Nantes | Hamburg | Helsinki

Ref. Ares(2019)7391509 - 01/12/2019

Deliverable due date: M36 – November 2019

D4.4 Report on implementation and performance of innovative smart system appliances and control algorithms, BEMS and Smart control

WP4, Task 4.2 (Subtasks 4.2.3 & 4.2.5)

Transition of EU cities towards a new concept of Smart Life and Economy

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 731297.

Project Acronym	mySMARTLife
Project Title	**Transition of EU cities towards a new concept of Smart Life and Economy**
Project Duration	1st December 2016 – 30th November 2021 (60 Months)
Deliverable	D4.4 Report on implementation and performance of innovative smart system appliances and control algorithms, BEMS and Smart control
Diss. Level	PU
Status	☐ Working ☐ Verified by other WPs ■ Final version
Due date	30/11/2019
Work Package	WP4
Lead beneficiary	VTT
Contributing beneficiary(ies)	HEN, HEL, FVH, FOU, SAL
Task description	**Subtask 4.2.3 Innovative BEMS and Smart Control Demonstration of heat demand response at apartment level** (VTT: 5 PM) Description: In Merihaka/Vilhonvuori and Kalasatama High-Performance residential buildings with waste heat recovery and an optimised control system for the district performance and user comfort. The solutions include smart meters and smart building automation systems with demand side management possibilities. The solutions enable demand side management both in heating and electricity use. In addition, the automation has interactive and visual user interface. The automation can use both temperature and human comfort set point values (HTM). The advantage in human comfort set point values is that it takes into account adaptive comfort aspect increasing users' well-being and making possible to save energy. Together with HTM also predictive algorithms are used for optimised energy and peak power use. HEN will lead this task, together with HEL, FVH and VTT. Other Partners participating: HEL (3PM), FVH (0,5PM), HEN (5PM) **Subtask 4.2.5: Smart appliances deployment**. Smart home solutions in new buildings and smart demand response system in office building with predictive control options and Flexible space management will be designed and deployed by FOU with support from FVH.

Date	Version	Author	Comment
05/04/2017	0.1	Mari Hukkalainen (VTT)	Structure of the report and allocation of writing work
03/11/2017	0.2	Mari Hukkalainen (VTT)	Updating the plans for the implementation. Synchronisation with D4.4. Inputs added from Tapio Toivanen (Salusfin), Marja Vuorinen (HEL)
16/11/2017	0.3	Mari Hukkalainen (VTT)	Inputs from HEL. Finalisation of interim version.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 731297.

30.11.2017	0.4	Mari Hukkalainen (VTT)	Finetunings based on CARTIF's comments
31.10.2019	0.5	Mikko Virtanen (VTT)	Integration of thermal sensation analysis results in the deliverable
31.10.2019	0.6	Suvi Takala (HEN)	Checking and updating Helen parts
31.10.2019	0.7	Henrik Jakobsson (SAL)	Checking and updating Salusfin parts
04.11.2019	0.8	Markku Markkonen (FOU)	Checking and updating Fourdeg parts
05.11.2019	0.9	Mikko Virtanen (VTT)	Alignment of updated inputs from all contributing partners
12.11.2019	1.0	Henrik Jakobsson (SAL)	Internal review of deliverable
18.11.2019	1.1	Mikko Virtanen (VTT)	Modifications to deliverable according to internal review
26.11.2019	2.0	Mikko Virtanen Esa Nykänen (VTT)	Finalized the deliverable for submission

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 731297.

Table of Content

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 731297.

Table of Figures

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 731297.

Table of Tables

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 731297.

Abbreviations and Acronyms

Acronym	Description
BEMS	Building Energy Management System
HTM	Human Thermal Model
mySMARTLife	Transition of EU cities towards a new concept of Smart Life and Economy
PMV	Predicted Mean Vote
RES	Renewable Energy Source

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 731297.

1. Executive Summary

This deliverable describes the design and implementation of smart home solutions in new buildings and smart demand response systems in office in Helsinki. The control algorithms and smart demand control systems have been introduced in D4.3 and this deliverable continues to describe how these algorithms and control systems have been designed, implemented and performing in Helsinki demonstrations.

This deliverable includes testing of smart thermal demand response in an apartment building in Merihaka with Salusfin, Helen and City of Helsinki. This performance has also been analysed using VTT's Human Thermal Model (HTM), with real life measurements related to HTM realized in four apartments. The second key point of the deliverable is the various smart building demonstrations done in an office building in Viikki, including the thermal demand response with Fourdeg's system, the electricity demand response with ventilation, lighting and electricity storage. Viikki demonstrations require integration with various existing Building Energy Management Systems (BEMS) and on-site RES appliances. Furthermore, HTM is used in Viikki in three office rooms to test the real time control of the indoor temperature based on individual performance and preference of the persons sitting in these rooms.

In the end, the learnings from both of these activities will be taken into account in the studies of the potential for thermal demand response in district heating owned and operated by Helen in Helsinki. Customer feedback surveys were conducted in Viikki Environment House as well as in the apartment building of Merihaka to get knowledge on how residents/employees experience the temperature in the room and whether any correlation between heat demand response commands and feedback on thermal sensation can be seen. According to the analysis conducted at VTT, no clear correlation between heat demand response commands and thermal sensations of the persons were noticed based on the answers of the residents/employees. However, it should be noted that the number of persons giving feedback is too low to make any further conclusions.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 731297.

2. Introduction

2.1 Purpose and target group

This deliverable describes the design and implementation of smart home solutions in new buildings and smart demand response systems in office in Helsinki. The control algorithms and smart demand control systems have been introduced in D4.3 and this deliverable continues to describe how have these algorithms and control systems been designed and implemented in Helsinki. The report is targeted at the building owners and facility managers, smart demand response solution providers, energy companies and researchers.

The work reported here is related to Task 4.2 focusing on Smart Homes Deployment. There is also a strong focus on Subtask 4.2.3, which aims to develop innovative BEMS and smart control demonstration of heat demand response at an apartment level, as well as to Subtask 4.2.5. The demonstrations have been performed in **Zone 1**: Merihaka and Vilhonvuori (Action 4), **Zone 2**: Kalasatama High-Performance residential buildings (Action 2) and **Zone 3**: Viikki Environment House (Action 7). The innovative BEMS and smart controls are demonstrated with waste heat recovery and an optimized control system with the final aim to improve users' comfort and the performance of the districts. The solutions include smart meters and smart building automation systems with demand side management possibilities. The solutions enable demand side management in the use of both heating and electricity. Additionally, the automation system has an interactive and visual user interface. The automation can utilize both temperature and human comfort set point values based on VTT's Human Thermal Model (HTM). The advantage in human comfort set point values is that it takes into account adaptive comfort aspect, which increases the users' well-being and leads to potential energy savings. The HTM is used together with predictive algorithms to optimize energy usage.

As a part of mySMARTLife Helsinki interventions, heat demand response has been piloted in Viikki Environment House and in pilot apartments of one apartment building in Merihaka. The purpose of heat demand response solution is to reduce the need for heat during peak consumption hours and enable greater flexibility. The peak consumption times increase the costs and emissions of energy production. With consumption being shifted to a different time of day, the demand response solution flattens out peaks that would otherwise occur. This shift allows the architectural foundations of a building, such as stonewalls, to be used as heat reservoirs. Helen is currently evaluating the potential of heat demand response in Helsinki, the benefits in system level and the possibilities to implement demand response. From the point of view of an energy company, heat demand response can be performed in two ways:

1) Building-level control: changing the set value of water coming to the radiator network (e.g. Helen's pilots outside mySMARTLife: Heka pilot and planned other pilots)

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 731297.

2) Room-level control: changing the set value of indoor temperature via smart thermostats if installed (two mySMARTLife pilots)

From the point of view of an energy company, demand response via building level control is more promising since smart thermostats are new tecnology and therefore, quite rare in the buildings of Helsinki.

2.2 Contributions of partners

Table 1 shows the contributions of the partners for this deliverable. VTT will lead the deliverable while HEN will lead Task 4.2.3 together with HEL, FOU, SAL and FVH.

Table 1: Contribution of partners

Participant short name	Contributions
VTT	Lead of the deliverable, main writing responsibility. Section 5.2 BEMS systems, HTM control (5.3) and users' feedback collection (5.4) in Viikki.
HEN	Lead of the task 4.3.2, which is reported in this deliverable.
HEL	Users' and stakeholders' involvement (Section 3.6); Inputs to Sections 4 and 5.
FVH	Inputs to Sections 4 Kalasatama regulations, and Section 5 (e.g. wlan network set up)
SAL	Sections 3.1 - 3.5. (Technical implementation of Action 4)

2.3 Relation to other activities in the project

The following Table 2 shows the main relationship of this deliverable to other activities and/or deliverables developed within the mySMARTLife project and that should be considered along with this document for further understanding of its contents.

Table 2: Relation to other activities in the project

Project activity	Contributions
D4.1	This deliverable provides the overall baseline for the Helsinki demonstrations.
D4.2	This deliverable describes retrofitting actions and actions implemented in new buildings. The described demand response solutions (in Action 4) complement Action 1.
D4.3	Description of New predictive and adaptive control algorithms and monitoring of performance, and smart demand control systems. Implementation and performance of these systems is described in this deliverable.

3. Smart control and thermal demand response at apartment level in Merihaka

3.1 Introduction to the thermal demand response demonstration action

The main results of Action 4: **Demonstration of heat demand response at apartment level at Merihaka/Vilhonvuori (in 167 flats)** are reported in this deliverable and it complements Action 1. The smart homes will also be connected to the IoT platform (Actions 47, 48).

In **Zone 1** Merihaka/Vilhonvuori, the smart heating system of Salusfin has been installed in 167 apartments. The system includes smart thermostats that are connected to the district heating through IoT and cloud-based intelligence to load balance the network. The data will be used to study more transparent and usage dependent cost sharing of heating. Currently the costs of heating are sent to the housing company and each apartment pays an equal share of heating. This means neither the residents nor the dwelling owners have economic incentives to reduce the heating costs. A technical and business model related to this action will be demonstrated where the resident will be made aware of the relative share of the heating of his dwelling as part of the heating of the whole building.

3.2 The technical implementation

Salusfin's Smart Living solution is based on a three-layered architecture as shown in Figure 1:

- Layer 1 contains wireless components, which communicate with a gateway using z-wave protocol.
- Layer 2 is the cloud solution. The Cloud is the integration layer and contains the data repository, optimization and machine learning features.
- Layer 3 is the user interface (UI) layer. The layer consists of native mobile clients on iOS and Android platforms as well as web interface.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 731297.

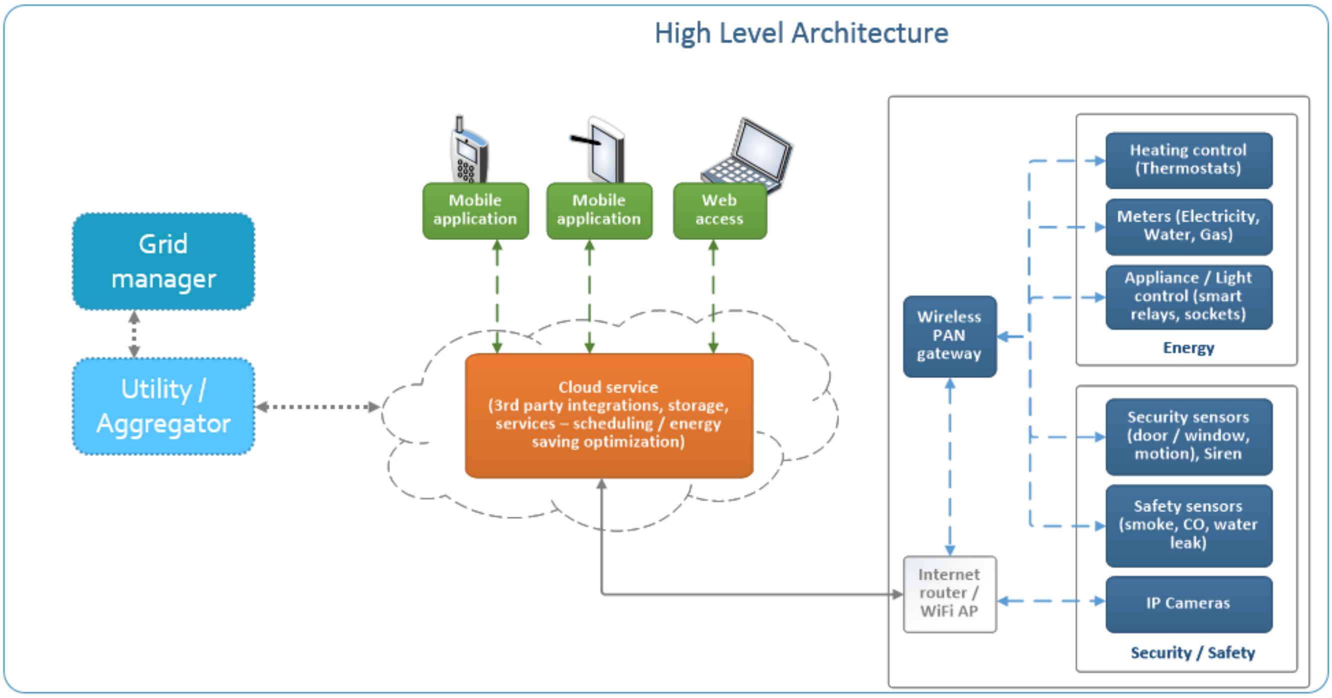


Figure 1: An example installation in a two-bedroom apartment consisting of a gateway, four smart thermostats and two temperature sensors

The Smart Living solution is mainly controlled through mobile clients that not only notify and report about items, but also allow the user to control these items, for example, by clicking on the On or Off icon as shown in Figure 2.

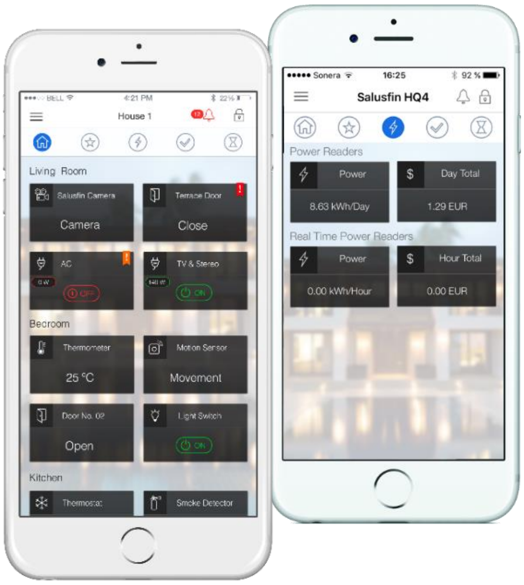


Figure 2: User interface to control items (figure from SAL)

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 731297.

A more detailed view, for example, about scheduling and controlling options, is visible in the web client (Figure 3).

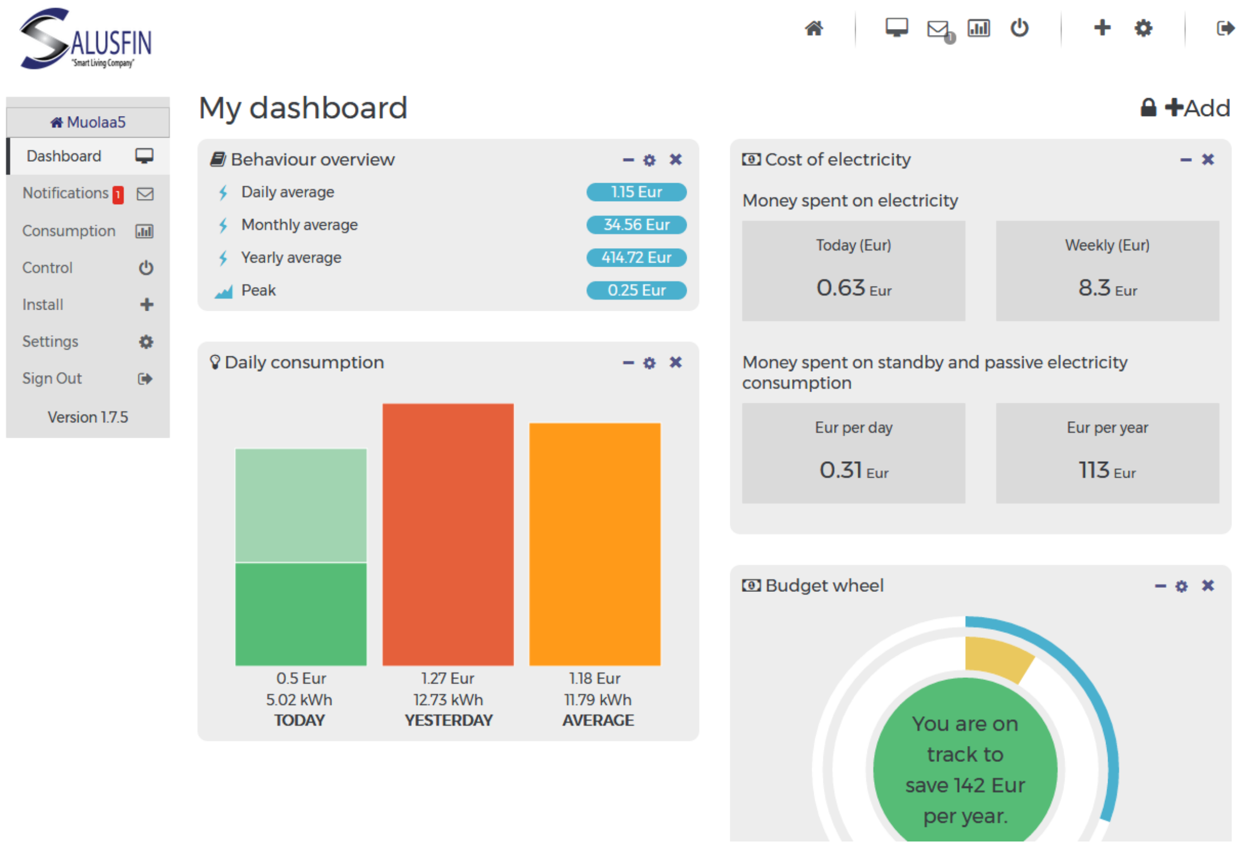


Figure 3: View of the web client (figure from SAL)

Additionally, users may set weekly temperature schedules. They may choose specific set points for the room level, copy one room schedule to another or set different temperature schedules for each room as illustrated in Figure 4.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 731297.

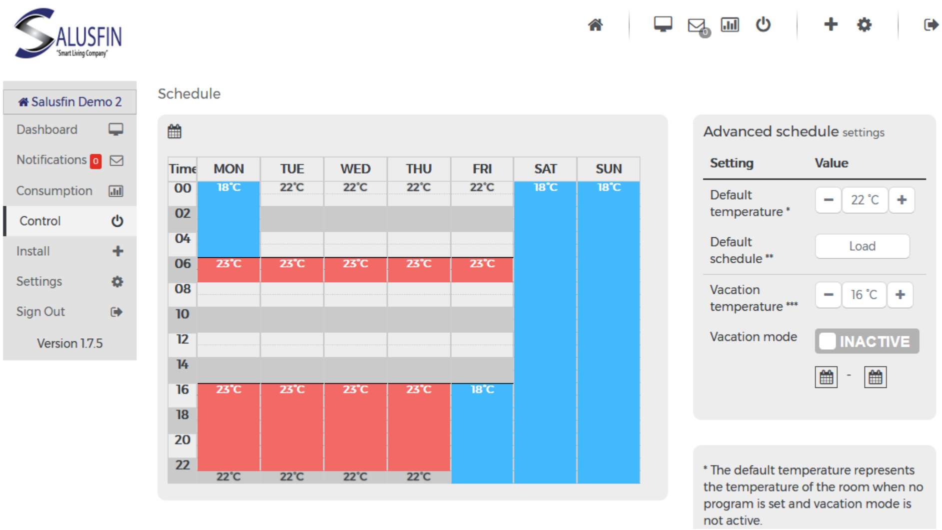


Figure 4: Temperature setting according to user preferences (figure from SAL)

The solution provides results in the form of graphs to show key energy consumption information to the users as shown in Figure 5.

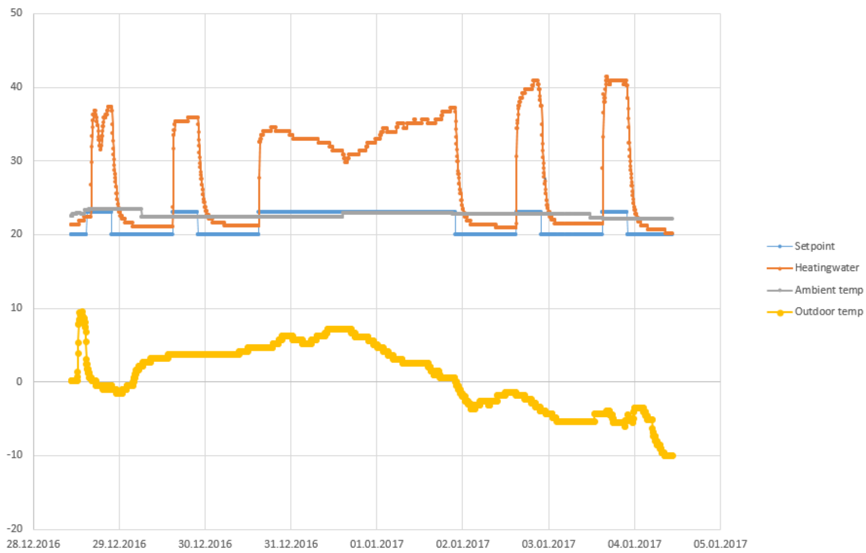


Figure 5: Temperature patterns (figure from SAL)

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 731297.

3.3 Decision making process with the pilot housing association

Two board members in a pilot housing association implemented the solution in their homes in December 2016. The project then made a proposal to the housing association's board in March 2017 and during their General meeting in April 2017 to implement the solution for the whole building. The discussions resulted in a positive decision and the board would supervise the progress. Furthermore, discussions were started with other housing association in the same district. However, the other housing association has to yet decide whether they will deploy the solution proposed.

3.4 Installation approach

Based on the proposal, the plan was to install the Smart Living solution in 167 apartments located as done in two phases: Phase 1 took place during September-October 2017 and the second phase took place between January-March 2018. To successfully implement the Smart Living solution, information was disseminated in the form of bulletins and training and information sessions were held for residents. Installation preparations included component sourcing, material preparations and logistics.

During the first phase, the Smart Living solution was installed in 20 apartments and during the second phase the rest of the 145 apartments were installed. The installation consisted of a gateway, 2-4 Smart thermostats (depending size of the apartment and amount of radiators), and temperature sensors for measuring ambient and heating water temperatures. The type of installed equipment was adjusted based on experiences gained during Phase 1 and from end user feedback.

3.5 End user support and post installation activities

End user support is organized in three tiers. The service company takes care of the Tier 1 support and Salusfin is responsible for Tier 2 & 3. The service personnel are provided with the necessary training and materials. Customer feedback was collected 2-5 weeks after the installation phase. Salusfin has organized frequent feedback sessions with Tier 1 and have had arranged onsite support for residents during the month after the installation of the system was completed. The onsite support was helpful for the apartment owners and many elderly residents got assisted to take the Smart thermostats into use, however with many of the apartments the limited internet connectivity made the communication difficult for the system.

3.6 End-users' and stakeholders' involvement

The installation plan for Action 4 includes several actions beginning from pilot experiments to ensuring social acceptance of the Smart Living solution to manage demand response. Residents of the apartments as well as the housing association were informed about the planned steps within the mySMARTLife project.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 731297.

3.6.1 Communication activities for the end-users

Initially, the smart thermostats were installed as a pilot experiment in two apartments in Haapaniemenkatu 12 in December 2016. There have been several discussions with the pilot testers they have been also shortly interviewed. Results of that interview discussed during the annual general meeting of the housing association in April 2017. The meeting led the housing association to proceed with further Smart Living installations. Prior to the annual general meeting there had also been several discussions with the housing association board.

Before the first set of installations (in 20 flats), the residents of the whole building were informed about the installations through info leaflets delivered to their homes containing brief information about the smart thermostats and possibilities to reduce energy consumption. User-friendly manuals were also distributed to the apartments during the installation phase. Furthermore, two info evenings have already been organized and will continue to be organized in the future as needed. Two workshops dealing with general energy retrofitting measures were also held as described in Chapter 3: Energy Renaissance in D4.2. The set of end-users, that decided to participate in heat demand response pilot (action 4), were contacted personally and they also gave feedback on their thermal sensations via QR-questionnaire developed by VTT. A press release was also sent after the first set of installations.

3.6.2 Training of the staff of Helsingin Merihaka Oy

Helsingin Merihaka Oy is responsible for the real estate management and maintenance of buildings in the Merihaka area. There have been several discussions about the mySMARTLife project with the CEO of the company. Trainings for the maintenance and customer service personnel have been organized to ensure understanding of the actions being implemented in Merihaka. Further trainings will be organized in the future as deemed necessary. Figure 6 is an example of an installation in an office.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 731297.

Figure 6: Installing smart thermostat in the office in Helsingin Merihaka Oy. The thermostat was installed as an example and a tool for advising the residents

3.6.3 Questionnaires and feedback collection

Satisfaction with thermal conditions and with the smart thermostat solution was measured by two questionnaires. First questionnaire was administered to the first set of apartments with the installation, after approximately one month of use, in November-December 2017. The second questionnaire was administered in April-May 2018, approximately one month after the installations to the whole building. Both questionnaires demonstrated that residents were generally happy with their thermal conditions. In addition, both questionnaires prompted to put more effort in guiding the users in the use of the smart thermostats and the application.

The smart thermostats have been installed in all apartments in the one building. However, it was revealed that all apartments do not have an internet connection as default. Therefore, the performance data cannot be collected from the apartments not having an internet connection. Each Smart thermostat and sensor per apartment are connected wirelessly to a dedicated Gateway per apartment. The Gateway utilizes resident’s personal internet connection for handling communication to Salusfin cloud.

This project has received funding from the European Union‘s Horizon 2020 research and innovation programme under grant agreement No 731297.

3.7 Results from demonstrating smart control and thermal demand response at apartment level

Salusfin has together with the service company of the housing association installed Smart thermostats which communicate wirelessly with Salusfin Gateway in the apartment. Besides the thermostats we have installed a number of sensors to get more information from the apartment.

In some of the apartments we have also installed additional sensors to support Human Thermal Model concept. This data, together with surveys conducted by VTT, helps to see and understand how the residents feel about the optimization.

An important part of the optimization is that Salusfin receives information from the energy company when the production cost of district heating is expected to be more expensive. Consumption is adjusted / switched off following the Demand response model of monitoring and control. The building mass can act as heat storage and balance heat consumption and property owner could get benefits in return from allowing the property to be used as a heat storage.

The benefits for the inhabitant of the apartment shall be increased comfort, possibility allow room level control, set a weekly schedule, arrange night-time temperature drop and have visibility to the temperature for the home at any time. The visibility and control are provided through a multilingual mobile APP / Web portal that is easy to access and use. In addition of having Comfort the Solution can be extended to having additional services like Security and Safety added. As one bonus feature is that the Smart thermostat have weekly exercise of the valve in order to prevent it from getting stuck, thus lowering the maintenance need. Benefits for the society shall be lower emissions due to savings when demand is impacted by cost of producing the energy.

Figure 7 shows the observed space heating energy consumption normalized for weather until end of October 2019. There is a noticeable decreasing trend in the heating energy consumption since the smart control system was commissioned in the whole apartment building. However, the data collected so far seem to indicate that the system is falling short of the 13 % energy conservation goal but on the other hand there is not yet enough data for a conclusive judgment. Moreover, it can be expected that a new system takes some time to have full impact as people familiarize themselves with using it and adjustments are made.

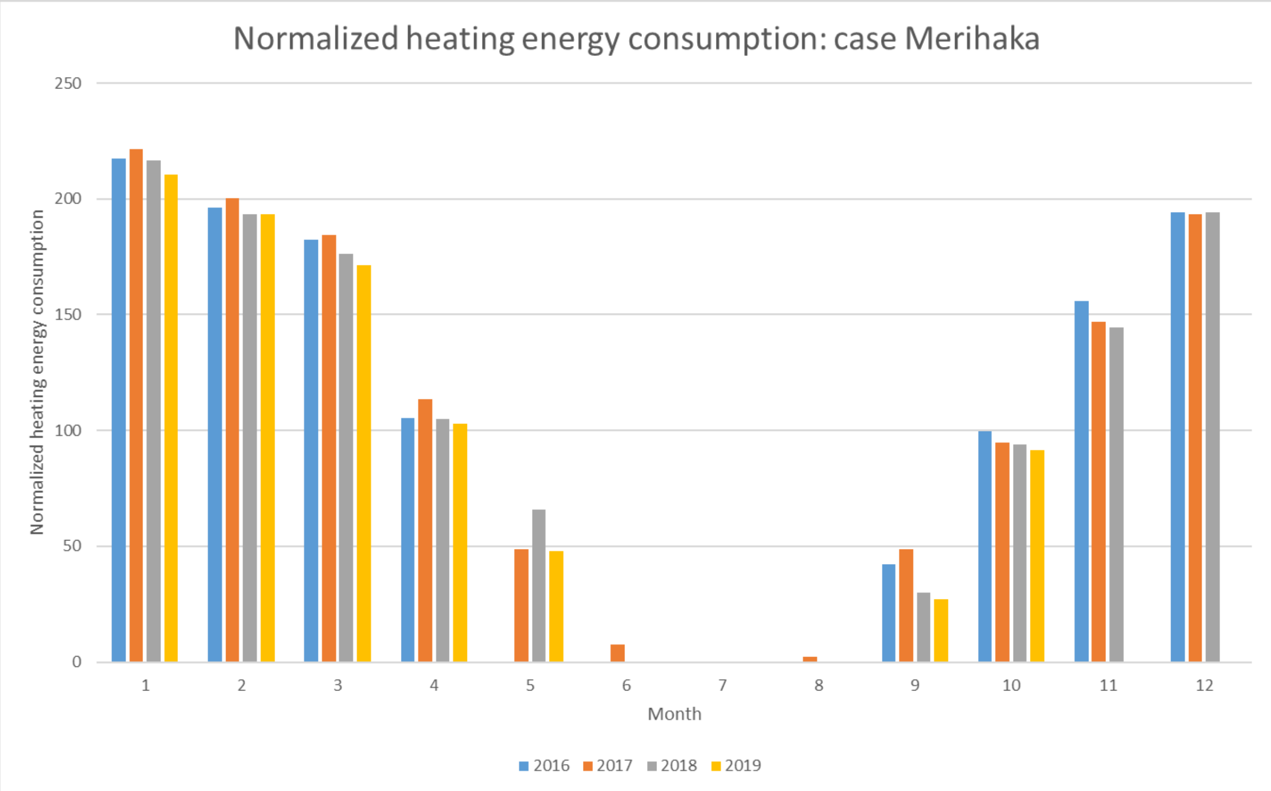


Figure 7: Normalized heating energy consumption in Merihaka pilot building

3.7.1 Heat demand response pilot in Merihaka

Heat demand response pilot in the apartment building of Merihaka started with three voluntary participants. The three pilot apartments were connected to heat demand response in spring 2018. Later in spring Helen gave a presentation on the carbon neutrality targets as well as on the concept of heat demand response in Summer Event "Kesäkarnevaalit" attended by the representatives of housing associations and residents of Merihaka. At the same event, VTT gave a presentation about thermal sensations of humans and the human thermal model (HTM). The objective of these presentations was to give information for the residents of the area about the mySMARTLife project as well as to encourage them to participate in pilots and take part in energy efficiency measures.

The three pilot apartments of Merihaka were connected to heat demand response in spring 2018. The residents gave feedback on thermal sensations via a QR-code questionnaire developed at VTT. The results of the questionnaire are presented in the next subchapter 3.7.3. During the spring and early fall 2018, the heat demand commands were based on a predetermined calendar schedule done by Helen and the commands were send from Helen's system to the cloud service of Salusfin. Salusfin then transmitted the commands to the smart thermostats of the apartments via internet connection.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 731297.

In fall 2018, Helen improved the calculation of heat demand response commands from a predetermined calendar schedule to a command that is calculated based on the estimated production status and the need for heat demand response in Helsinki. Therefore, the heat demand response commands sent to Salusfin's cloud service have been based on automated calculation in Helen's system since fall 2018. The commands sent from Helen have been -1, 0, +1 during the pilots. The demand response commands are reported more in detail in D4.3.

In March 2019, an expansion of heat demand response was planned by Helen, Salusfin, VTT and the City of Helsinki. The aim was to ask the residents, that have accepted the terms and conditions of Salusfin, which contain heat demand response, to voluntarily participate in heat demand response pilot and give feedback via QR code on thermal sensations. The questionnaire to participate in demand response was sent via email to ca 50 residents. A few residents got interested in the possibility to participate but eventually only one new resident was willing to participate in demand response and give feedback on thermal sensations until the end of the heating season (May 2019). Therefore, in spring 2019, four voluntary participants were giving feedback.

After the low response percentage, it was concluded that the participation demanded too much from the residents' side, since it required to read email in detail, sign a paper to give permissions to use the temperature data of the apartment for research purposes as well as giving feedback via a QR-code system on thermal sensations. In addition, it can also be concluded that the customer engagement is hard to reach if the participation requires extra activity from the customers' side, In this case, the heat demand response would have been totally automated and the customer would not notice it. However, giving feedback via QR-code still requires an extra effort since the QR-code must be read and the feedback needs to be given via phone or tablet. In addition, heat demand response as a technical concept is usually not familiar to non-energy experts, which may affect the interest to participate.

As a result of the low success with the voluntary participation, the housing association was contacted and informed about the planned next steps in heat demand response pilot. The original idea was that the apartments agreed on the terms and conditions of Salusfin will be connected to heat demand response during the heating season 2019-2020 and a paper survey on thermal sensations will be conducted for all residents of the building. However, eventually, due to technical difficulties, heat demand response cannot be expanded to the planned ca 50 apartments. Salusfin's smart heating system is using the personal internet connections of the residents to send the heat demand response commands to the smart thermostats in the apartments. At Salusfin, based on the historical data, it was observed that the internet connection is not continuous in all apartments or the internet connection has changed and therefore, there is a risk that the heat demand response commands might not go through. It was concluded by Salusfin, that due to the internet connection issues, the demand response could be expanded only to the apartments where the smart thermostats have a continuous internet connection, meaning less than 10 apartments. Less than 10 apartments are not enough to give valuable information to the research done

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 731297.

under mySMARTLife pilot. In the end of October 2019, it was decided by Helen and agreed between the project partners that heat demand response will not be further continued due to the issues with internet connections.

One of the objectives of the heat demand response pilot in Merihaka was to demonstrate the technical capabilities to perform demand response via smart thermostats in an apartment building. In the case of the piloted building, there was no internet connection provided by the housing company and the residents are therefore using their own internet connections. If heat demand response is done via smart thermostats in an apartment building in the future, the smart thermostats should be connected to the Wi-Fi network of the housing company instead of personal internet connections of the residents. The personal internet connections might not be continuous and can change to a new internet connection. In addition, some residents might use only the mobile data and share the internet via phone, meaning that the internet connection will be gone if the resident is not at home. The mobile internet network is generally very good in Finland including limitless internet with rather low price and therefore, especially in small apartments, there might not be any need for other internet connections. In addition, if the resident of the apartment has changed, the internet connection will change too. Therefore, the smart thermostats system should be connected to the internet of the new resident, which requires an extra effort.

The internet connection issues or change of internet connection result in a risk that the demand response commands do not go through to the smart thermostats continuously. This risk can be avoided if the smart thermostats are connected to the internet network of the housing company instead of residents own internet connections.

3.7.2 User feedback

Human thermal model based thermal sensation feedback system was commissioned in spring 2018 in Merihaka within three apartments. During autumn 2019 one more apartment was included in the feedback cycle. Figure 8 presents the feedback received from the occupants as well as the outdoor temperature during the time the feedback has been collected. The larger dots in the figure represent the feedback of the occupants whereas the smaller blue dots represent the outdoor temperature.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 731297.

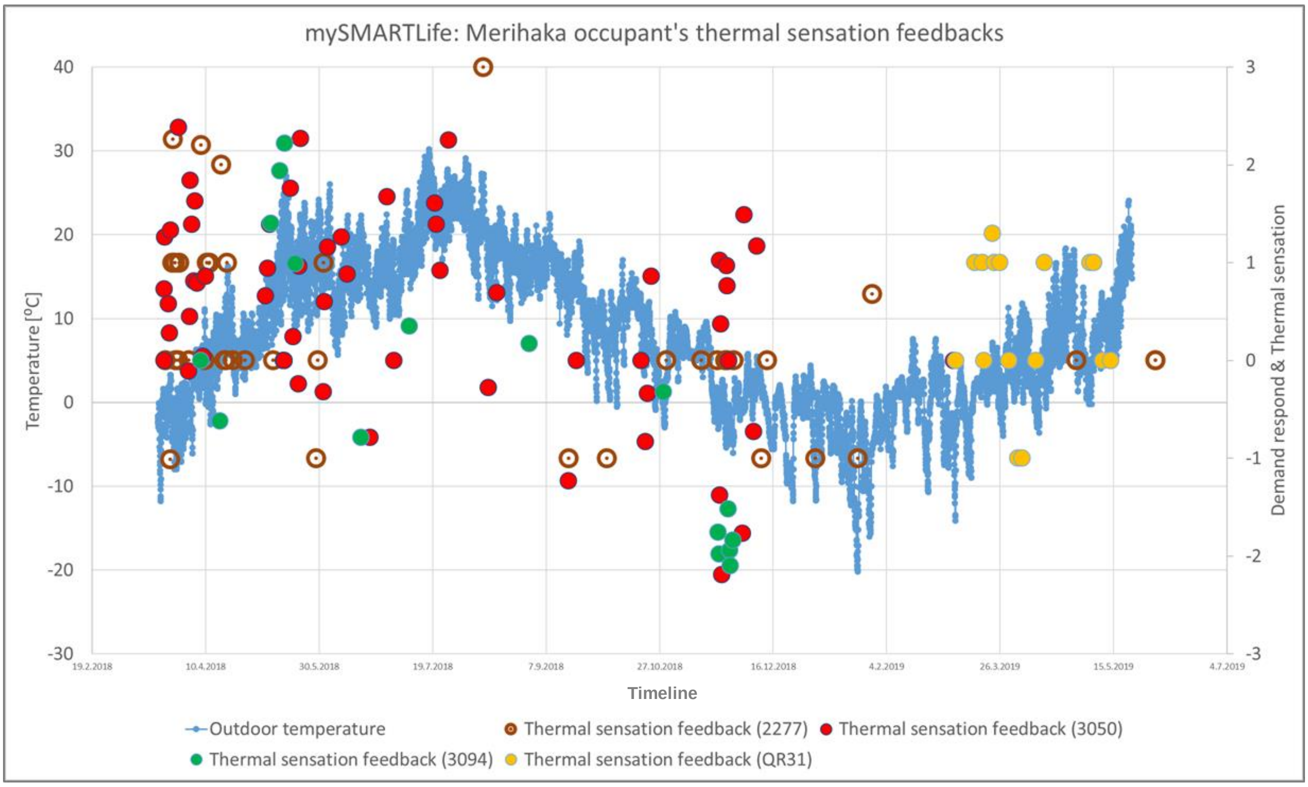


Figure 8: Thermal sensation feedback of Merihaka occupants

It can be noticed from Figure 8 that there is a significant difference in the way the thermal sensation is felt on an individual level. There is one occupant, whose thermal sensation seems to correlate with the outdoor temperature (green dots) while the feedback of the other three occupants included in the HTM-piloting seems to not be correlating with the outdoor temperature.

The normal distributions of occupants' feedback during demand response test sessions is presented in Figure 9. The peak of the curve when a negative demand response signal has been active and the room temperature has been decreased by one degree is between 0 and 1. Thus, the thermal sensation of the occupants is between normal and slightly warm. When the demand response signal has been positive and the room temperature has been increased by one degree, the peak of the curve is below 0.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 731297.

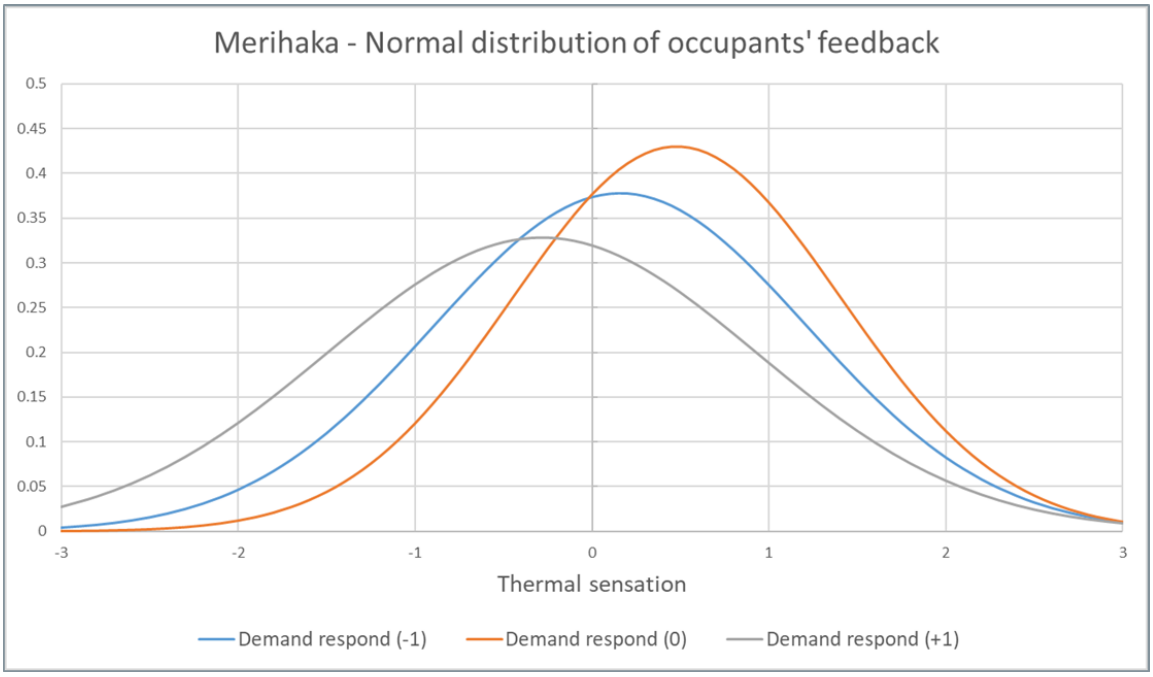


Figure 9: Normal distribution of Merihaka occupants' feedback

The results of the feedback analyses suggest that there is no correlation between the thermal sensation of the occupants and the thermal demand response. This can also be noticed from Figure 10 which presents the average feedback received, the standard deviation of the feedbacks and the share of satisfied occupants during positive and negative demand response signals and during the time there has been no demand response in either direction.

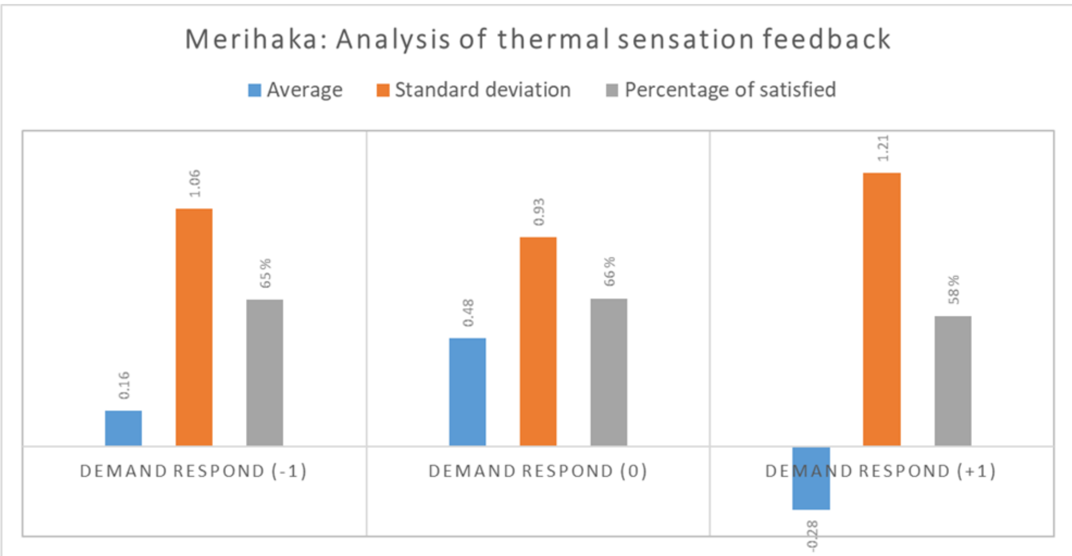


Figure 10: Thermal sensation feedback analysis from Merihaka

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 731297.

4. Smart demand response in an office building: Viikki Environmental House

4.1 Design and implementation

The smart demand response systems (both electricity and heating) was demonstrated in an office building in Viikki Environmental House. The target is to test energy efficiency measures in an office building, which already combines several renewable energy solutions.

4.2 BEMS systems and performance monitoring in Viikki Environmental House

Several systems exist in the Viikki Environmental House:

- Building automation and control system (Trend's BACnet based system)
- Electricity consumption measurement with approximately 35 electric meters (provided by Mitrix)
- Energy storage (provided by Siemens), PV production and EV charging points
- Lighting with the occupancy based control (ABB's KNX based system)

In the Viikki demonstration actions, BEMS has been supplemented with Fourdeg's solution in the whole building. Additionally, VTT's HTM control has been applied in three rooms instead of Fourdeg's control. Control signals for the heat demand response will be sent by HELEN. The existing and new systems are connected (where applicable) to the Cloud, which allows to analyze the required performance monitoring and related indicators for the demonstration actions.

4.3 Human Thermal Model based control

Human Thermal Model (HTM) is based on true anatomy and physiology of the human body and it can be used for estimating thermal behaviour of the human body under both steady-state and transient indoor environment conditions. In Viikki case HTM model is used for individual thermal comfort control via Fourdeg's smart heating system in five different spaces (total eight smart thermostats). The HTM control concept is shown in Figure 11.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 731297.

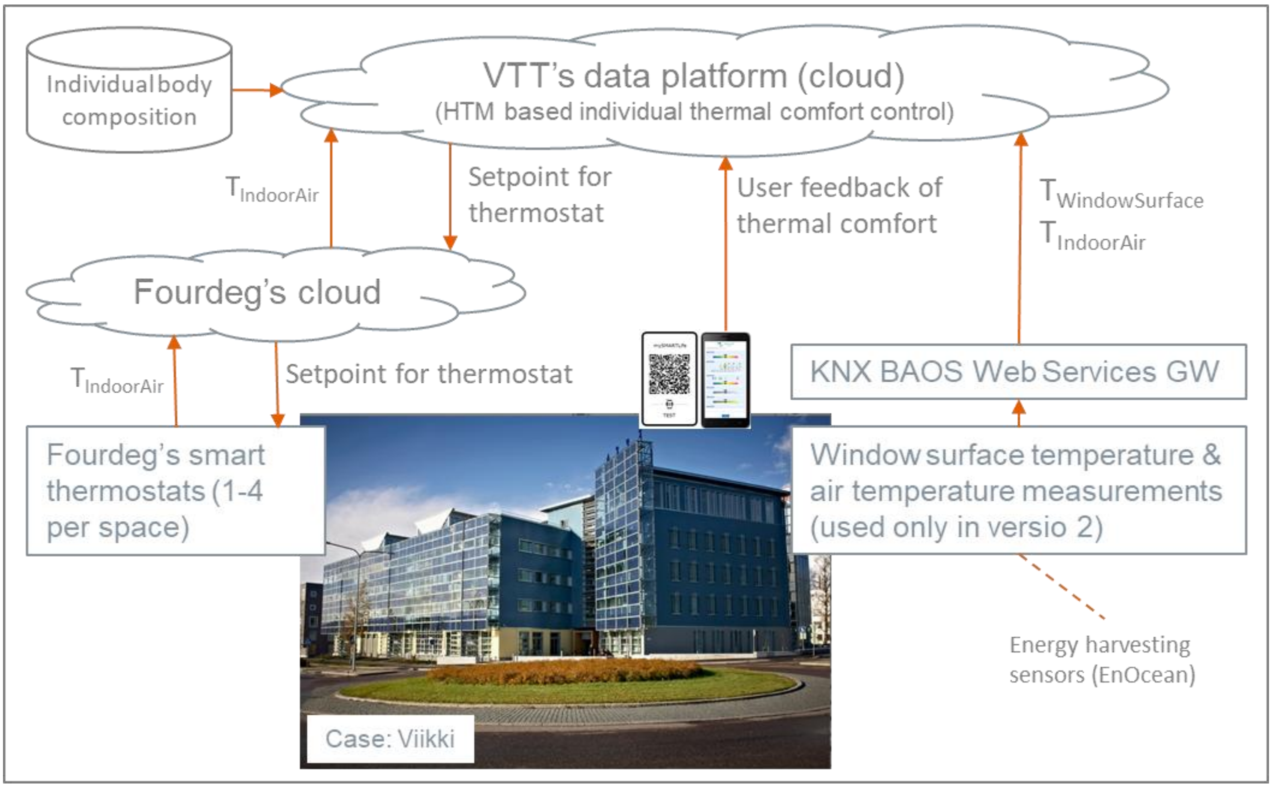


Figure 11: HTM control concept

HTM control works as follows:

1) Update studied space related measurement values every 5 minutes
   a. Version 1: Read indoor air temperature value (sensor location in the thermostat) via Fourdeg's smart heating solution RESTful API.
   b. Version 2: In addition to version 1 read also window surface temperature value and indoor air temperature value in the occupied zone via KNX BAOS RESTful API. Used sensors are based on the EnOcean energy harvesting technology and connected to KNX based system via EnOcean-KNX gateway.
2) HTM is running on VTT's data platform (cloud) and it will calculate new optimal operative temperature setpoint value for the control every time the indoor air temperature has changed. The calculation utilizes also user's thermal sensation feedback(s) given by VTT's QR code based feedback application.
   a. Version 1: The input for the HTM calculation are the measured indoor air temperature and the body composition of the occupant (measured or calculated before) in the studied space.
   b. Version 2: The operative temperature is calculated based on the measured indoor air and surface temperatures. The input for the HTM calculation are operative temperature and body composition of the occupant (measured or calculated before) in the studied space.

3) Update the smart thermostat setpoint value via Fourdeg's smart heating solution's RESTful API every 15 minutes.

The user satisfaction of thermal comfort (based on VTT's QR code based feedback system) was 68 % before the HTM control and 98 % when the HTM control version 1 was used. The difference in user satisfaction was quite big (+44 %) and more research is needed.

4.4 Users' feedback

The effects of thermal demand response actions on the users' comfort are to be monitored and analysed in the course of the project, since these affect not only the energy related costs, but also the users' well-being and work efficiency. The user's experience is monitored in single office rooms, both in the rooms adapted for Fourdeg's thermal demand response system and in the rooms adapted for VTT's Human Thermal Model. In order to reliably compare the users' experience of comfort and evaluate the effects of thermal demand response actions, three separate campaigns to gather feedback are conducted at representative points of the project:

1. Baseline questionnaire in 11/2017 to measure the current status of comfort before installation of demand response systems
2. Questionnaire in 12/2017 after the installation of demand response systems, but before any control actions are started
3. Questionnaire in 1/2018 during the demand response actions

The questionnaires are accessible for the users of the office rooms through a QR code feed-back application developed at VTT. The QR code is printed in the rooms, in which either Fourdeg's thermal demand response system or VTT's HTM is tested. The users are asked to give feedback based on their experience at the moment. Each campaign to gather feedback lasts approximately five working days, and the users are encouraged to answer several times during the campaign. From the point of view of analysing the effects of changes in room temperatures, it is important to receive feedback trackable to the location and time.

The questionnaires aim at monitoring the instant comfort experience of the user. Thermal sensation measures the experience of temperature. However, also other measures for comfort are used, since many devices, such as air conditioning affects the user experience and can be controlled as a part of the demand response actions in Viikki Environmental House. The following measures and units are used to measure the experience of comfort in the office rooms:

- **Thermal sensation:** Thermal sensation is a personal experience about heat balance in the existing environment. This is evaluated with a numeric scale from +3 (hot) to -3 (cold).

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 731297.

- **Clothing:** The amount of clothing and heat resistance are evaluated with a unit clo. For example, the value of 0 clo is given for a person without any clothing, a regular dark lounge suit has a value of 1.0 clo and thick outdoor winter clothing has a value of 3.0 clo.
- **Activity:** Activity effects the metabolism and the body's own heat productions, and it is typically described with a unit MET. For example, activity of a sleeping person is 0.67 MET, of a sitting person 1.0 MET and of a breezily walking person 3.0 MET.
- **Air quality:** Air quality affects heath, well-being and work efficiency. It is evaluated here with a qualitative range.
- **Lightning:** Illuminance, surrounding materials, reflections and orientation of the lights as well as the requirements of the work affect the experience of lightning conditions. It is evaluated here with a qualitative range.

The scales to evaluate different measures are presented in **Table 3**.

Table 3: Predicted Mean Vote (PMV) sensation scale used to evaluate the level of thermal comfort (ISO 7730:2005).

Thermal sensation [-]	Clothing [clo]	Activity [MET]	Air quality [-]	Lightning [-]
+3 / Hot	3.0	3.0	Satisfied	Satisfied
+2 / Warm	2.0	2.5	Fairly satisfied	Fairly satisfied
+1 / Slightly warm	1.0	2.0	Neutral	Neutral
0 / Neutral	0	1.5	Fairly unsatisfied	Fairly unsatisfied
-1 / Slightly cool		1.0	Unsatisfied	Unsatisfied
-2 / Cool		0.5		
-3 / Cold		0		

Details and the results of the QR code based questionnaire will be provided at the next phase, by M36.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 731297.

4.5 Results from demonstrating smart heating system and demand response in an office building

4.5.1 Thermal energy savings and demand response

Fourdeg Smart Heating(R) is an A.I. and IoT technologies based service to predict and provide the correct heating to every room in buildings which are heated with water radiators. Fourdeg holds an EU patent for the method and system thereof. The users in the rooms can give their desired comfort temperature within the limits that are allowed by the building landlord and the services delivers the very temperature. The users are present typically in office buildings only during the office hours which enables to reduce ventilation but also heating during the absence. The key feature of Fourdeg Smart Heating(R) is to ensure that the comfort temperature will be reached before the ventilation will be running higher and the users are back in business. The energy efficiency is optimised while each room has now synchronized targets for ventilation (cooling) and heating. Fourdeg Smart Heating(R) operating principle is presented in Figure 12.

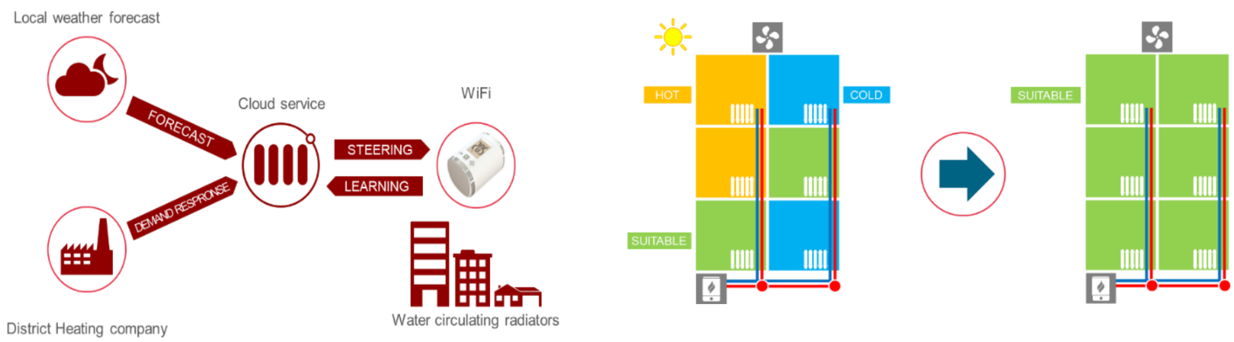
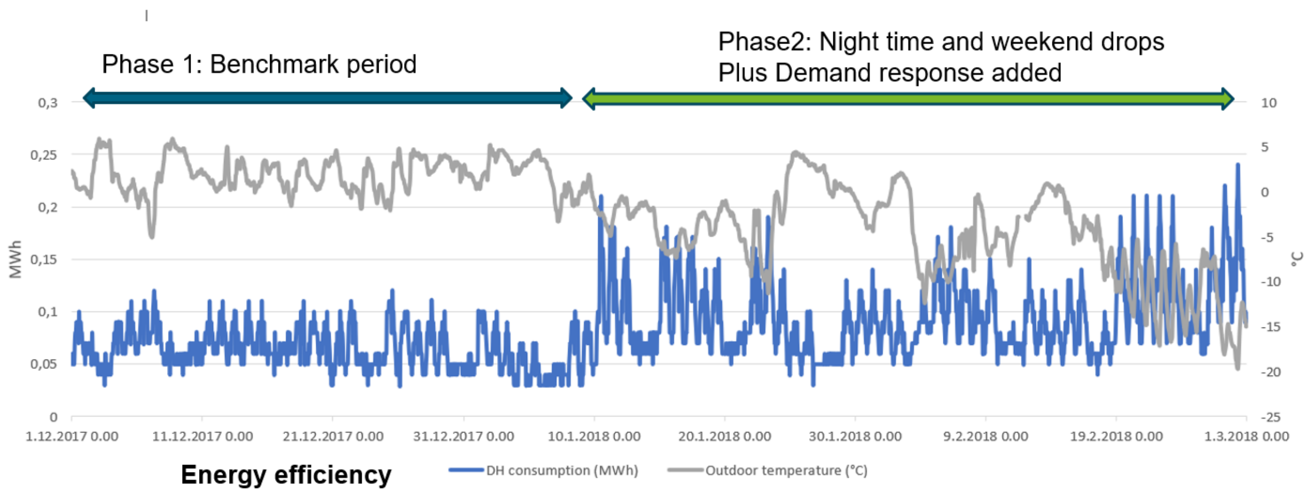


Figure 12: Fourdeg Smart Heating(R) operating principle and impact in heating quality

In Viikki case another parameter was taken into consideration to optimize energy consumption by obeying the demand response signal from the district heating energy production. The idea was to reduce heating during the peak load hours in the network and at the same time ensure that the user comfort will not be sacrificed.

The Viikki Environmental House energy consumption measurements were conducted first as a benchmark during December before the installation of Fourdeg Smart Heating(R) and then measuring the consumption after the installation. The weather corrected energy efficiency gain varied between 7.3...10.9% during the winter months even if the demand response signal was applied. Note that the district heating demand response does not reduce building level consumption but rather moves the peaks and may cause a little extra consumption. The Viikki Environmental House is a very specific building due its construction methods and thus the achieved 10% gain was beyond expectations. Viikki energy performance is presented in Figure 13.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 731297.



Energy efficiency

	2016/2017	2017/2018	Difference
December	61.57	61.29	-0.45%
January	73.57	68.20	-7.30%
February	68.71	61.21	-10.93%
March	59.98	54.49	-9.16%

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 731297.

Figure 13: Energy efficiency gain data and results in Viikki Environmental House.

Excellent results were reached in piloting the district heating demand in Viikki Environment House to a) reduce the need for heating during peak consumption hours and b) enable greater flexibility for energy production. Even more interestingly Fourdeg Smart Heating(R) supports heating quality management at room-level accuracy which performs automatic heat demand response in each room to the extent of the very room capability to flex. That functionality is required to perform the flexibility of the heating energy consumption without compromising users' comfort. During the pilot, employees of the Viikki Environment House gave constant feedback of their perceived thermal sensations. The results are presented in chapter 5.5.3.

The heat demand response commands are based on a calculation in Helen's production management system and the commands are published via an API for the smart heating automation system providers. The heat demand response commands of Helen are explained more in detail in D4.3. An example of heat demand response and night and weekend drops in Viikki Environment House is presented in figure 5.1.1-3. The heat demand response commands of Helen are +1, -1 or 0 and these commands affect to the set point value. In the normal situation, the set point curve is 21.5 degrees, up regulation is 22.5 degrees and down regulation 20.5. At night and on weekends, there is the own down regulation of the office building, which also affects the set point values.

The temperature of the room (red curve) follows the set point values (yellow curve) and the measurements of the temperature in the room. Valve position sets the room temperature to follow the set points and the measured temperature. The valve position control is based on a PID controller, which softens the effects (it anticipates the coming temperature change and controls the valve position so that the temperature stays as stable as possible). At weekend 15.2. and 16.2., there is a night drop (buildings own down regulation, not related to heat demand response commands), which follows also the outside temperature. It can be seen that the valve position stays closed during weekend and it is not much affected by the set point changes. An example of heat demand response curves is presented in Figure 14.

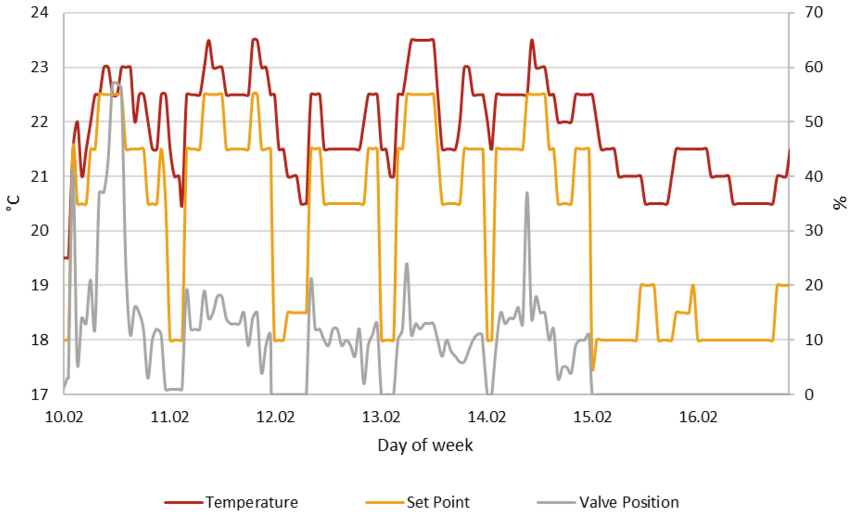


Figure 14: Example of heat demand response and night and weekend drops during one week period. Red curve: Measured temperature of the room, yellow: set point values of one week, Grey: valve position.

4.5.2 Electric demand response

For electricity consumption, production and storage, Viikki Environment building has smart control and optimization algorithm for the energy system provided by Siemens. The electrical energy storage at Environment building is Siemen's SieStorage(SIESTORAGE) which is controlled and optimized by DEMS, distributed energy management system. DEMS is used for local optimization of the assets installed in Environment building, mainly by controlling the operation of the battery energy storage system (BESS). Monitoring other the assets connected to the building, the system can optimize the usage of the BESS. Following assets power measurements are deliver to DEMS:

- electric vehicle charger
- solar panels
- elevators

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 731297.

In addition, main power consumption is delivered to the system, enabling point of interconnection (POI) energy optimization (price-based optimization). Optimization is realized once per day and is based on following topics:

- Forecast of the building consumption based on the measurement of POI
- Forecast of the PV production based on the day-ahead forecast
- Energy optimization based on the day-ahead electricity prices

In addition to the local optimization, system is able to provide ancillary services to the transmission system operator (TSO). The resources are connected and aggregated to the market via DEMS by Helen, the utility company and service provider. The assets which can participate to the Fingrid (Finnish TSO) markets are BESS, air conditioning and lighting of the building. In principle, BESS can participate to the market at the same time than optimizing the energy at the POI by dividing the control of the BESS in two virtual assets. One can do optimization and other one can provide ancillary services.

4.5.3 User feedback

Human thermal model based control was commissioned on 6.11.2018 in Viikki Environment House. Thermal sensation feedback before the commissioning of the HTM-control is presented in Figure 15. The figure presents the averages and deviations of thermal sensations as well as the share of occupants being satisfied with the thermal conditions within their office rooms. The range for being satisfied is from slightly cold to slightly warm.

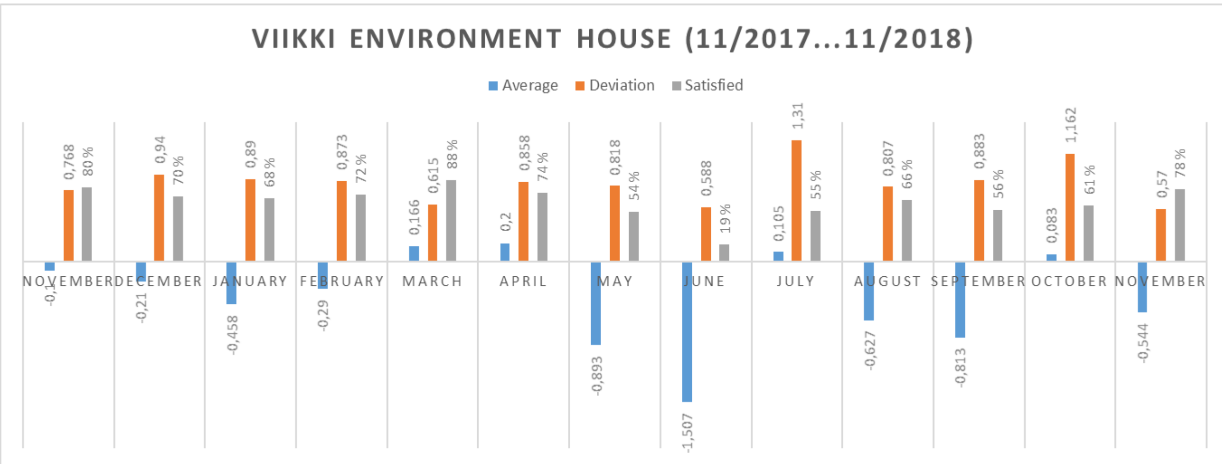


Figure 15: Thermal sensation feedback Viikki Environment House 11/2017-11/2018

There is some variation within the share of satisfaction regarding the thermal sensation especially during May and June. This was identified to be caused by poorly calibrated cooling control which was later

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 731297.

improved. The effects of the improvements can be seen from the feedback received during July, since the average thermal sensation already exceeds 0.

Figure 16 presents the feedback results before the implementation of HTM-based control, during heat demand response experiments and after commissioning of HTM-based control. There is a significant increase of 30% in the share of satisfied thermal sensation between the original control and HTM-based control. During the demand response experiments the satisfaction seems to decrease. Therefore, there seems to be some correlation between the thermal demand response and thermal satisfaction within an office building.

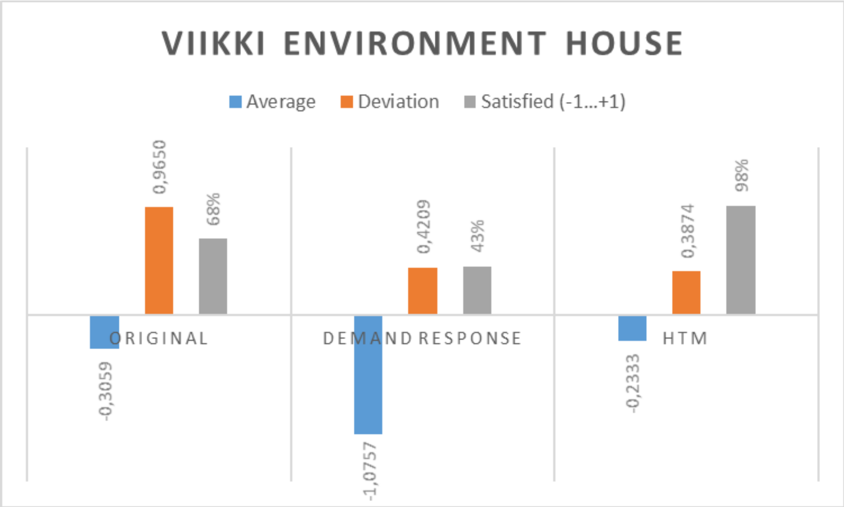


Figure 16: Thermal sensation feedback Viikki Environment House before commissioning of HTM-based temperature control, during heat demand response experiments and with HTM-control

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 731297.

5. Conclusions

This deliverable describes the design and implementation of smart home solutions in new buildings and smart demand response systems in office in Helsinki. The control algorithms and smart demand control systems have been introduced in D4.3 and this deliverable continues to describe how have these algorithms and control systems been designed and implemented in Helsinki. Main focus in this deliverable is in zones 1 and 3.

This deliverable includes testing of smart thermal demand response in an apartment building in Haapaniemenkatu 12 in Merihaka with Salusfin, Helen and City of Helsinki. This performance is also analysed using VTT's Human Thermal Model (HTM), with real life measurements related to HTM realized in four apartments. The second key point of the deliverable is the various smart building demonstrations done in an office building in Viikki, including the thermal demand response with Fourdeg's system, the electricity demand response with ventilation, lighting and electricity storage. Viikki demonstrations require integration with various existing BEMS and on-site RES appliances. Furthermore, HTM has been used in Viikki in three office room to test the real time control of the indoor temperature based on individual performance and preference of the persons sitting in these rooms.

The learnings from both of these activities have been used to study the potential for thermal demand response in district heating operated by Helen. This also includes investigating possible business models as well as analyzing the value for the thermal demand response. The potential business models have been discussed and developed together with the partners participating to the demonstrations and will be reported in detail in D8.9 "Report on business models of selected use cases" as thermal demand response has been selected as one of the use cases for the exploitable results of the project.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 731297.