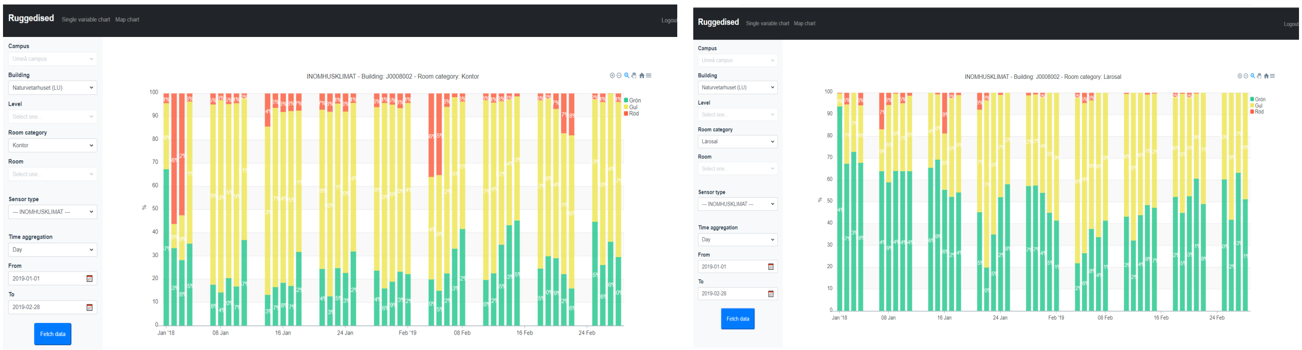

Figure 16. Results from the analysis tool, indoor climate in offices (left) respectively lecture halls (right) during office hours for 2 months. The green staples show a good indoor climate, the yellow staples show a deviation and red staples show unsatisfactory indoor climate.

4.1.3 Unnecessary electricity use

In the quality indicator Unnecessary electricity use is shown for non-occupancy and the electricity use should preferably be approaching zero. In Figure 17 indoor climate in offices during office hours on weekdays is shown.

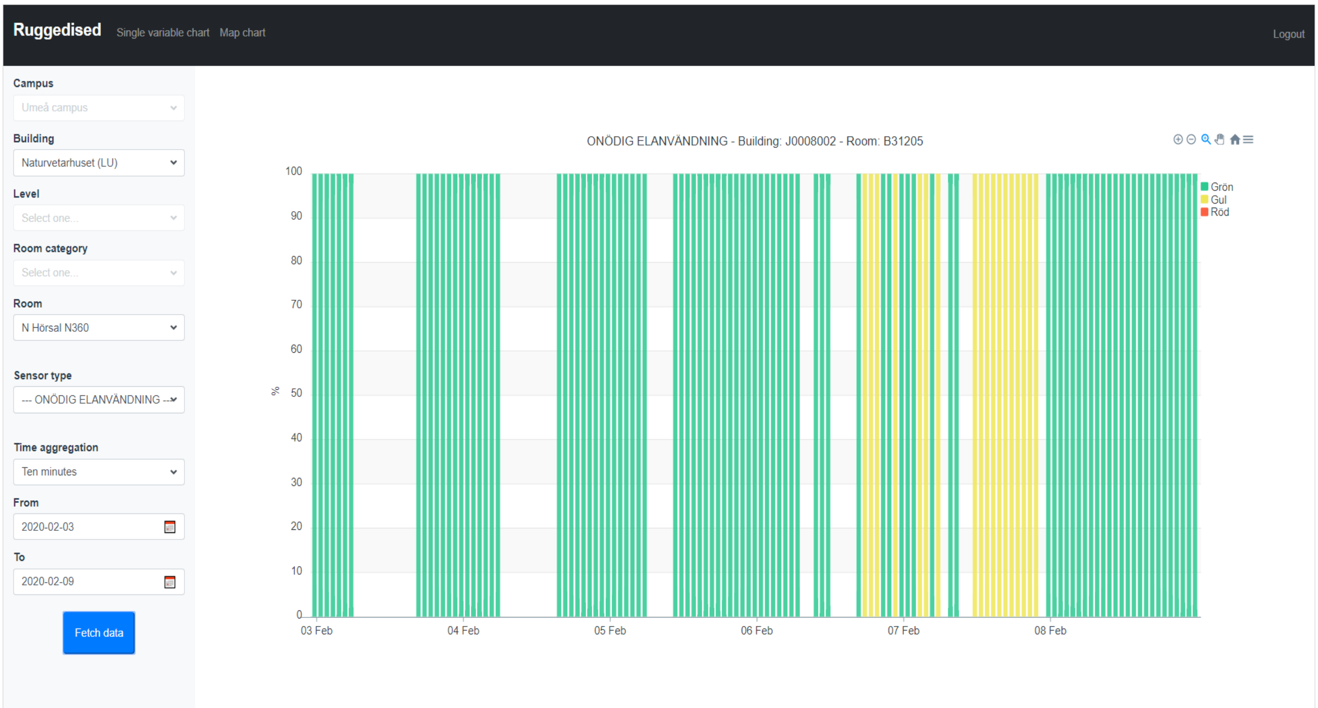

Figure 17. Results from the analysis tool, Unnecessary electricity use in a lecture hall for one week. Green staples show non or very low electricity use during non-occupancy.

4.1.4 Heat supply

The early studies have shown that heat supply is even more inefficient than expected in offices with conventional HVAC-systems. The early result of a further analysis, where the heat supply in lecture halls with conventional HVAC-systems is followed, also suggests this. In Figure 18 an inefficient heat supply in a lecture hall is shown. Figure 19 presents the supply of heat to offices in NB building during 1st February 2020. Accordingly, there is not a significant difference on heat supply during day time and night time despite the heating system is supposed to operate based on occupancy detection

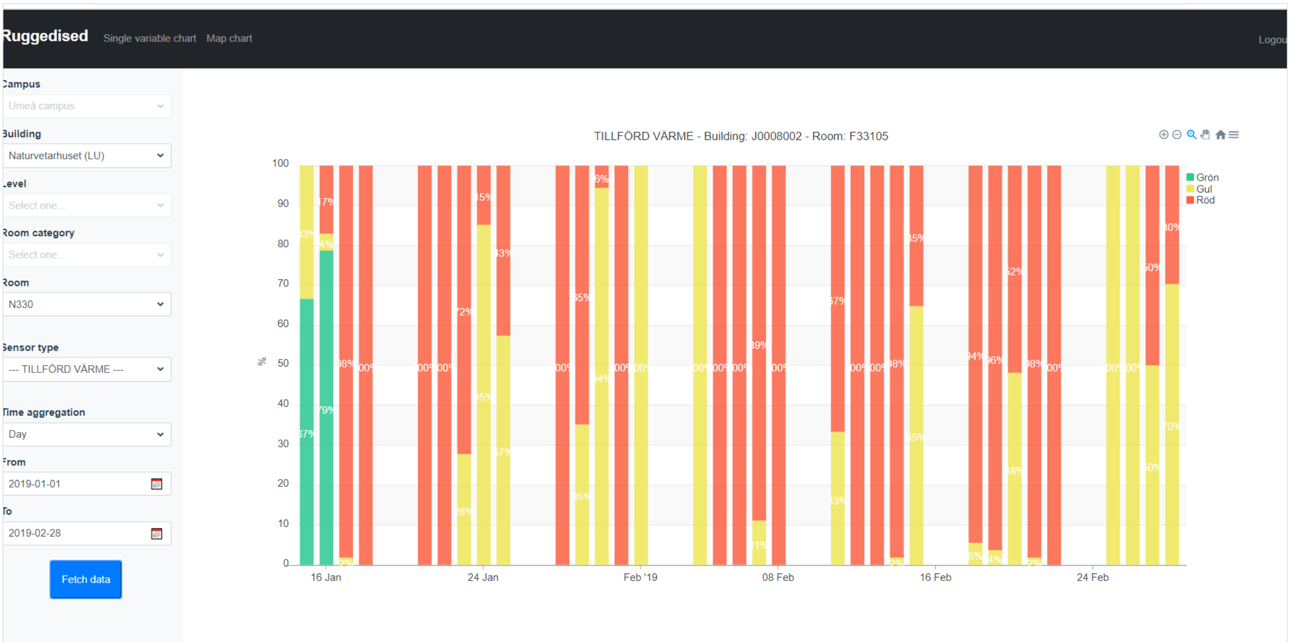

Figure 18. Results from the analysis tool, heat supply in a lecture hall for two months. Green staples show an energy efficient heat supply while red staples show that the radiators are heating the lecture hall too much, which has been seen in many cases.

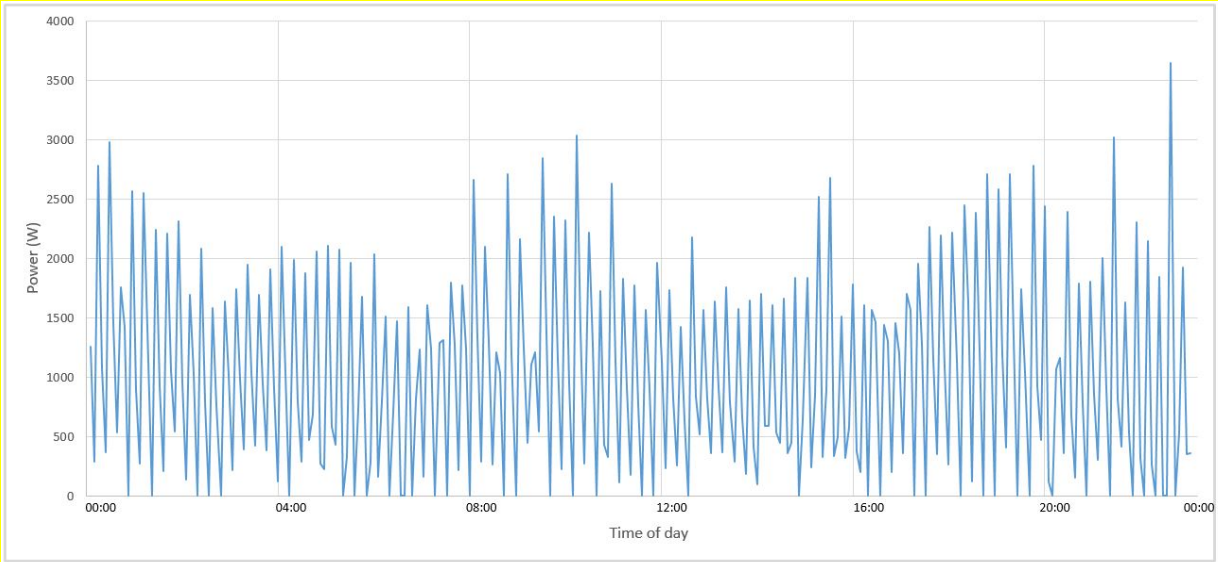

Figure 19. Aggregated radiator heat supply to 5 offices with Lindinvent systems during one day on 1st February

4.1.5 Noise level

Noise levels should stay below certain values to cause persistent hearing problems or in other ways affect the working environment negatively causing mental strain or tiredness. According to Swedish work environment regulation actions should be taken when the daily exposure level exceeds 80 dB. Figure 20shows the maximal noise level in a lecture hall during a week in February 2020.

Figure 20. Results from the analysis tool, maximum sound level in a lecture hall during a week. Red line shows the level for unhealthy noise according to Swedish work environment regulation.

5 Progress through in-depth research studies

Questions that have arisen during the work with RUGGEDISED solution U9 are being further developed in additional in-depth research studies at Umeå University. A brief description of the research studies is presented below.

5.1 Sensor installation for improved accuracy in occupancy detection

The building digitalization enables using data to enhance facility management in buildings. This approach can be a game changer due to effectivity, relative low cost, low embodied emission, flexibility and multi-functionality. Sensor-based occupancy detection can provide extensive information about building usage that can be used to improve the building management. Occupancy information can be used for different applications often associated with opportunities for significant energy saving. Different applications require different quality of occupancy information such as accuracy of detection. The installation aspects of sensors such as sensor placing and frequency of data transmission could significantly influence the accuracy of occupancy detection, and thereby the energy savings.

Investigating the sensors' detection accuracy, based on sensor placing and frequency of data transmission, were conducted in 11 offices in a University building. The "ground-truth" information was provided by the occupants. The investigated parameters related to sensor placing including distance from occupant, height, orientation and light exposure. The effect of these parameters was found to defer in various types of environments and for different types of sensors such as PIR and CO_2 sensors. Therefore, such installation parameters and data transmission frequency should be taken into consideration to have a better accuracy and optimum results from the occupancy sensors.

5.2 Optimized use of building space

Optimal space management in this context means using the lecture rooms in a university building for its designated capacity while minimizing the operation and maintenance costs. Such optimization can lead to direct savings of energy and other services such as cleaning. Moreover, the information of space utilization is useful for planning future building developments. Smart tools in an Internet of Things environment enable accurate and frequent space use information which can facilitate the management to optimize space and energy use.

The analysis in this study involves investigation of space use by occupancy data and booking information in 8 different lecture rooms in a building at Umeå University. The preliminary results suggest interventions such as modification of access permission and closing redundant lecture rooms may lead to energy savings. We are in the process of carrying out more detailed analysis to understand different scenarios that may influence the outcomes on optimizing the buildings' space use.

5.3 Energy analysis of demand-controlled energy HVAC

Demand controlled energy systems aim to provide energy services only when and where they are required, and in the amount that they are required. Replacing the conventional control strategies by demand control strategies is claimed to have significant energy efficiency potential in the buildings. However, this potential is mainly related to the occupancy pattern of the buildings, the existing control method and the outdoor climate that determines the length of period that energy supply is needed throughout a year.

The study would estimate the energy efficiency potential of demand-controlled energy systems by using the real-world data that applies to building energy simulation models. This analysis mainly involves the office environments and provide a comparison between demand control and conventional control strategies. The studies would consider the varying local factors such as intensity of occupation, climate condition, building features and baseline control strategy would be applied to the simulation model to develop sensitivity analysis. The sensitivity analysis enables generalizing the results to other buildings in different regions.

6 Next step: replication and upscaling

The overall goal of this solution is to develop an analysis tool for demand side management in order to further reduce the energy usage and the climate impact of a building. By using the result from the analysis, Umeå University and Akademiska Hus will be able to refine the calculated potential of energy savings. Early estimates of the potential of energy saving has been set to 5 to 30 percent, depending on existing energy/HVAC-system in the building.

The tool will also help to streamline the facility usage, both for bookable and non-bookable offices, seminar rooms and lecture halls, as well as optimize facility services such as cleaning and waste management.

The property owner, Akademiska Hus, owns and manages about 3.2 million m^2 of property in Sweden. Optimizing energy usage, including the tenants' use of energy, could be vital for reaching ambitious climate goals. In the future, the solution could potentially be used in any building, favorably in buildings where the ventilation load is already variable.

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