Field trial user experience including visualization systems

Evaluation of trial results with regard to system applicability, basic requirements and interaction strategies

Version 0.3

Deliverable D2.2 and D2.3

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About ERA-Net Smart Grids Plus

ERA-Net Smart Grids Plus is an initiative of 21 European countries and regions. The vision for Smart Grids in Europe is to create an electric power system that integrates renewable energies and enables flexible consumer and production technologies. This can help to shape an electricity grid with a high security of supply, coupled with low greenhouse gas emissions, at an affordable price. Our aim is to support the development of the technologies, market designs and customer adoptions that are necessary to reach this goal. The initiative is providing a hub for the collaboration of European member-states. It supports the coordination of funding partners, enabling joint funding of RDD projects. Beyond that ERA-Net SG+ builds up a knowledge community, involving key demo projects and experts from all over Europe, to organise the learning between projects and programs from the local level up to the European level.

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1. Background

E.ON, Malmö City and Chalmers are the Swedish partners who participate in the project as a team. Within the international consortium, the Swedish team distinguishes itself with their focus on user-centred energy use and initiatives related to smart grids and energy optimization. E.ON, Malmö City and Chalmers will work towards the common goals set up and defined within the international application.

The project aims to further develop a software platform that can support intEROperability to make technologies and services available for smart grid.

2. E.ON - CESO

2.1 Introduction

E. ON uses a Customer Energy and System Optimization (CESO) system that uses the buildings natural thermal inertia to shift heat power demand. Heat demand is controlled during a short period of time, typically a few hours, without affecting the indoor climate and comfort. Indoor temperature is only allowed to change ±0,5°C.

Figure 1. CESO system

The CESO system aims to reduce peak generation by approx. 5-10% of the district heating system’s nominal installed heat output. Allowing to reduce 20% of the customers heating needs without decreasing the indoor temperature more then 0,5 ℃. The purpose of this system is to be able to distribute heat to as many customers as possible in case of unavailability in the heat production.

2.2 Overview technology

The CESO technology has three layers of functionality which continuously communicates and operates synergistically. The first layer is the cloud platform from which the system is controlled, and steering signals are generated. The cloud communicates with Energy managers placed in recruited buildings. The Energy manager handles the communication between the cloud and the existing building monitoring system (BMS). The last layer is the BMS system in the building which commonly steers the heating system but also coordinates and monitors other functionalities such as sensors, actuators ventilation, fire alarm and security system.

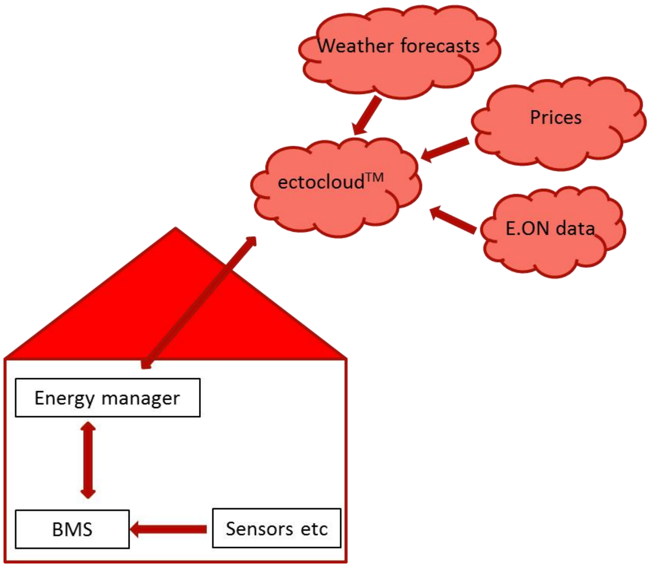

Figure 2. CESO system overview

Heat demand control is the basic strategy available through CESO which functionally means that district heating DSOs can temporarily lower the heat output by allowing CESO to control connected heating systems and lower their demand for heat. The control strategy is described in Figure . Upon activation, a desired heat demand reduction signal is generated and sent to the Energy manager. The Energy manager interprets this through algorithms while also analysing data sent from the BMS and generates an optimized offset signal in degrees (°C) which can interact with the BMS generated setpoint.

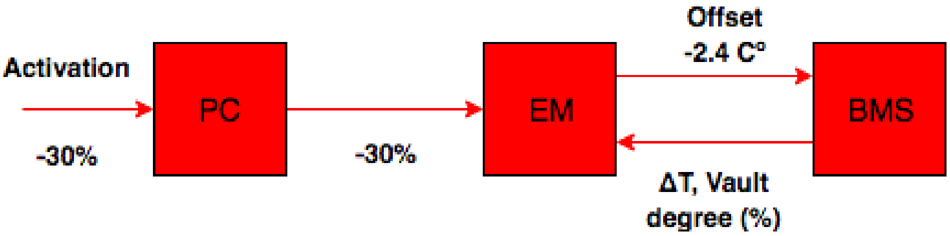

Figure 3. Visualization of heat control strategy

Schedules defining the power increase or reduction (%), duration and starting time are manually inputted in the heat control system. The heat control system calculates the indoor temperature impact based on the programmed schedule.

Once the buildings are enrolled and the control software is ready, the technical solution is tested. The testing period started February 2019. A first validation on the algorithms has been performed to ensure that the control power system was correct.

2.3 Power control

Power control is a CESO functionality. It allows for the district heating DSO to reduce or increase the power demand temporarily by allowing CESO to control connected heating systems and reduce or increase their heat demand. This functionality does not require continuous communication and iteration. It activates on command and operates until de-activation.

On activation, the desired power control signal (in %) is generated and sent to the energy manager. The energy manager could at present handle this signal by converting the power control signal to an offset signal in degrees (°C), which is then applied to the BMS generated flow temperature setpoint.

2.3.1 What makes power control possible?

The power control strategy is possible due to the natural thermal inertia in buildings. Thermal inertia is the measure of how quickly or slowly an object gains or loses heat to its environment. Something with high thermal inertia takes a long time to reach equilibrium with its environment; something with low thermal inertia reaches equilibrium quickly. It depends on several factors such as the specific heat of the material, conductivity and geometrical dimensions. Buildings typically has a great thermal mass which means that it also has high thermal inertia.

CESO utilizes a building's natural thermal inertia to shift heat power demand by controlling the heating (never affecting tap water or ventilation). Power demand is controlled during a short period of time, typically a few hours, without affecting the indoor climate and comfort. Indoor temperature is only allowed to change ±0,5°C, typically allowing e.g. 75 % power reduction for 2 h or 25 % power reduction for 6 h.

2.3.2 Generating power control signals

Currently power control signals could only be generated manually by the CESO operator. Schedules are created defining power increase or reduction (%), duration and starting time.

How much flexibility, i.e. controllable power, that is available is continuously calculated and updated in ectocloud™ and is visualized in the operator interface.

2.4 Installation

2.4.1 The energy manager

The energy manager is a pre-programmed industrial computer which primarily handles the communication with the BMS or scada system. It is a local gateway and translates control signals generated in ectocloud™ to applicable signals for the connected BMS.

Figure 4, shows a schematic illustration. The centre of the energy manager is a SQL database which organizes, stores and forwards relevant data. There are two main interfaces, one which handles the data exchange with ectocloud™ and one which manages the data exchange with the connected BMS or scada. Additionally, the energy manager contains algorithms that supplements the algorithms in ectocloud™. The purpose with algorithms in the energy manager is to assure that the energy manager will still be able to generate control signals to the BMS or scada during connection failures with ectocloud™. There is also a watchdog supervisory functionality in the energy manager, which continuously controls the operation of the energy manager with a timer function. If the energy manager malfunctions this triggers a timeout signal and automatically initiates corrective actions. It could also reboot the system if the error is not recoverable.

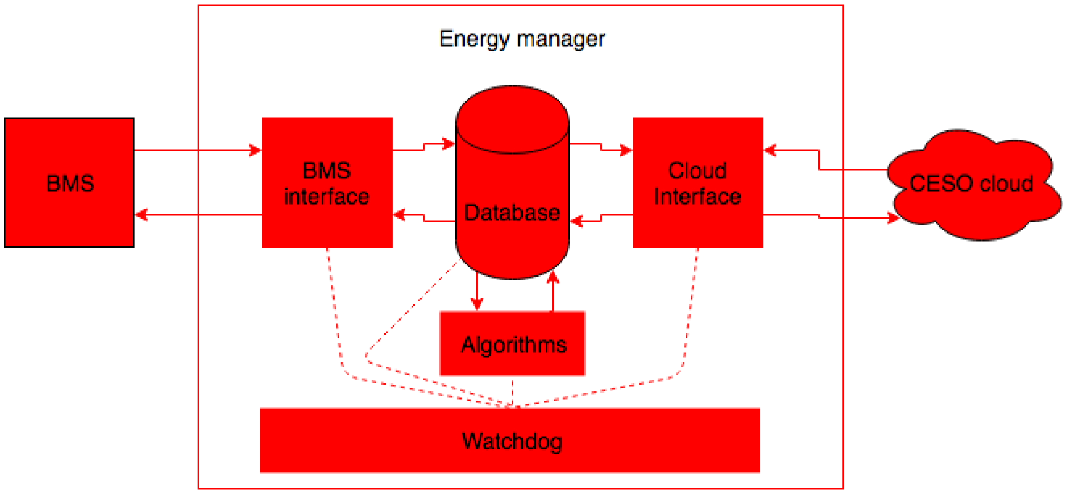

Figure 4. Schematic illustration of the components within the energy manager

2.4.2 Interaction with the BMS

The energy manager communicates with the BMS and delivers the control signals generated from ectocloud™. In the case when the power control signal is converted to an offset signal in degrees (°C), the control signals are translated into offset values in the energy manager. The offset is added to the original setpoint for the heating system calculated within the BMS.

In a system without CESO the setpoint for the radiator system is calculated from a setpoint curve. This is normally a linear function relating the setpoint for the radiator to the outdoor temperature. CESO adjusts this setpoint by adding the generated offset value. The adjusted setpoint then enters the PID-controller which regulates the valve-degree accordingly. The actual value position is fed back to the controller.

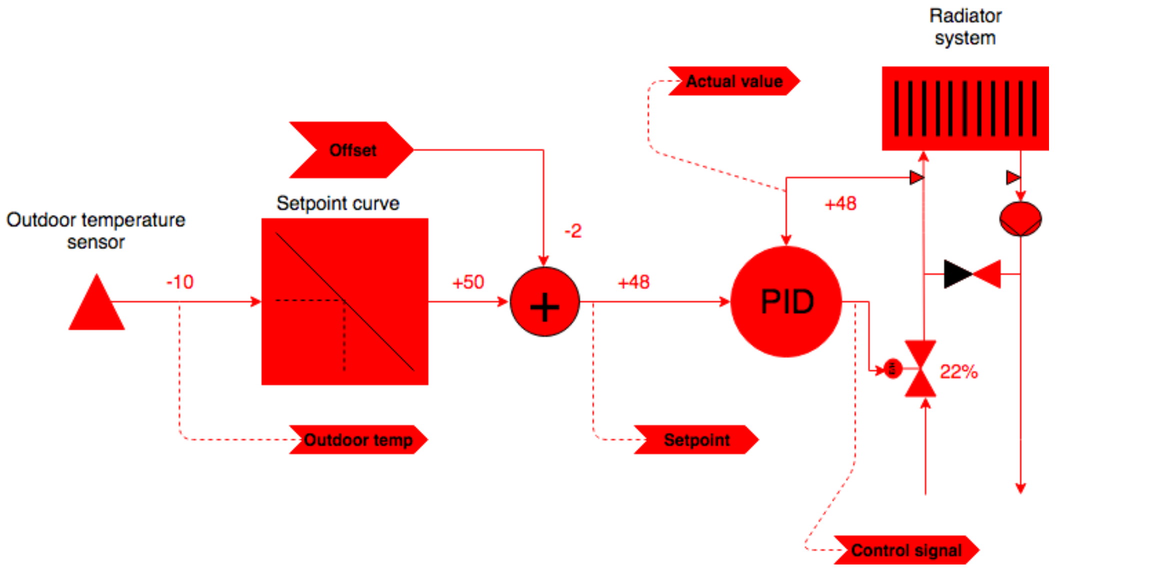

Figure 5. Schematic picture of control mechanism for a building heating system and the interaction obtained through CESO.

2.4.3 Installations - MKB

Mid september there where 38 installed buildings, connected to power control within MKB AB (Malmö kommuns bolag för bostadsförsörjning) that could be used in the field-trial. The test system can only be run in 15 buildings at a time so this was the maximum limit of buildings that could be used. Malmö Stad was responsible for the selection of the buildings and the communication with the end-users. This is further explained in the chapter 4.

2.4.4 Installation - Roth Fastigheter AB

The field trail also includes a new construction in Hyllie that is built by Roths Fastigheter AB. The tenants moved into the buildings on January 1st in 2020, and E.ON preformed test of the buildings (Dungen) during week 2 and 3 in 2020.

2.5 Control functions in ectocloud™

Implemented in the user interface of ectocloud™ is a warning when the operator tries to set a too aggressive schedule in the power control function. When the schedule is set to steer a lot of the effective power during a longer time, a warning is shown on screen that the indoor temperature might be remarkable affected by the action.

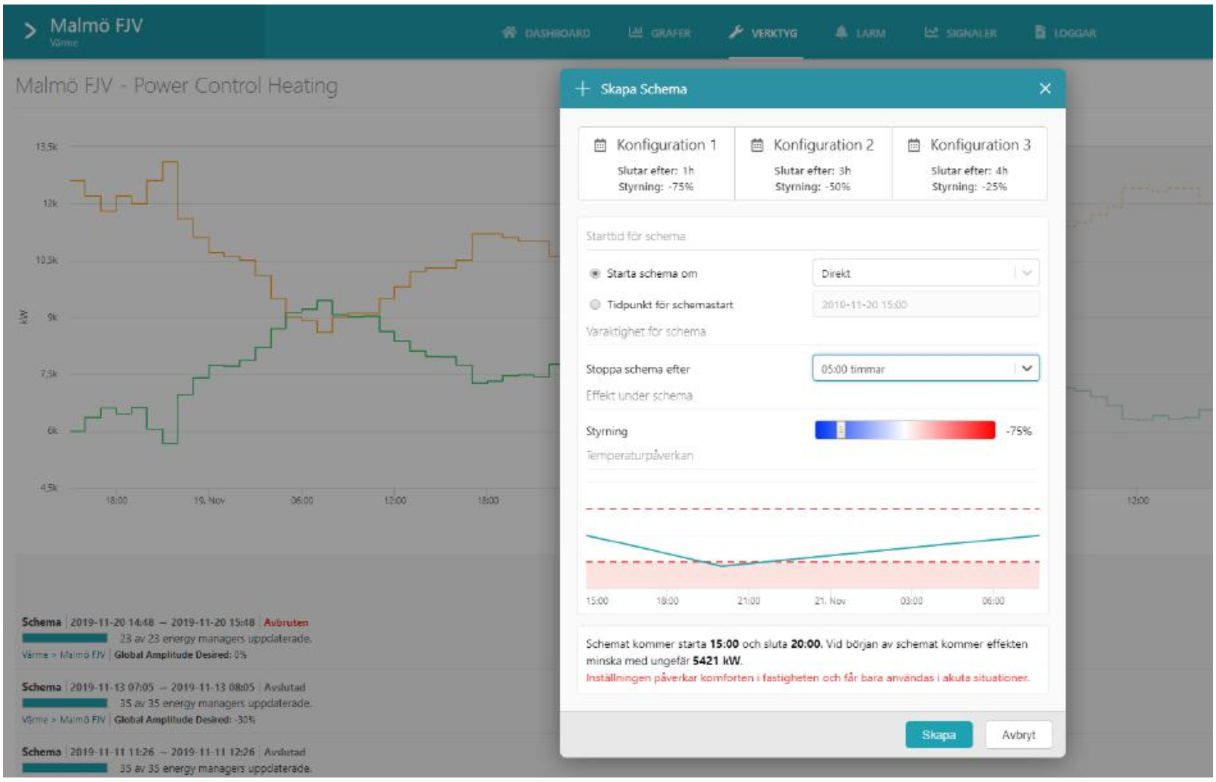

Figure 6.user interface – warning in power control

2.6 Test schedules – power control

The purpose of the test sequence is to:

- Evaluate the power control functionality of the building
- Analyse the effect on the power output
- Analyse the impact on the indoor temperature (where indoor temperature sensors are available).

The test is to verify that the functions effectively can lower the power, increase the power and raise and lower the power in direct succession. It should also provide the basis for analysing the effect on the power outlet, and how the indoor temperature in effected, under some typical power control actions. A test to control the maximum steering of available power (100%) is also done for a short period. The test sequence is the last step in the installation process before a building is commissioned.

Maximum 15 buildings can be included in the test schedule. The following schedule was decided for the test of the MKB-trail during week 47-48 in 2019:

	Weekday	**Time**	**Schedule**
1	Mon	09-10 am	+50% 1h
2	Tue	09-10 am	-50% 1h
3	Wed	09-11 am	+50% 1h, -50% 1h
4	Thu		
5	Fri	01-04 am	-50% 3h
6	Sat		
7	Sun	01-04 am	-50% 3h
8	Mon		
9	Tue	01-1:30 pm	-100% 0,5h
10	Wed		
11	Thu	00-07 am	-25% 5h, +25% 2h
12	Fri		
13	SAt		
14	Sun	00-07 am	-25% 5h, +25% 2h

Figure 7. Set test schedule for the MKB trial, Nov 25th – Dec 08th in 2019

2.7 Integration ectocloud™ to FIWARE

2.7.1 Implementation

To be able to create value in FISMEP project according to the WP2, we need to have integrated the applications from E.ON and Chalmers, known as ectocloud™ and ERO. ectocloud™ as a forecast tool for District Heating producers has Machine Learning Models that can forecast the amount of energy that a connected building needs during the upcoming 24hrs. From energy consumption and historical temperature, the ML Model extracts the part of energy that is used to heat the building as the total consumption including tap-water, ventilation and other internal loads that cannot be regulated. The value received is called "Steerable Power" according to ectocloud™.
The communication between the services happens over REST API:s communicated over a secure channel.

To integrate ectocloud™ to FIWARE, the Chalmers team connected to an E.ON-provided API Gateway and achieve the following:

- OAUTH2 sign-in to get tokens for communication.
- POST forecast of building aggregated heating flexibility per hour.
- GET Steerable power forecast for building for a specified time range.

2.7.2 Result

The implementation of the cloud to cloud integration described in 2.6.1 was implemented during Q2 and Q3 2019 by the ectocloud™ team and working as intended.

3. Evaluation of HSB LivingLab from a FISMEP perspective

The HSB LivingLab is a research infrastructure at Chalmers University of Technology that consists of an apartment building with 33 real tenants and a wide array of sensors that cover aspects such as electric consumption or indoor environmental factors. The HSB LivingLab has been used in a previous study leading up to the FISMEP project to explore how tenants change their energy consumption behaviour when receiving information about energy availability and their consumption through an App[1].

Various areas from the LivingLab and previous studies have been of value for the FISMEP project:

- Database server and the code to continuously store data from IoT sources could to a large extent be modified and re-used. This system has over years been refined into a stable production environment with production necessities such as backup, service monitoring functions and cyber security aspects taken care of. The LivingLab code base has made information gathering from other sources such as the Tempiro backend a matter of extending or modifying existing code rather than building everything from scratch, and has hence reduced development time significantly.
- The architecture of the App from the previous ERO study was re-used while the code base itself was not re-used. The FISMEP App only works for iOS-devices which allows for a simpler design with less volatile software components. Having a previous implementation with similar project made the FIWARE App development more akin to a refactoring the code. Several times during the project we have been able to look back and re-use algorithms or design patterns which also have saved development time.
- From the previous ERO study we also learnt a few hard lessons about the limitations of IoT-devices. Firstly that the sensor resolution of electrical sensors are not good enough to generate a smooth continuous graphs for low power household equipment such as a mobile charger. Secondly that the stability of radio communications between sensor and sensor gateway is really important to get a reliable service. This led us to use metal doors with a plastic window for electrical cabinets mounted in the apartments at Roth fastigheter and to use equipment that was known to have a robust radio signal.

In conclusion, components from the HSB LivingLab and experiences from the previous study there has proved valuable in avoiding bad design decisions and to reduce development time in general.

[1] Renström S, Andersson S, Jonasson A, Rahe U, Merl K and Sundgren M, 2019. Limit my energy use! An in-situ exploration of a smart home system featuring an adaptive energy threshold. The 19th European Roundtable on Sustainable Consumption and Production – Circular Europe for Sustainability (Proceedings of ERSCP)

4. Description of the FIWARE implementation

FIWARE is mainly implemented as a proof of concept where a subset of data is transferred to FIWARE, stored according to the information model developed by the project and visualized with Grafana. We use the same FIWARE installation for both HSB LivingLab and Roth fastigheter/E.ON.

4.1 FIWARE Installation

FIWARE has been installed with the Orion broker, Mongo DB for storage, a time series database, suitable for sensor data and Grafana for visualization of the data. These services run in Docker containers on one physical machine at the HSB LivingLab. The reason for this special machine set-up is information security rules set by the HSB LivingLab, and that we have not implemented a solution yet to stretch this data security zone outside of the physical premises of the LivingLab. However, the FIWARE installation is close to production status at this point, where issues with stability, backup, operations monitoring, and security have been solved.

4.2 FIWARE and HSB LivingLab

Sensor readings at the HSB Livinglab are stored in a Postgres database. As a first proof of concept, we have written a program that continuously fetches a subset of the latest sensor data from the database and feeds it to FIWARE using the JSON IoT agent.

4.3 FIWARE and Roth fastigheter Dungen

As a second proof of concept, we have written a program that fetches information about the district heating for Roth Fastigheter Dungen from E.ON ectocloud™ and feeds it to FIWARE using the JSON IoT agent.

5. Visualisation systems for the field trial with users

5.1 MKB diary application

The MKB application provides the tenants in the study with a digital diary where they can enter information every day during the study.

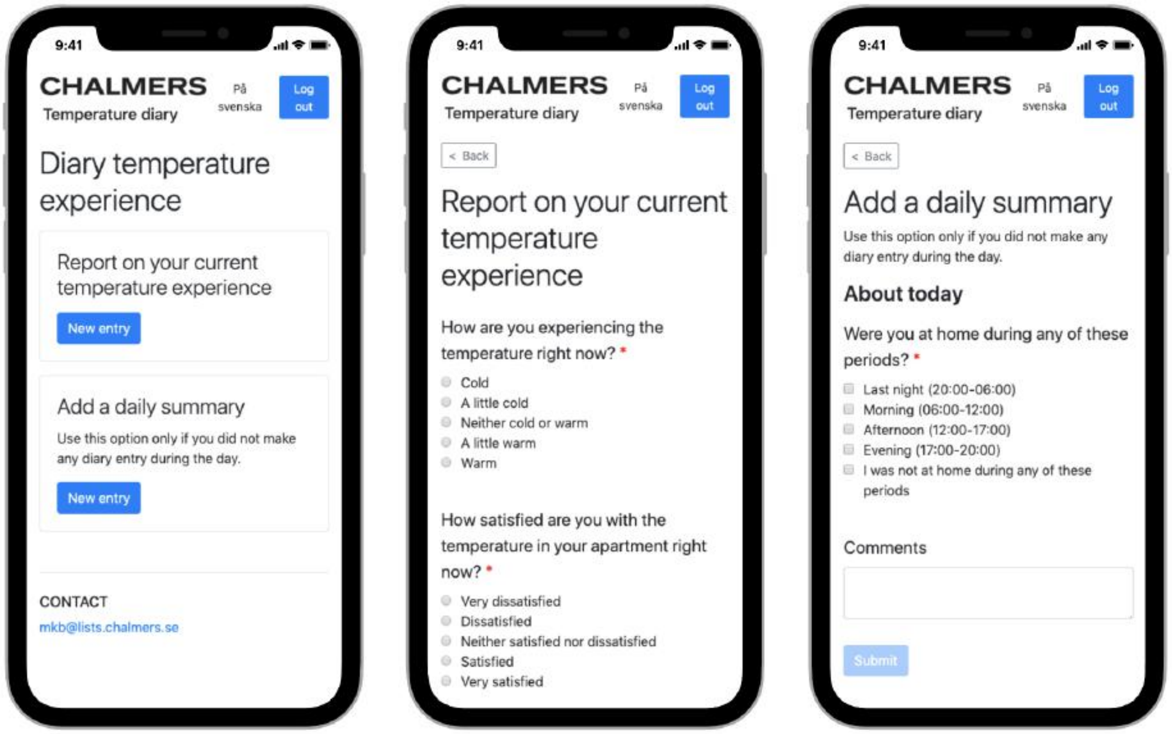

Figure 8. Example screens of the MKB diary application, specially developed for the field trial user-test

The diary is built as a web application using the Questback survey system at Chalmers. The Questback system lacks diary-like functionality for this type of panel studies, but has good functionality for surveys and for generating reports. Therefore new diary functionality was developed by using the API backend of Questback and building a simple web-service that enables to present the survey questions on a phone or regular computer, see figure 8.

From the participants' perspective, they log in with a personalized link every day and can access their diary. The application aggregates the daily information and the Questback system generates a report for research.

An existing system for sending emergency SMS messages to the employees at Chalmers was used to send SMS notifications about changes in the district heating to the participants. The SMS were sent out manually rather than through an automated schedule, which led to some minor mistakes, but required a minimum of effort.

5.2 Chalmers ERO App for Roth residential building Dungen

The ERO App provides tenants in the study with information about their electric, district heating and water consumption.

Electric energy consumption is displayed in relation to the ERO-threshold (blue bars in the image), which is self-set-up by the tenant him/herself. The ERO-app enables the tenant to see his/her individual consumption in relation to the availability of the preferred energy sources. This indicates to the tenant when there is time to save energy and when it would be be more suitable to perform an energy intensive activity such as drying laundry.

Consumption is monitored at apartment level and broken down to specific home appliances/services. The devices monitored in this study are:

- Fridge
- Dishwasher
- Washing machine
- Dry tumbler
- Floor heating in the bathroom/shower area

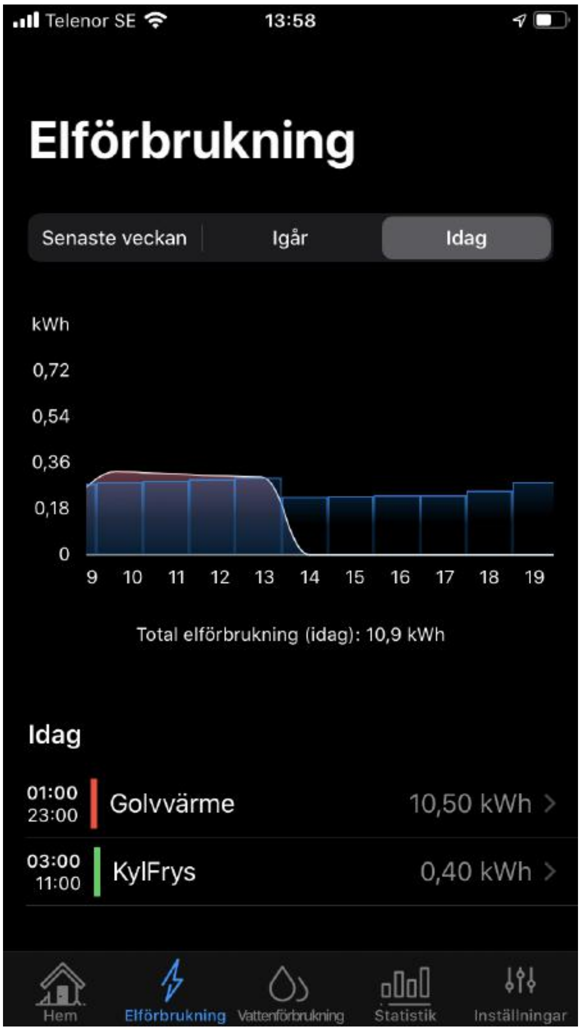

Figure 9.

Example screen of the ERO app, specially developed for the field trial user-test in Roth residential building

The above listed appliances can be monitored and controlled from the app to enable and stimulate users to save electrical energy in an encouraging and motivating way. Because of safety regulations, only the control of the floor heating is currently available to the tenants, the rest of appliances can only be monitored, see figure 9.

Additionally, the ERO app shows how much of the power generation is generated from hydro, nuclear, wind and fossil sources.

Further, district heating consumption for the entire building is displayed in the app. The tenants cannot control the district heating in any way yet, but the functionality has been prepared to enable uploading of individual user temperature preferences to give the heating providers consumer feedback in the future.

Finally, also hot- and cold-water consumption for each apartment are monitored and visualised in the ERO app. The water consumption is displayed in relation to the historic average to give a daily/weekly water budget to easily reveal extravagant deviations in consumption on a daily/weekly comparison level.

5.3 Technical overview

The ERO-app is built to collaborate with several services from different suppliers. One of our design principles has been to re-use as much technology as possible to keep the development cost under control.

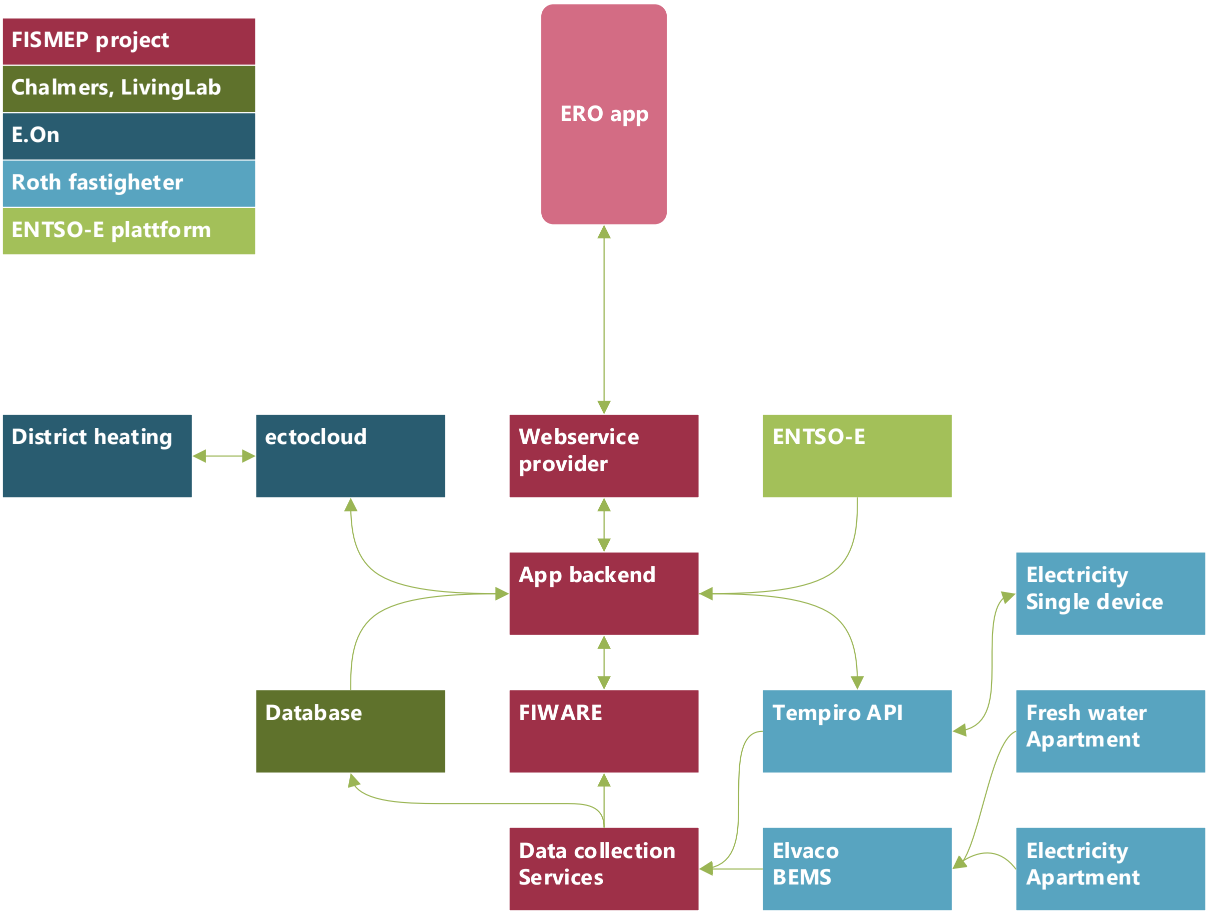

Figure 10. Systems plan and technical overview, specially developed for the field trial user-tests in Sweden

5.3.1 E.ON ectocloudTM

A service that facilitates communication between the project and E.On internal services (CESO). The service is a REST/JSON API.

- From E.On: The projected temperature in a house for the next 24 hours.

5.3.2 Tempiro API

A service for controlling and reading smart plugs and to read the power consumption by the floor heating. The service has been developed by Tempiro, a subcontractor of E.On, and has been used in similar studies before. The service is a REST/JSON API.

- From the project: Signals to turn on and off a smart plug.
- From Tempiro: Confirmation that a smart plug has turned on or off.
- From Tempiro: Reading of electricity currently flowing through the smart plugs.

5.3.3 Elvaco

Elvaco is the building management system of Roth fastigheter. It provides the project with the overall power consumption and the fresh water consumption per apartment. Information is transferred to the project as XML-reports that are transferred with sftp.

- From Elvaco: Total energy consumption per apartment.
- From Elvaco: Total tap water consumption per apartment, hot and cold water.

5.3.4 ENTSO-E

ENTSO-E provides information about the current electric power production in Sweden. It presents the energy mix of different means of production in broad categories such as hydro or nuclear. This is used by the app to calculate the availability of desired energy sources and set the personal consumption threshold. The data from ENTSO-E is available as a JSON webservice.

5.3.5 Data collection services

The data collection services are a collection of small programs that communicates with the APIs and transfer the data into FIWARE and the database. Initially all data is transferred into the database and a subset will go into FIWARE. As we grow more confident using FIWARE we will gradually migrate data to go through FIWARE in the future.

5.3.6 FIWARE

FIWARE is used to collect, store and distribute the data between ectocloudTM and the app. In the future we plan to use FIWARE with the extended version of the SAREF ontology for sensor readings. We judge the more general use of FIWARE would be an investment in an infrastructure that would simplify projects such as this. The general implementation of FIWARE has not been done due to time constraints.

5.3.7 App backend

The app backend implements all logic and data transfer needed by the app. Our design goal has been to gather as much functionality as possible in the backend to simplify the app-development and make the code base more dynamic. The backend acts as a façade exposing all underlying services as a JSON web service to the app. A Postgres database is used for storage persistent storage.

5.3.8 Webservice provider

The webservice provider is a NGINX webserver that handles the requests from the App and forward them to the App backend. The NGINX takes care of important low-level tasks such as handle ssl encryption and manage the connections between the app users and the backend.

5.3.9 The ERO App

This the App the tenants in the study will use. The app is written in native code on iOS. The app is designed to be very thin, meaning that a minimum of the functionality is implemented in the App. Nearly all functionality and actual data is handled by the app backend and send to the app when needed. This design has been chosen to reduce time for development and future upkeep.

5.4 Security considerations

All project components (red and green in picture) runs in Chalmers' production environment. The same environment and security standards as used for Chalmers' own internal services:

- All network traffic on public networks is encrypted. Most data on private networks are encrypted.
- All servers are behind firewalls with only relevant ports open to relevant hosts.
- All servers and software are regularly updated.
- All servers are backed up.
- Privileged access to data and services is restricted to relevant personnel at the IT-office.
- The continuous operation of components such as virtual machines, web servers or integrations are monitored and are logged.

5.5 Installation

Smart plugs and a controller for the floor heating are installed in 35 of the 70 apartments in Roth residential building Dungen, see even 5.2. The smart plugs are installed between the household appliance and the power socket and can easily be removed by the tenants themselves if there is a problem.

6. City of Malmö

6.1 Recruitment of end-users

The inventory of suitable properties where the case study in Malmö could be carried out was done together with MKB Fastighets AB (or just MKB), the municipal housing company in Malmö. MKB Fastighets AB is one of Sweden's largest public utility housing companies. With more than 23,800 apartments and 1,000 commercial premises, it is the largest real estate company in Malmö. The owner of MKB is the city of Malmö.

The inventory concluded that 84 buildings would be suitable for the case study, since they had E.ONs Customer Energy and System Optimisation platform (CESO) installed. Due to technical limitations, only the temperature in 15 buildings could be managed at the same time. It was decided that invitations to partake in the study should be sent out to the tenants in all 84 buildings, that the 15 buildings with most volunteers would be chosen, but that the other buildings could be used as double-blind in the study (no temperature steering was done on the double-blind houses). It was decided that the recruitment period would take place between the October 28th and November 10th.

Information material in the form of flyers (to hand out in the tenants' mailboxes), posters (to put up in the entrances of the buildings) and digital information (to deliver by email) was prepared with the assistance of the communication team of the Environmental Department in Malmö. The material consisted of information about the study, and that the participants would receive cinema tickets as a thanks for their involvement in the study. Two local students were recruited to assist with the distribution of the flyers and posters. This was done during October 28 – October 30, where they distributed flyers and posters to the tenants of all 84 buildings. During this period, the city of Malmö also had an agreement with MKB to send out two e-mails with digital information, including a link where the tenants could submit their application to the study, one on October 28 and one on November 4. However, due to an internal communication glitch within MKB, this was not done. It was only after the recruitment period that the city of Malmö was informed that no digital information had been sent out.

In total 88 tenants were recruited to the study in Malmö. The 15 buildings were most of those recruited lived were picked for temperature regulations. Almost all participants applied to get their cinema tickets in conjunction with the last digital survey.

6.2 Communication material

The communication plan was created together with a member of the communication team at the Environmental Department, at several workshops together with the project members from the Environmental Department at the City of Malmö. A first draft was then delivered to the entire Swedish project group, and then complemented according to the feedback it received from the group.

7. Further work

Due to the adaptation of the timeline for the field trials in Sweden in close consultation with the Swedish National Energy Agency, the evaluation of trial results with regard to interaction strategies will be complemented after completely executed field trials and their analysis in the intermediate report in June 2020 as well as in the final report.