DELIVERABLE ICE T3.4.1 ASSESSMENT OF THE PERFORMANCES

DECEMBER 2021

ICE Deliverable T3.4.1 REPORT

Assessment of the performances

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Recommended Citation Format:

Vonk, G., Vente, H., Li, X., Ioannidis, A., Stephanides, P., Chalvatzis, K. J, 2021. Assessment of the Performances (ICE report T3.4.1), Intelligent Community Energy. https://www.ice-interreg.eu/public-deliverables

About ICE

Supported by the Interreg VA France (Channel) England program, the Intelligent Community Energy (ICE) project aims to design and apply innovative intelligent energy solutions for isolated areas of the Channel. Islands and peripheral territories face specific energy challenges. Many islands are not connected to European electricity grids and are dependent on imported fossil fuels, especially oil-fired thermal generators. The energy systems on which they depend tend to be less reliable, more expensive and emit more greenhouse gases than on the European continental grid.

In response to these issues, the ICE project considers the entire energy cycle, from production to consumption, and integrates mature or new technologies to develop innovative energy solutions. These solutions will be tested and tested at two pilot demonstration sites (Ushant Island and the University of East Anglia campus), to prove their feasibility and develop a general reproducible method for other isolated smart energy systems. elsewhere. To transfer this methodology to other isolated territories, ICE will offer a global low-carbon transition commercial offer. This will include a comprehensive assessment of local energy resources and conditions, a tailor-made model proposal for the energy transition, and a set of low-carbon skills and technologies available in a consortium of selected companies. This ICE-certified consortium will promote this offer to other isolated territories in and outside the Channel area (5 territories initially). The ICE partnership brings together researchers and support organizations for SMEs and benefits from France – UK complementarity in terms of knowledge and technological and commercial development.

The involvement of local and European SMEs will help to strengthen competitiveness and transnational cooperation.

Table of Content

1. Introduction

This document presents the experimental results of the technical solutions for an intelligent energy system (smart grid) selected and deployed on the island of Ushant, as part of the European ICE project of the Interreg France-Channel-England program.

This document presents the results of the connected object infrastructure with, first, the results of the sensors reporting information on the level of energy consumption, then the results of experiments making the link between production and consumption of energy with the control of electric radiators, then the deployment of informative objects for consumers.

We do not present in this document the experiments relating to the tidal turbine as well as the data relating to energy management. Regarding the tidal turbine, technical problems did not allow sufficient data to be accumulated to allow a complete and relevant analysis. As for energy management, this part is handled by EDF, the sole operator of Ushant, and performance data could not be transmitted.

2. Analyses of the results of the experimentations

2.1. Internet of Things (IoT) infrastructures:

In this section we present the results of the connected object infrastructure. We start by presenting the data collected by the sensors in public buildings and the rendering of the data processing and display on the online platform. We then present the radiator control solution. Finally, we present the experimentation with informative connected objects distributed to residents.

2.1.1. Sensors in publics buildings

In this section, we present the data from sensors installed in public buildings. In summary, the sensors installed can be broken down into two families: electrical sub-metering and ambient measurements. The data type for each building is therefore very similar and below we present the data from the Library as an example.

The first range of sensors installed makes it possible to measure the electricity consumed, by the entire building or by performing specific sub-metering on heating, lighting, outlets, etc.

The electricity consumption statement is presented in the form of a graph with time on the x-axis, and on the y-axis the electrical energy consumed, expressed in kilowatt-hours (figure below).

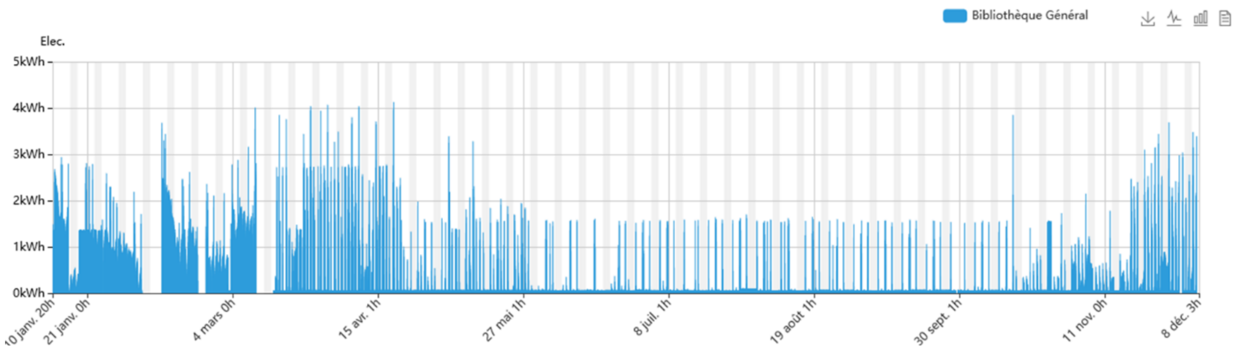

Figure 1 : Electricity consumption statement at the Library - January 2021 to December 2021

It is possible to add different electricity sub-metering to the same graph, in order to identify which equipment is responsible for the energy consumption. In the example in the figure below, we have represented the total power consumption (blue), then added the consumption of the electric heaters (green and grey), and finally added the consumption of the lighting. We see that in winter, electric heaters are the main source of electricity consumption. On the other hand, in summer, lighting represents a good part of consumption. We can also guess a consumption heel in summer, which is of the order of 60-70 Wh per hour, or a power of 60-70W. It could be a computer on standby.

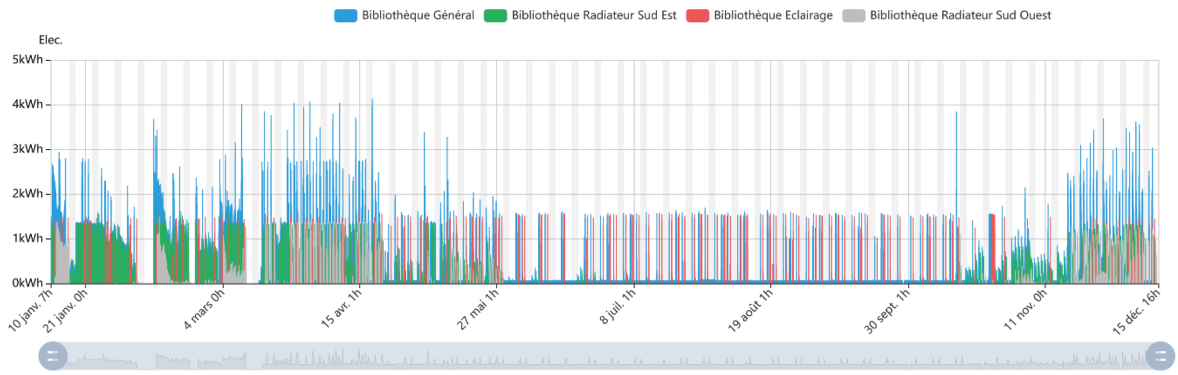

Figure 2 : Electrical sub-metering at the library - total (blue), radiators (green and grey), and lighting (red)

In addition to sensors for under-consumption of electricity, room sensors have also been installed. These sensors measure the ambient temperature, light, humidity and activity of the room in which they are installed. Some sensors can also measure the level of CO2. In addition to these data measured on site and transmitted by radio wave in LoRaWan, we have added to the supervision the information on the outside temperature, which is retrieved by API on a meteorological site for the location in question (here Ushant).

With the example of the Library (figure below), this makes it possible to analyse the temperature variation in the building (blue), and as a function of the outside temperature (pink). The activity data (red) consists of measuring the activation time of the sensor when there is movement in the room.

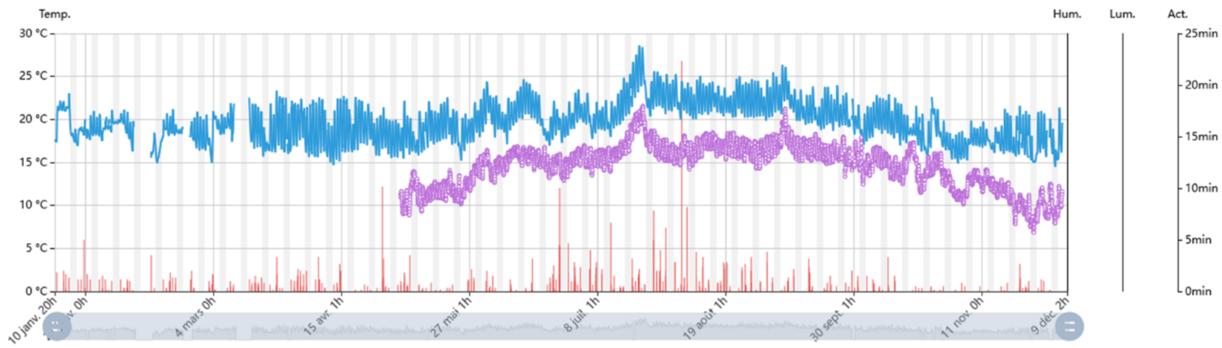

Figure 3 : Temperature reading at the Library (blue), outside (pink), and activity (red bars)

The coupling of energy data and ambient data allows more detailed analysis, in particular on the use of a building and the match between energy consumption and the use of the building. For example with the Library, we have shown in the figure below for a period from February 12 to February 21, 2021 the electricity consumption and the ambient temperature as well as the activity measured in the room. It can be seen that the heating (blue) is activated continuously, resulting in an almost constant temperature (green). At the same time, the activity data (red) show that the room was only occupied occasionally over the period. As a result, we can therefore identify that in this building the heating was not regulated and that energy savings are possible. This building in particular is one of those equipped with a heating control solution, presented in the next point.

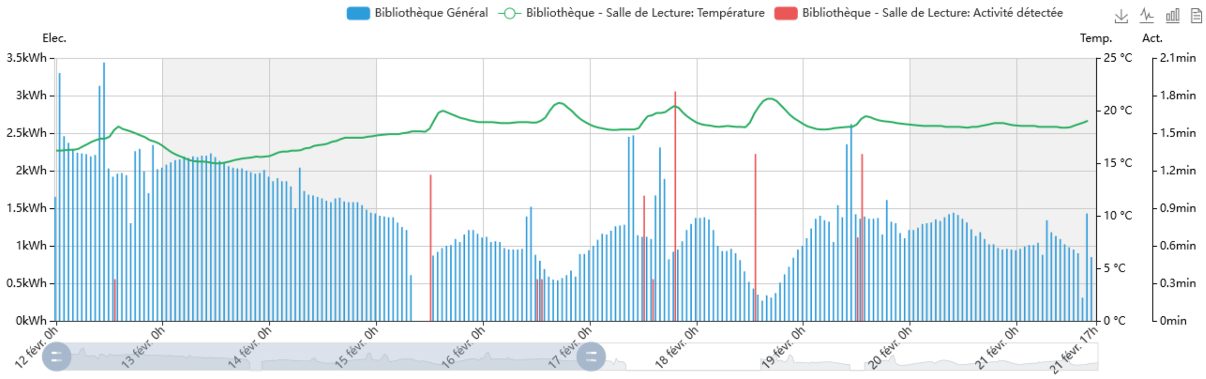

Figure 4 : Library - Reading of electricity consumption (blue), temperature (green) and activity (red) - Heating indicator when the building is unoccupied

The online platform makes it possible to analyse all the data collected and display it in the form of a graph. By providing the comfort and reduced temperature data for each building as well as the occupancy schedule, the platform produces an analysis based on the measured temperatures and thus estimates the potential for energy savings during working hours and non-working periods. worked. This saves time and makes it possible to identify the buildings where priority action will be taken.

EHPAD Période de chauffe du 2 novembre 2020 au 15 avril 2021	9%	d'économie potentielle en heures ouvrées	36%	d'économie potentielle en heures non ouvrées
Salle Polyvalente Période de chauffe du 2 novembre 2020 au 15 avril 2021		toujours en dessous des seuils	4%	d'économie potentielle en heures non ouvrées
Mairie Période de chauffe du 2 novembre 2020 au 15 avril 2021	2%	d'économie potentielle en heures ouvrées	17%	d'économie potentielle en heures non ouvrées
Aérogare Période de chauffe du 2 novembre 2020 au 15 avril 2021		toujours en dessous des seuils	2%	d'économie potentielle en heures non ouvrées
Algues et mer Période de chauffe du 2 novembre 2020 au 15 avril 2021		toujours en dessous des seuils	13%	d'économie potentielle en heures non ouvrées
Auberge de Jeunesse Période de chauffe du 2 novembre 2020 au 15 avril 2021		toujours en dessous des seuils		toujours en dessous des seuils
Bibliothèque Période de chauffe du 2 novembre 2020 au 15 avril 2021		toujours en dessous des seuils	11%	d'économie potentielle en heures non ouvrées
Club des Anciens Période de chauffe du 2 novembre 2020 au 15 avril 2021		toujours en dessous des seuils	12%	d'économie potentielle en heures non ouvrées
Cantine Période de chauffe du 2 novembre 2020 au 15 avril 2021		toujours en dessous des seuils	2%	d'économie potentielle en heures non ouvrées
Ecole Publique Période de chauffe du 2 novembre 2020 au 15 avril 2021	1%	d'économie potentielle en heures ouvrées	15%	d'économie potentielle en heures non ouvrées
Maison Médicale Période de chauffe du 2 novembre 2020 au 15 avril 2021	2%	d'économie potentielle en heures ouvrées	5%	d'économie potentielle en heures non ouvrées

Figure 5 : Analysis of the energy saving potential for buildings, based on the measured temperatures. The potential savings seem greater during non-working periods

This sensor infrastructure makes it possible to collect a large amount of data, over long periods, which allows cross-analysis between energy and comfort in buildings. The platform performs automated analysis but there is no direct action on consumption. This is why we have worked on a heating control solution that allows direct action on consumption.

2.1.2. Electric heating control and monitoring

The installation took place from March to April 2021, during the period of COVID-19 presence in France, with moreover a 3rd confinement which began on April 1, 2021. This did not prevent the correct installation of the equipment, on the other hand, the buildings were less occupied (Canteen and Library) or even never occupied during the experimentation period (Elderly Club).

2.1.2.1. Comparison of March-April 2021 results with previous periods

The analysis of the impact of the piloting experiment is based on the comparison of heating in public buildings for two periods: before and after installation. The period before installation covers the year 2019 and until November 2020. The period after installation covers the period from March to April 2021.

The comparison of the heating consumption is made by periods of 7 continuous days, by comparing one by one the periods which have the temperature evolutions closest to those observed during the controlled period (Table below and Figure below). In Figure below, the average outdoor temperature reading is shown in blue. The green line is built from several periods of 7 days before installation. In total, 46 7-day periods before installation were identified to build the basis of comparison.

Overall, the reference curve (green) follows the curve well after installation. We still notice a period of 4 days when it was particularly hot at the end of March 2021-beginning of April 2021 (blue curve).

The light green area around the green line represents the standard deviation of the average outdoor temperature for the periods selected.

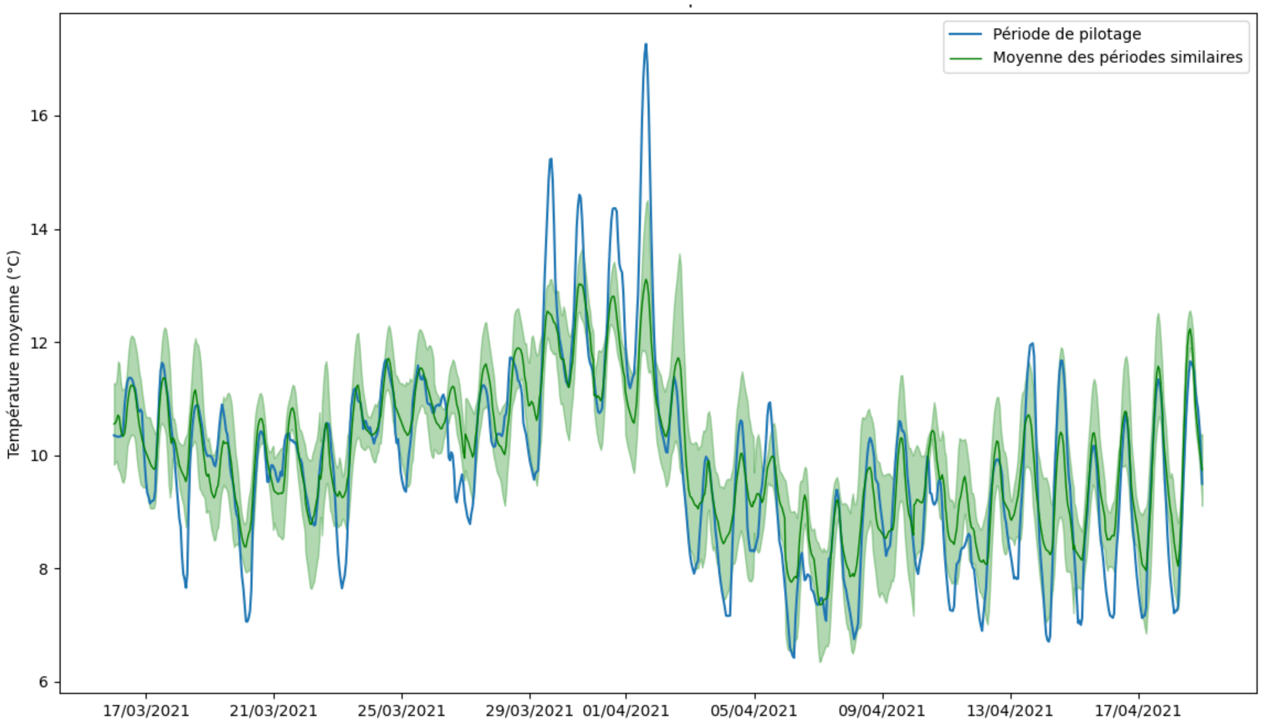

Figure 6 : Average outside temperature profile for the piloting period (blue) and the averages for similar periods of 2019-2020 (green)

Table 1 : Start date of similar 7-day periods from the reference period (2019-2020) retained for comparison with the piloting period (March-April 2021)

22/03/2019	05/04/2019	29/04/2019	17/01/2020	04/04/2019
08/02/2019	16/11/2019	14/03/2019	02/04/2019	25/03/2019
11/11/2019	13/11/2019	22/02/2020	18/01/2020	26/03/2019
17/02/2020	11/03/2019	02/04/2019	01/03/2020	12/02/2019
14/01/2019	04/05/2019	21/01/2020	09/02/2019	10/04/2019
21/03/2019	26/04/2019	19/01/2019	24/03/2019	03/05/2019
29/12/2019	25/04/2019	22/01/2020	16/01/2019	
13/02/2019	05/05/2019	01/03/2020	03/04/2019	
05/04/2019	03/05/2019	30/03/2019	21/11/2019	
16/11/2019	21/11/2019	26/12/2019	31/03/2019	

2.1.2.2. Results of the experiment at the Town Hall and the Library

Over the period from March to April 2021, the piloting of electric heaters reduced the Library's electricity consumption by around 38%, reducing the average daily consumption from 25.8 kWh / d to 16 kWh / d. For the Town Hall, the experiment seems to have slightly increased electricity consumption, by around 12%. In the following point, we present the detailed analysis for these two buildings, and we show that this increase in consumption is explained by better service.

Table 2 : Electricity consumption before and after piloting for the Town Hall and the Library

Bâtiment	**Consommation journalière moyenne non pilotée (kWh)**	**Consommation journalière moyenne pilotée (kWh)**	**Evolution**	**Commentaire**
Mairie	75,5	84,7	+12%	Écart qui pourrait ne pas être significatif car écart-type important et impact ponctuel de températures élevées
Bibliothèque	25,8	16,0	-38%	Écart significatif

2.1.2.3. Consumption analysis: validation of the technical solution

Townhall

For the Town Hall, the control of the electric radiators was put into operational service from 03/26/21. The commissioning was done later, due to an additional intervention to be carried out (installation of a 2nd local control antenna to cover all the radiators in the building).

The Town Hall's electricity consumption profile is shown in the figure below. Once the pilot is in operation, it is clearly visible that the electricity consumption is tightened over the period of the building's occupation. In addition, at night, the residual consumption is very low (light yellow), or even zero (white).

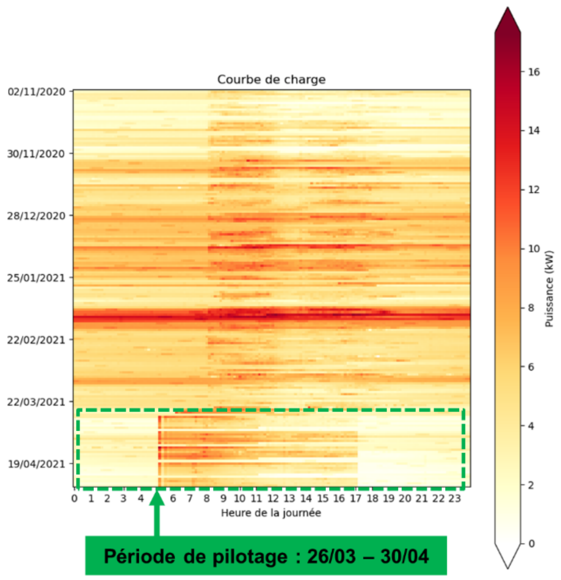

Figure 7 : Electricity consumption profile at the Town Hall, after control - Power demand in kW

The figure below represents the daily electricity consumption as a function of the average outside temperature. Baseline data for all of the 2019-2020 period is shown in green. The benchmark data selected for the comparison (days of the 46 periods in Table 1) are shown in blue. Consumption data with control are shown in red.

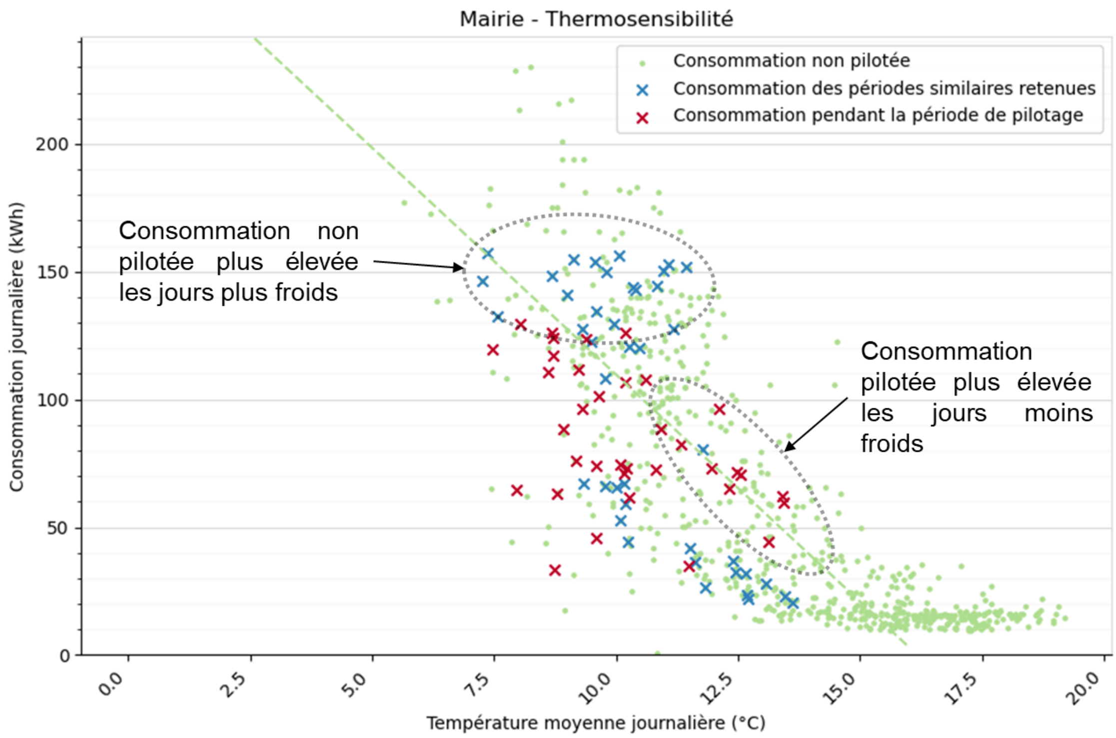

Figure 8 : Thermosensitivity analysis for the Town Hall, after management - Daily consumption according to the average daily outside temperature

On cold days (average outside temperature less than 10 °C), the control reduces the electricity consumption compared to the non-controlled periods. More precisely, consumption does not exceed 130 kWh/day, while similar unmanned periods show consumption of up to 160 kWh/day.

During less cold days (lower average outside temperature between 11 and 13 °C), the data show a higher consumption with piloting.

Beyond the energy aspect, it is also important to be interested in the service provided by the heating, that is to say the thermal comfort in the building. As shown in the figure below, before piloting, the temperature encountered in the morning in the premises could be relatively low (17 °C) because the heating could be switched off, and only switched on when the personnel arrived. The result is a period of discomfort while the radiators heat up. There is also a temperature peak at 21 °C, which could be the result of the heating being left on all night, and therefore high energy consumption.

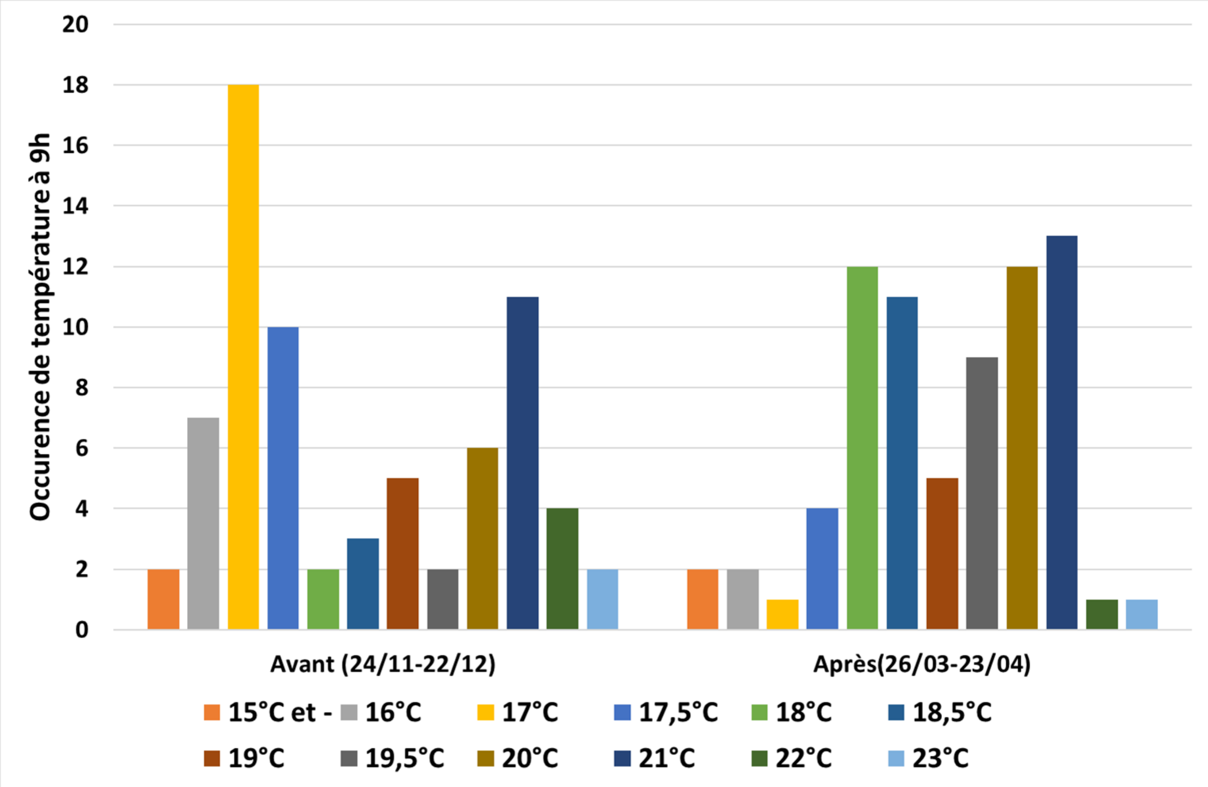

Figure 9 : Temperature distribution at the reception of the Town Hall at 9 a.m., before and after controlling the heaters

With piloting, the temperature at 9 o'clock is mostly between 18 ° C and 21 ° C. The control makes it possible to harmonize the temperature in the premises around the set temperature (20 ° C), and to ensure a small variation from one day to the next. With piloting, a comfortable temperature is ensured for the start of the working day, which implies upstream consumption to reach the desired temperature. In comparison with the period without piloting, this represents an overconsumption of energy but linked to an improvement in comfort for the users.

In conclusion for the results of the Town Hall, by looking only at the energy aspect, the control solution can increase consumption for the intermediate periods (spring and autumn), but it ensures comfort for users. With colder days, the solution does seem to significantly reduce electricity consumption and therefore be effective on winter days, however this last point must be verified and validated by collecting data for a complete winter.

Library

For the library, the control of electric heaters was put into operational service from 03/16/21.

The library's power consumption profile is shown in the figure below. Once the pilot is in operation, it is clearly visible that the electricity consumption is tightened over the period of the building's occupation. In addition, at night, residual consumption almost zero (white). For a few days, there is low consumption in the morning, which corresponds to reduced heating to maintain a minimum temperature of 15 ° C in the building, when it is unoccupied.

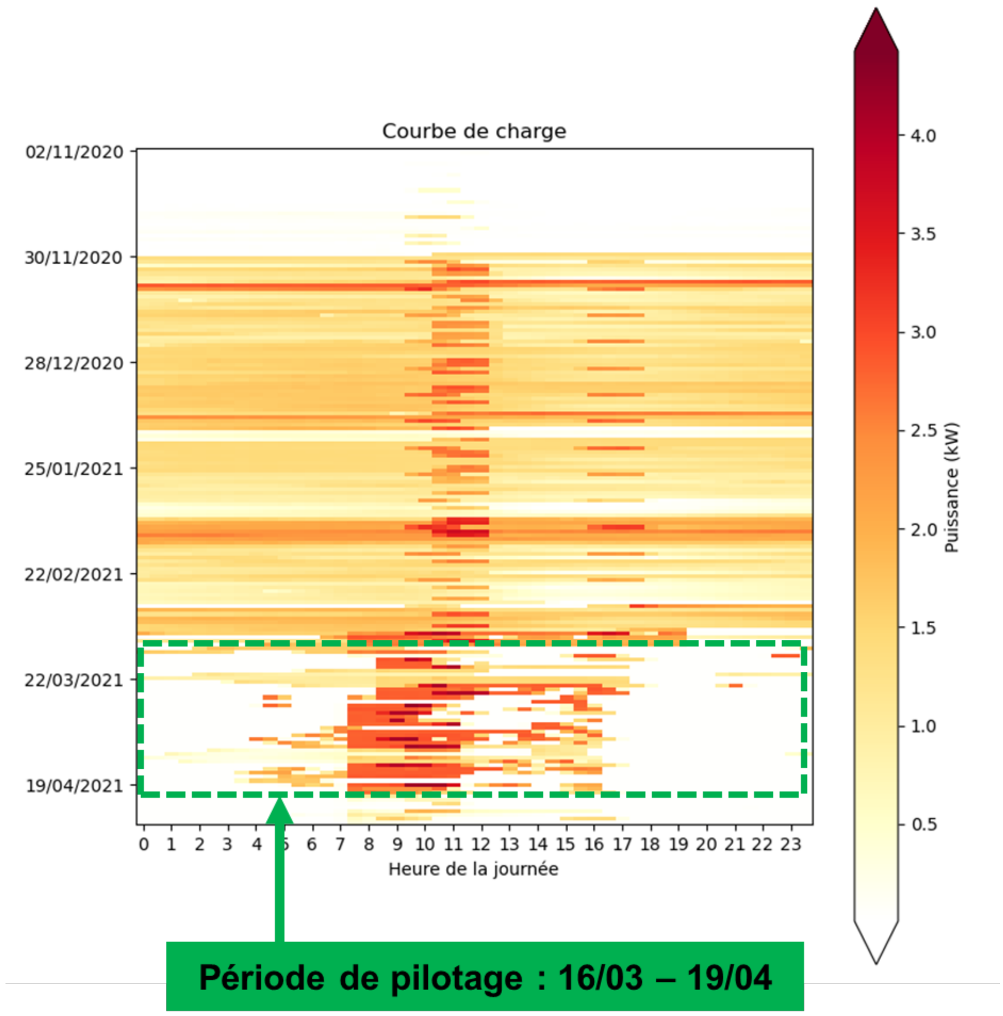

Figure 10 : Electricity consumption profile at the Library, after control - Power demand in kW

The figure below represents the daily electricity consumption as a function of the average outside temperature. Baseline data for all of the 2019-2020 period is shown in green. The benchmark data selected for the comparison (days of the 46 periods in Table 1) are shown in blue. Consumption data with control are shown in red.

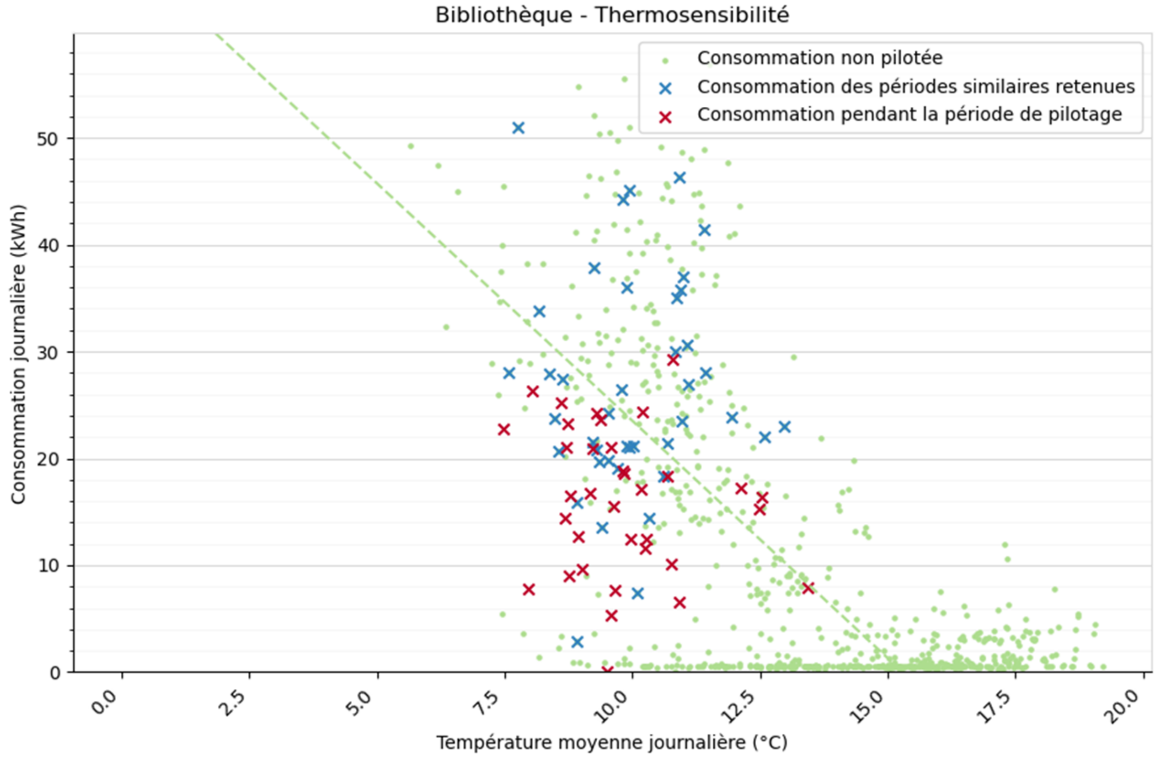

Figure 11 : Thermosensitivity analysis for the Library, after control - Daily consumption according to the average daily outside temperature

The days of consumption with piloting of the radiators (red) are clearly more grouped together and show lower energy consumption than the reference days before piloting (blue). The maximum daily consumption encountered with piloting is of the order of 30 kWh / d while for the reference period before piloting, several days showed consumption greater than 45 kWh / d and up to 50 kWh / d.

The daily consumption analysis based on the average outside temperature shows that the control solution significantly reduces the consumption of the Library.

The temperature readings of the connected sensor of the library before (blue) and after (orange) piloting are shown in the figure below.

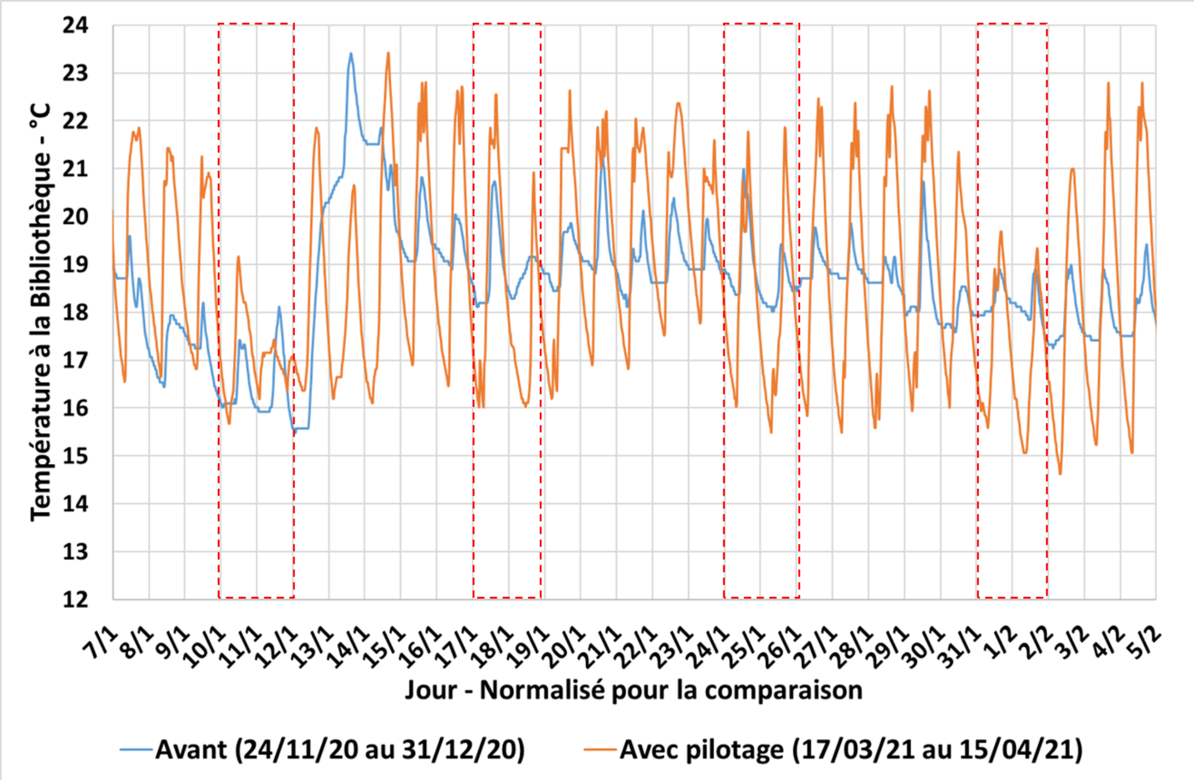

Figure 12 : Temperature readings before and after piloting at the Library - red frame: weekend

Before piloting (blue), the temperature in the Library shows little daily variation. The temperature is at the beginning of 19 ° C then decreases to reach 16 ° C-17 ° C, over a weekend (red frame). Then the temperature increases to reach 23 ° C and finally it reaches a plateau around 18-19 ° C minimum, with daily peaks at 20 ° C. We can see that even on weekends, the temperature remains above 18 ° C.

After piloting (orange), the temperature shows significant daily variations, resulting from piloting alternating between setback temperature (16 ° C) and comfort temperature (20 ° C). The temperature often exceeds 20 ° C during the day, due to the building being heated by the sun (March-April 2021 was a very sunny period).

Canteen and Elderly Club

The piloting of the heaters took place from March 2021 to April 2021, a period during which France imposed an evening curfew until early April, then a third confinement until mid-May. As a result, the canteen and the alumni club were used very little or not at all during the experimentation period. The results are therefore not representative and the comparison with the period 2019-2020 is not relevant.

2.1.3. Information to the consumer: the prosumer

In this part we present the experiments in the distribution of information objects intended for users / consumers / inhabitants in the experimental areas of the ICE project. We start with the experiment in Ushant then we present the experiment on the campus of the University of East Anglia.

2.1.3.1. Ushant

In this section, we present the results of the experiment at Ushant. Information items on the state of the electricity network in Ushant were designed and distributed during the summer of 2021.

The analysis of the experiment is based on the identification of changes in the electricity consumption of the volunteers as a function of the colour changes on the object.

The colour signal is determined by a formula based on the proportion of renewable energy produced divided by the total power demanded. The signal therefore changes during the day, and markedly by the consumption profile (figure below).

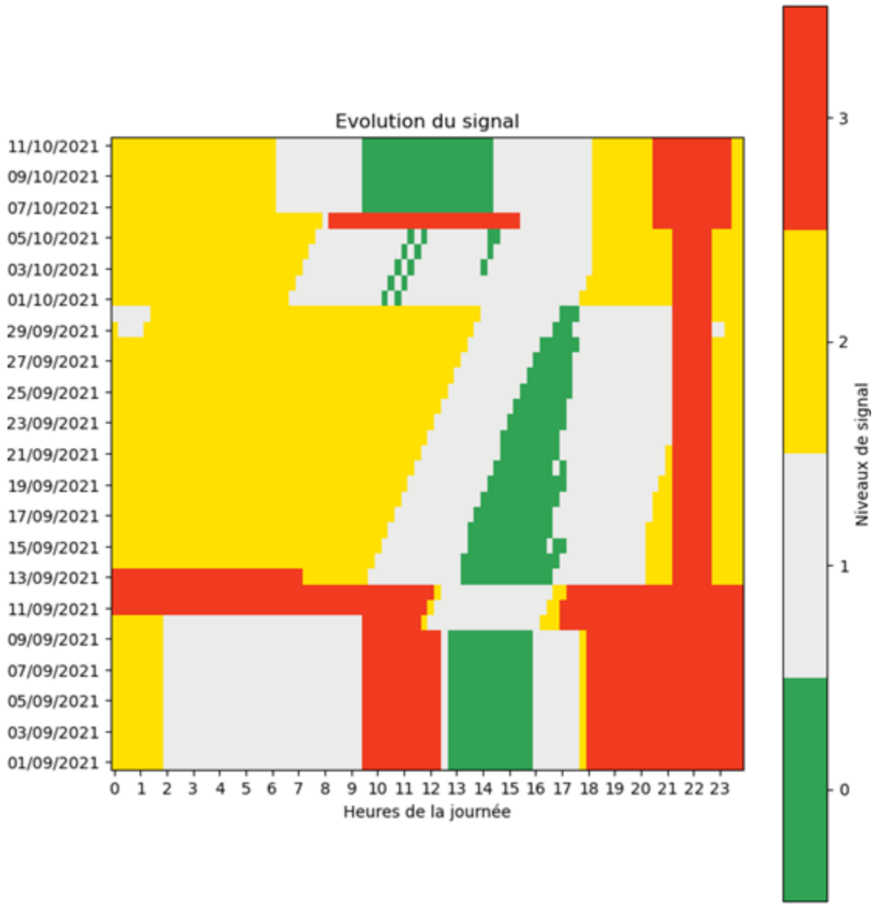

Figure 13 : Evolution of the colour signal during the experimentation period

The signal has several very short periods (15-30 min) which do not seem relevant to assess a change in consumption. To simplify the analysis, periods of less than 1 hour are deleted and converted with the following colour (figure below).

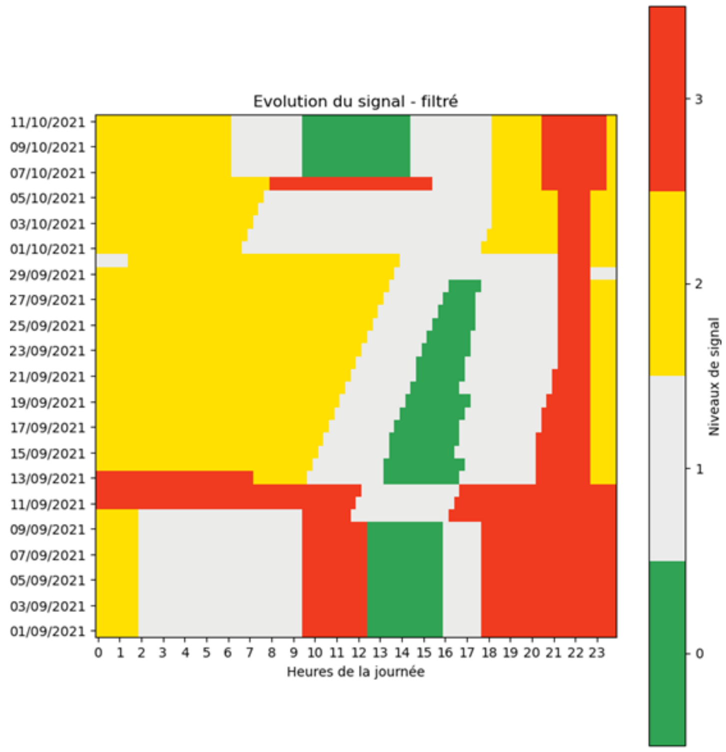

Figure 14 : Evolution of the simplified signal (elimination of short transitions)

The signal is characterized by 3 distinct periods:

- From 01/09 to 09/09: Regular period, in the "summer" profile
- From 10/09 to 06/10: Variable period where the signal has been modified several times, it shifts from one day to the next in particular. From 11 to 13 the signal was mostly red
- From 07/10 to 11/10: Regular period in the "winter" profile

To study the impact of signal changes, we also filter night time transitions that volunteers will not see. In addition, we are only interested in colour transitions to identify changes in consumption during these times (figure below).

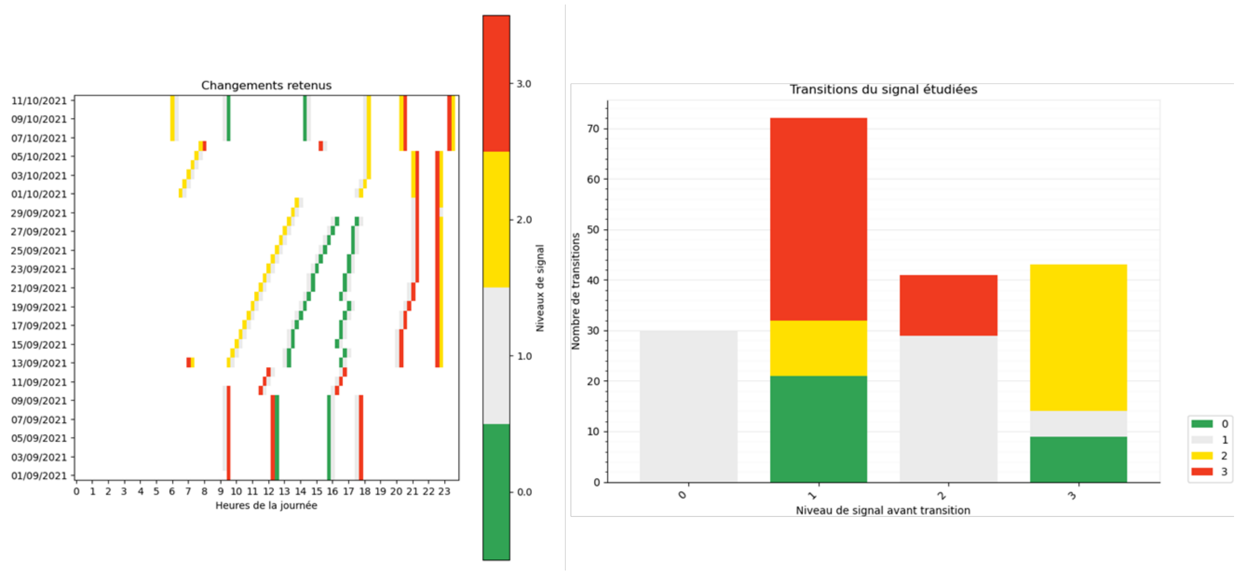

Figure 15 : Colour transitions during the experiment (left) and distribution of the transitions as a function of the colour at the time of the transition (right)[1]

In the end, a total of 186 transitions are counted, or about 4.5 per day. Some transitions often occur at the same times (red → yellow around 10 p.m., white → yellow around 6 p.m.) and others vary more (yellow → white), this could bias the analysis. Some transitions never occur: green → yellow, green → red, and yellow → green.

<u>Measuring the impact of a colour transition on energy consumption:</u>

To quantify the impact of the object, we compare the average power before and after each signal change. The average power is calculated over a certain period which must be long enough to smooth the point behaviours and short enough to stay close to the signal change. The overall impacts can be calculated on the average of all consumption or on standardized consumption (the average of which is equal to 1) so as not to give too much weight to a consumer who consumes more than the others.

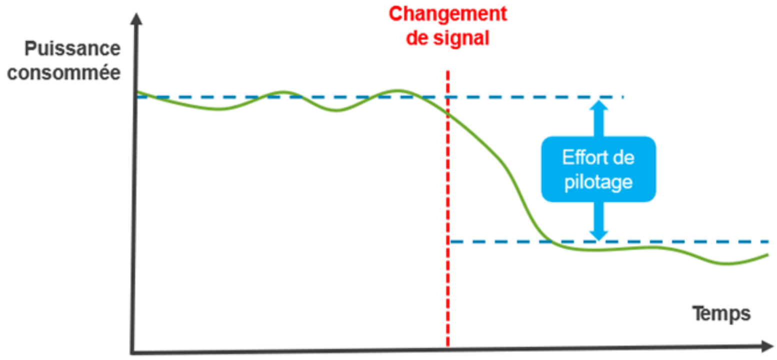

Figure 16 : Diagram of the piloting effort during a color change

[1] How to read the graph: When the signal was green (= 0) it transitioned 30 times to white (= 1) and no other color. When the signal was white, it transitioned 21 times to green, 11 times to yellow and 40 times to red…

"Pilot effort" is a measure of the power that may have been adjusted according to the change in signal. It is positive when the consumer changes his consumption in the "right" direction:

- Increase in consumption if the colour drops (towards green)

- Reduction in consumption if the signal level increases (towards red).

Result of the piloting efforts throughout the experiment:

The analysis of the piloting forces shows a distribution of the forces centered around 0 kW with a Gaussian curve shape (figure below), which means that at the global scale of the experiment, the color signal does not does not seem to impact the consumption of volunteers.

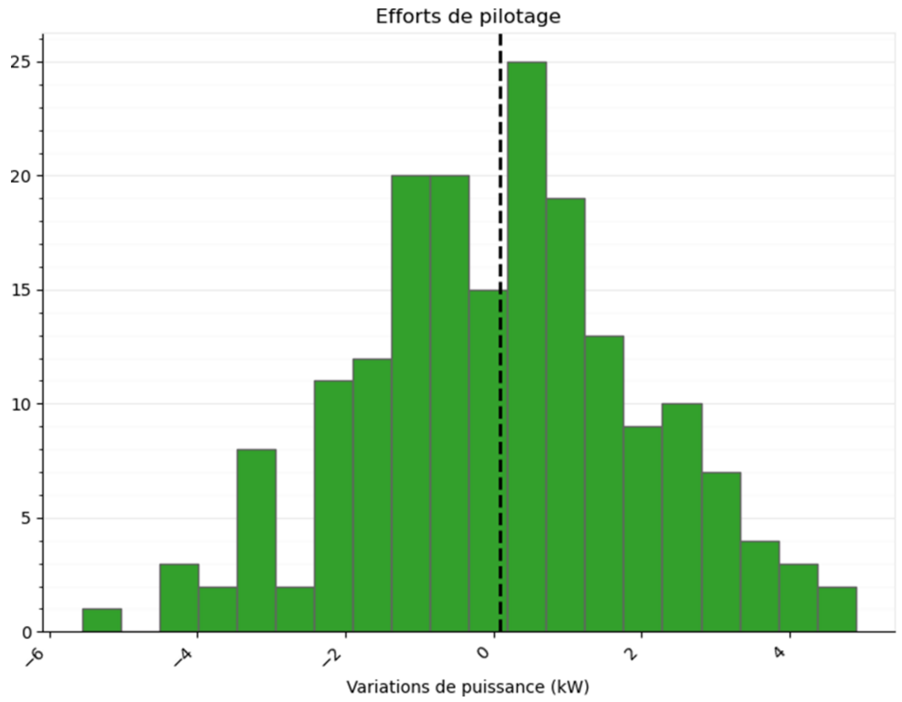

Figure 17 : Distribution of piloting efforts

Result of the management efforts over the 6 p.m. to 11 p.m. period:

Volunteers' action on their consumption can only be done when they are present in their homes, when the signal is visible and they can decide to postpone a consumption. Therefore, we have refined the analysis by focusing on the period 6 pm-11pm, which in fact is the period when volunteers are more likely at home.

The number of transitions (68) is lower and certain signal levels are never reached (green signal).

The piloting efforts of most participants do not show a positive trend in their piloting efforts and / or the efforts appear to be randomly distributed. Only 3 participants show potentially interesting behaviors (figure below).

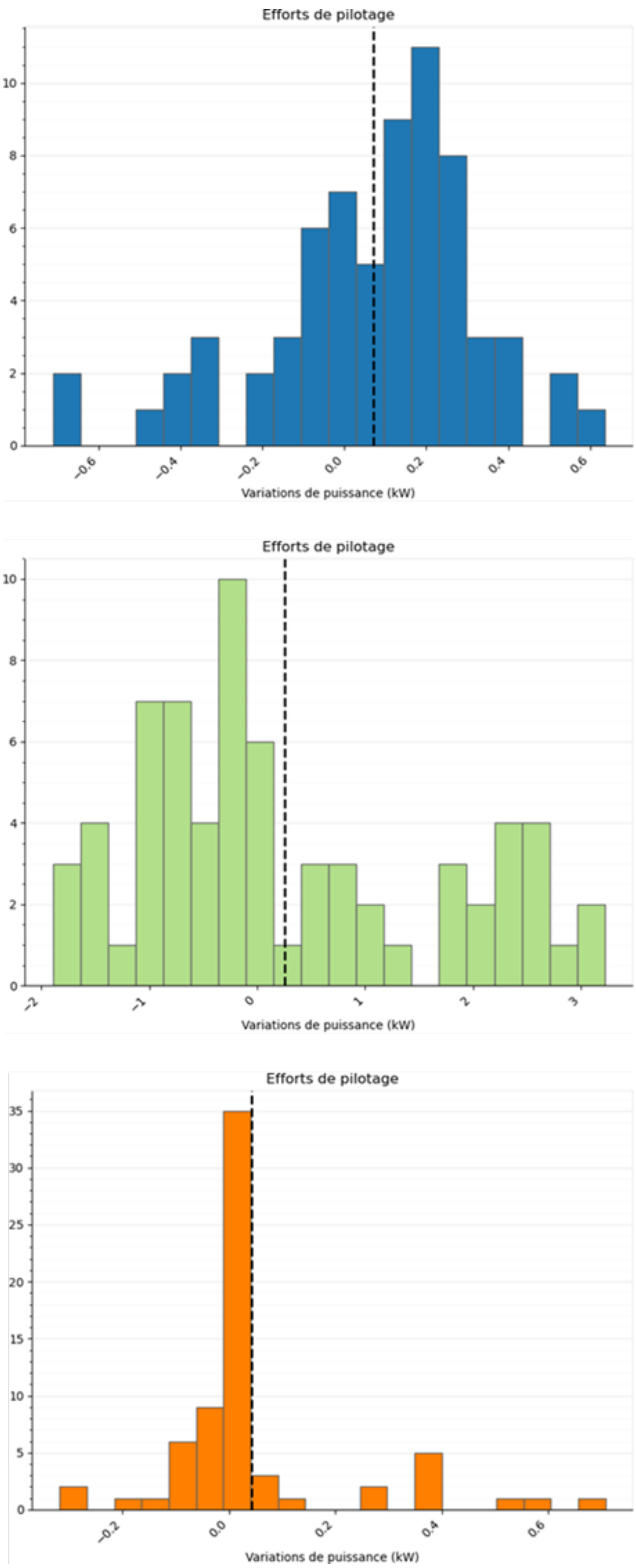

Figure 18 : Distribution of piloting efforts for 3 voluntary households: a slightly positive effort identified

Blue curve: The distribution of forces seems distorted to the right, the average is slightly positive (0.07 kW)

Green curve: Some piloting efforts are relatively high, up to 3 kW, which means that the average is slightly positive (0.25 kW)

Orange curve: Some positive piloting efforts stand out and cause the average to be slightly positive (0.04 kW)

At this stage, it would be early to conclude that the experiment has a definite positive effect on changes in the consumption of volunteers. However, it would be interesting to follow these participants closely as the experiment continues.

Limitations of the experiment:

Several difficulties were encountered during this experiment which had the consequences of limiting the conclusions of the experiment:

- The short duration of analysis (1.5 months) with a signal which was under development and which could have been more dynamic.

- The low number of distributed objects (40 out of a total of 80 available).

- The low number of people whose consumption could be recovered (17 out of 40 items distributed).

Improvement prospects for the future:

- Carry out a survey among the participants: Did they see the changes in the signal? If so, have they taken action to change their consumption? What levers did they use?

- Examples of actions could be given in a booklet that would accompany the object so that individuals have the right reflexes: delay in starting up household appliances, lowering the heating setpoint for a few hours ...

- Collect EDF consumption and production data to provide a more realistic and motivating signal for participants.

- Continue the experiment over a longer period to have a more representative sample of all the possible transitions.

- Replicate the experience in other isolated territories to increase the data.

- Carry out the experiment, in particular during the heating period during which individuals can have greater control over their consumption (cut off electric heaters during red slots, for example). Actions on heating could also be easier to quantify.

2.1.3.2. UEA

The University of East Anglia (UEA) has announced its plans to become carbon neutral by 2045. With its existing low carbon development strategies, the University has adopted several low carbon technologies in its energy use, including the installation of solar PV, the upgrade of combined heat and power (CHP) plants, the replacement of old inefficient boilers, the adoption of a thermal heat storage system, and other smart and low carbon technologies such as the use of TermoDeck technology in buildings, and the installation of a district cooling system.

UEA uses an integrated top-down and bottom-up approach to optimize the performance of low carbon technologies. For instance, thermal storage allows excessive heat to be stored from the CHP units and released when heat demand increases; the upgraded gas boilers operate at their optimal energy efficiency levels (60 percent of rated production) and rely on thermal storage to adapt to changes in heat demand. The heating distribution network allows both CHP and gas boilers to produce heat with maximum efficiency. With the installation of air chiller equipment, it is also possible to convert it into an air conditioning unit. Additionally, UEA staff and students have been engaged in the development of climate-friendly technologies and measures in order to achieve its climate goals.

Despite effort to upgrade its low carbon technologies with better energy efficiency and lower environmental impacts, there is still room to further improve the energy consumption performance from the demand side. The ICE project provides a pilot demonstration of a smart heating technology (SHT) with aims to increase energy users' awareness of their energy consumption, change consumption behaviour through better management of heating use, maximize user comfort, improve overall energy efficiency for heating, and potentially provide a decarbonised source of flexibility in the future. The technological solution is combined with a series of consumer engagement activities throughout the project. These activities are of paramount importance to the understanding of consumer needs, priorities, values, which in turn help to facilitate the integration of low carbon technologies at UEA campus.

This section assesses benefits and challenges of implementing the SHT.

Smart heating technologies and its performances

The SHT includes specific key components, including a zoning control system, programmable thermostatic radiator valves (PTRVs), a central controller, sensors, actuators, and a wireless interface. Figure 19 shows the technologies implemented at UEA dormitories. Details on system design and operation can be found in Deliverable T3.3.1.

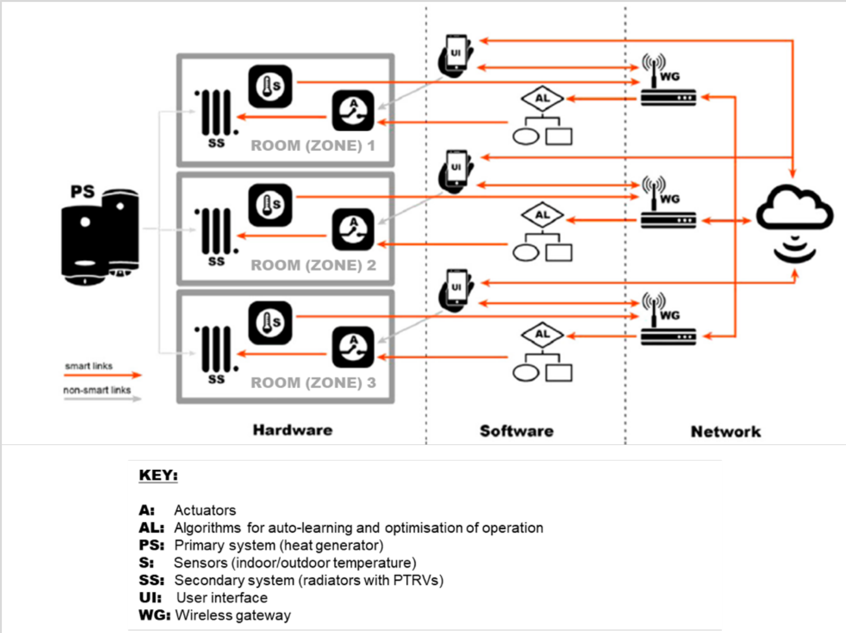

Figure 19: Schematic representation of all the components and connections of the SHTs designed and delivered in multi-zonal residential units on the UEA campus.

<u>Performance of the SHTs</u>

The implementation of the SHTs led to savings in gas consumption over a period of 26 weeks (see Figure 20). In particular, up to 40% energy savings were observed at one of the Living Labs (Courtyard B) comparing to the control group at the same location between week 4 and week 14. However, there was bounce back in energy consumption after week 14 at both Living Labs, when higher energy consumption than the control groups were observed.

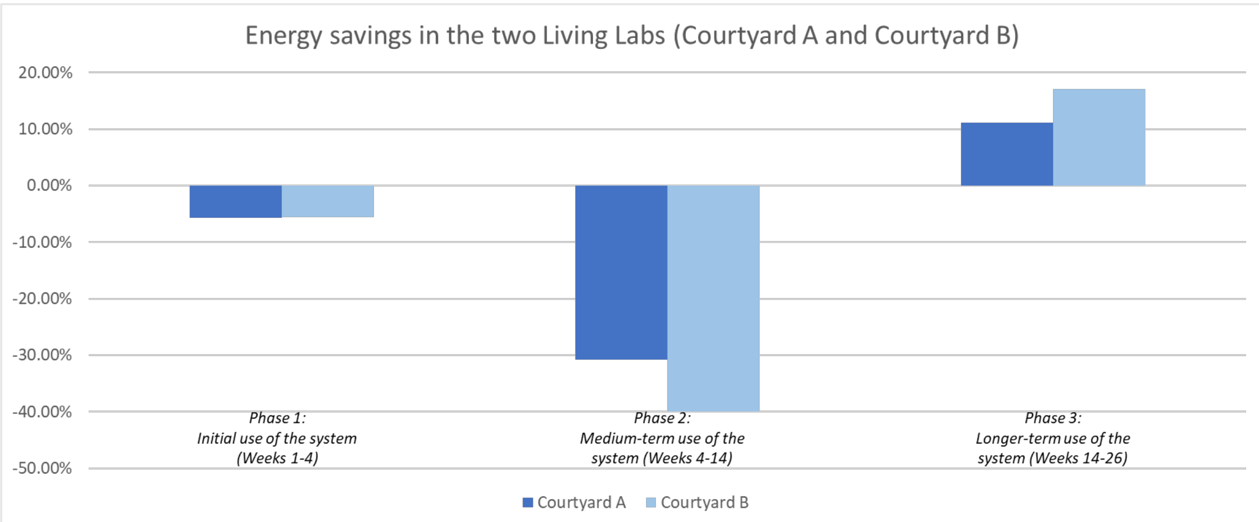

Figure 20: Energy savings in UEA's two Living Labs (compared against control flats in Courtyard A and Courtyard B respectively)

Benefits of increasing SHTs uptake

The installation and operation of the SHTs can be an important element to the overall low carbon energy transition at UEA. There are multiple benefits that can be offered by extending the demonstration project to a large-scale deployment of the smart heating solution at UEA's residential buildings.

- It can strengthen the user-oriented low carbon solutions at UEA.

The installation and operation of the SHTs can strengthen the existing user-oriented approach by extending the user group to students. Several engagement activities with students were implemented during the whole process, through focus groups, surveys and interviews. These activities are used for the evaluation of students' attitudes towards energy transition, the assessment of their consumption behaviour, the consultation on their opinions about the smart heating technologies, and the demonstration of the technologies. Students were well-informed about the adopted technology, their means to be involved, and possible outcomes from their participation.

- It fits the existing low carbon energy systems and can contribute to the future low carbon development plan through flexible management of heating consumption at residential buildings.

The University has plans to increase electricity use due to accelerated decarbonisation of power supply from the grid. Together with the proposed closure of CHP units, there are also plans to switch to heat pumps for heat supply on campus. The replacement in technology as well as the switch to electricity for heat supply will inevitably lead to higher electricity consumption from the grid. Electricity consumption in peak hours is considerably more costly than that of off-peak hours. That reflects the use of expensive fossil fuels to generate electricity when demand is very high. Typically, costs are lower when demand is covered by mostly low cost and low carbon energy technologies. If heat consumption could be better managed through the adoption of a scaled up SHT, it can be helpful to reduce electricity bills and most importantly consume energy when that is produced by low carbon energy technologies.

- It provides new opportunities for energy efficiency improvement

The smart heating system offers a novel approach to reduce emissions by improving energy efficiency through user engagement. The more granular control over heating at different time periods and with more precise temperature settings offer an effective means to increase savings in heat demand. One other important element from user participation is that it can improve the user awareness on issues related to climate change in general and transition in energy provision in particular. These are fundamental to the successful implementation of the Net Zero plan at UEA as well as the low carbon energy transition at national level.

- It offers a cost-effective means to reduce energy consumption and emissions

Potential scaling up of the smart heating system also offers a cost-effective way to reduce heating consumption at residential buildings. The smart heating system does not require significant spending on equipment and its operation and maintenance costs are negligible. Existing heating supply equipment can be compatible with SHT without significant upgrade.

The system use and its patterns are presented in Figures 21-25 to facilitate the understanding the insights of the smart heating technology in different time periods. It is shown that the use of SHTs was gradually reduced on most occasions. For example, at the start of the project, use of the in-room heating controls is frequent at least several times a week. Over the mid-long term of the project, in around 50% of applications it was only used less than once a week (See Figure 21).

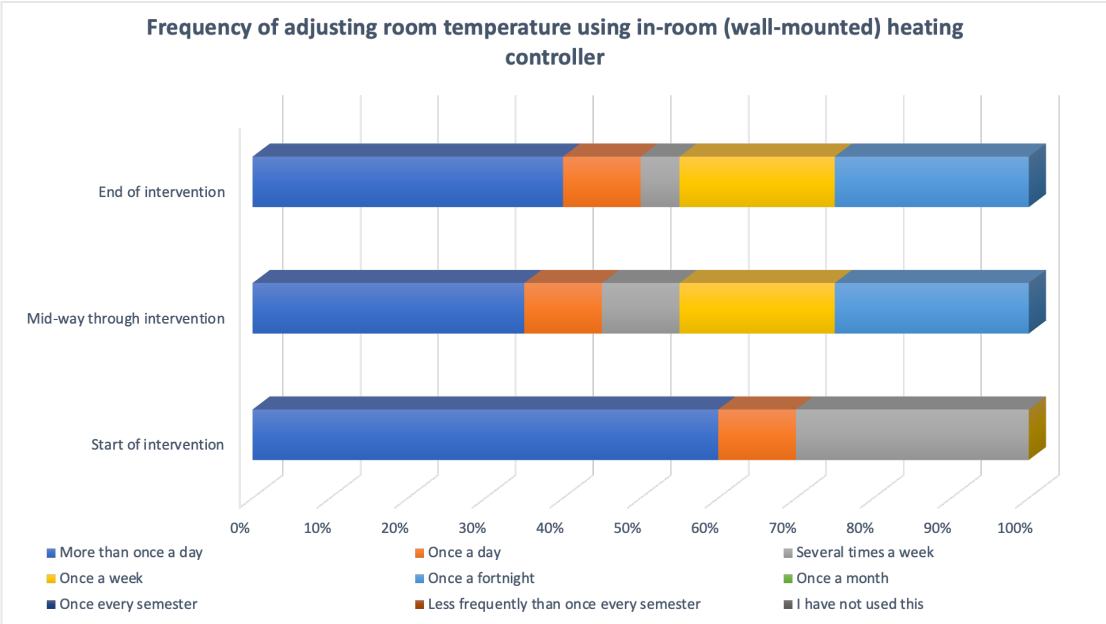

Figure 21 Reported frequency of adjusting room temperature using in-room heating controller

More advanced functions of the SHT received even less attention over the same period. There was gradual loss of interests in the SHTs with the time being. For instance, the frequency of using the wireless heating interface and the automatic control features dropped significantly toward the end of intervention, comparing to the start (Figure 22 and 23).

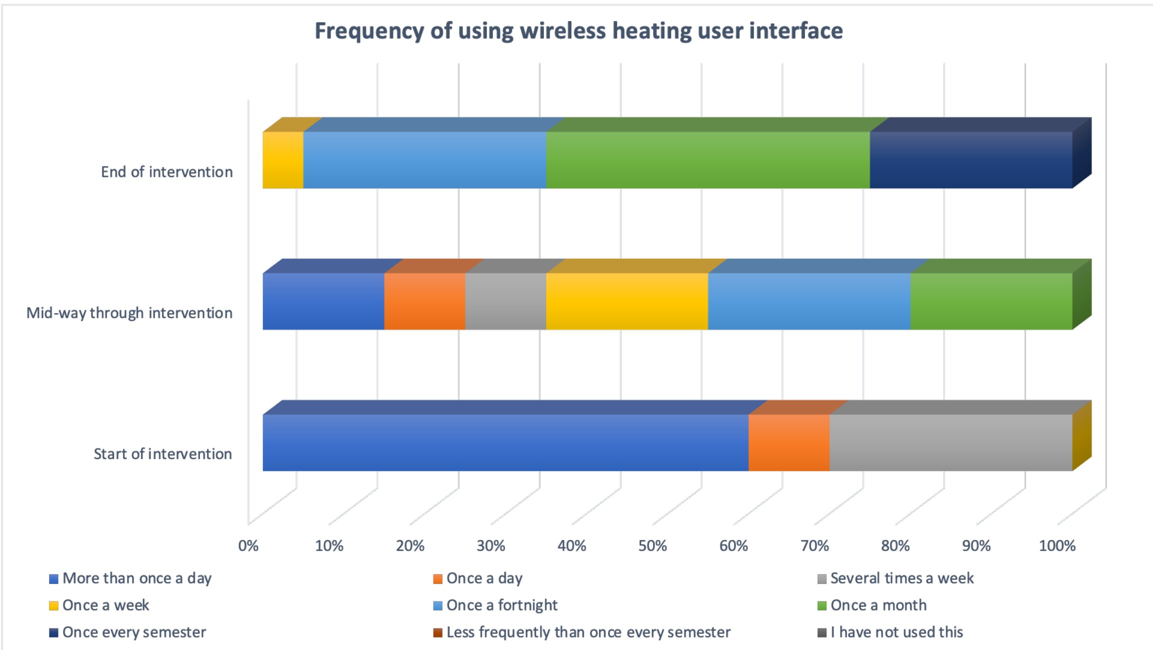

Figure 22: Reported frequency of using wireless heating user interface

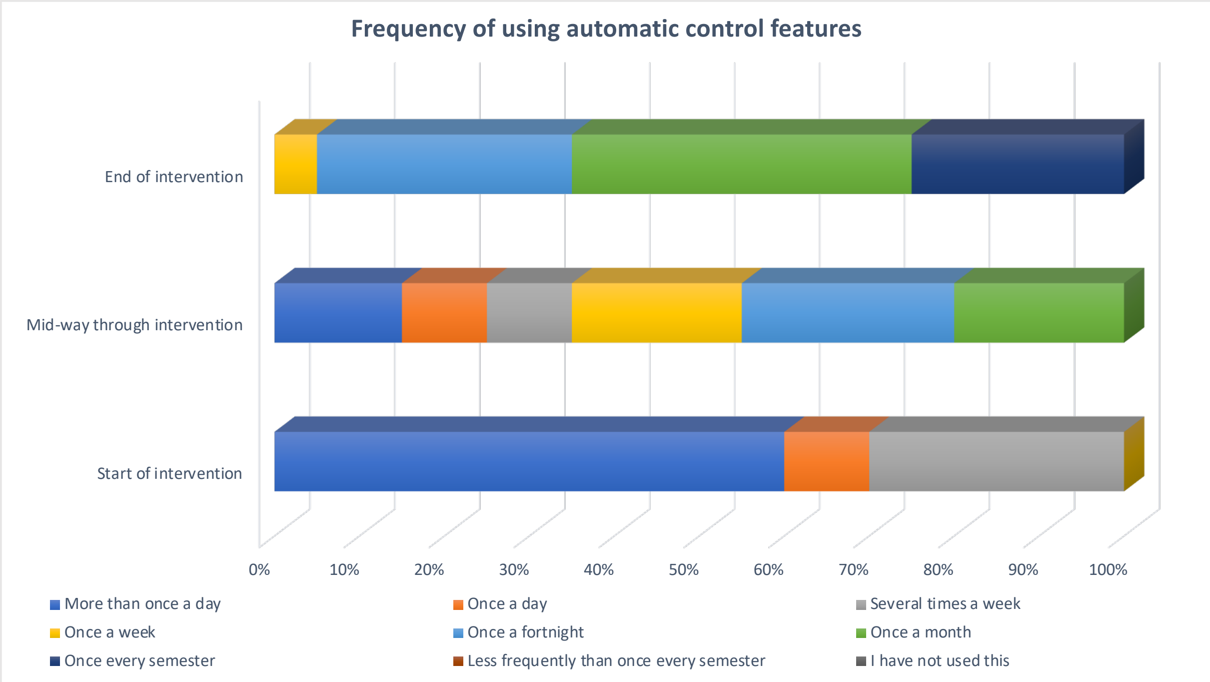

Figure 23: Reported frequency of using automatic control features

Pre-set operation modes on the other hand saw a slight increase in use frequency with around 20% of the participants started to use the function (Figure 24). By contrast, most students stopped paying attention to their energy consumption (both heat and electricity consumption) at the end of the project, comparing to a good level of interest at the beginning of the project (Figure 25). More details can be found in Deliverable T5.2.1.

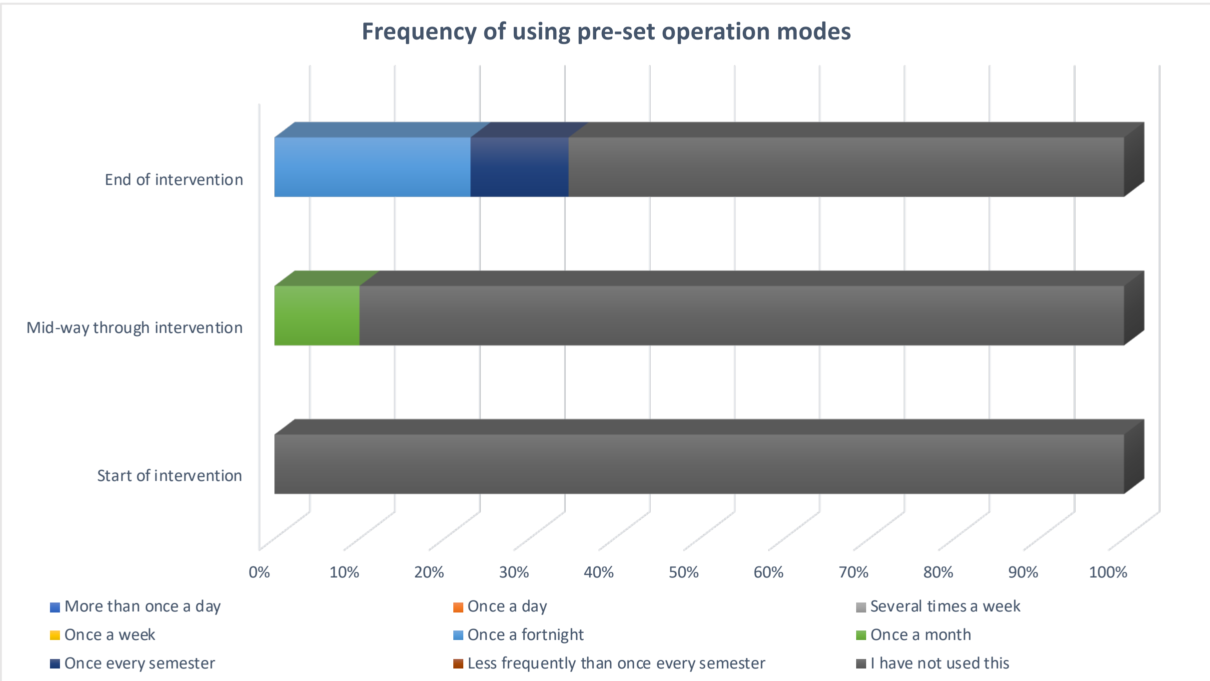

Figure 24: Reported frequency of using pre-set operation modes of the smart heating technology

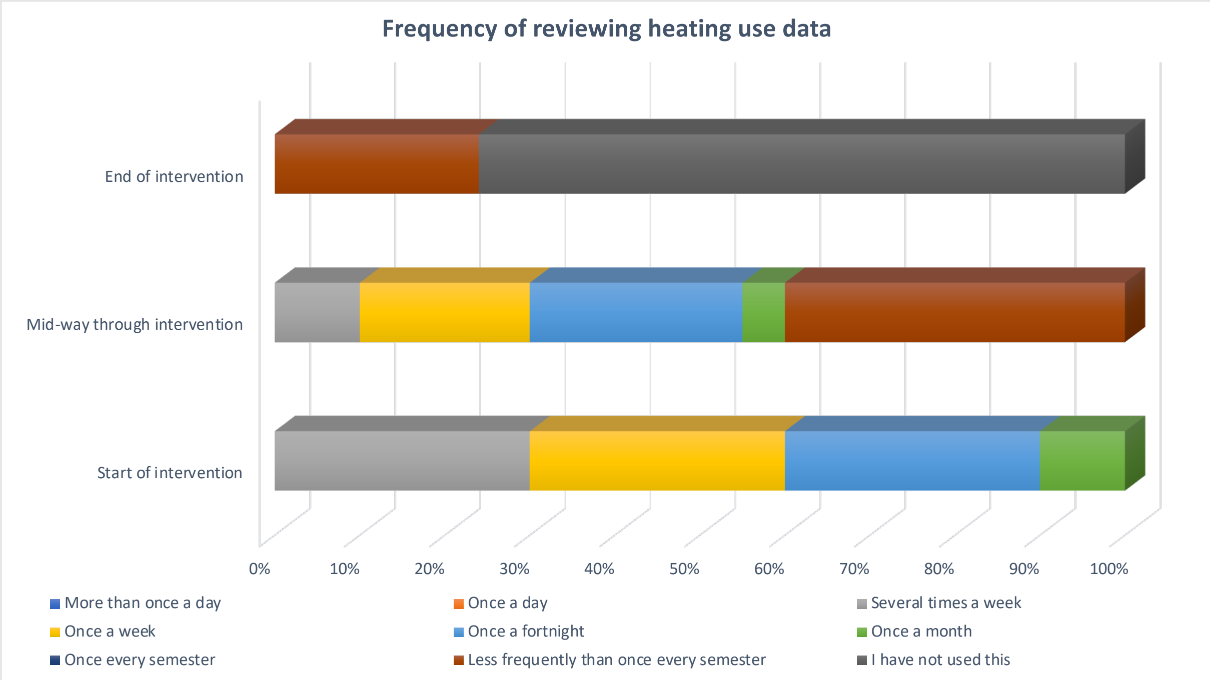

Figure 25: Reported frequency of reviewing data on individual energy demands for heating

Challenges and limitations of SHT development

Despite the potential benefits of adopting SHT, there are a few challenges that may impede the development of SHT in the future and have been identified during the pilot study in ICE. Some of the challenges are related to the technology itself, others are related to the user experiences in adopting the technology. SHTs even though they have an excellent fit with existing infrastructure they can still be technically and socially disruptive. It is especially relevant for university students at UEA for 2 reasons: Firstly, students are used to have centralised heating system with no precise control over room temperature and did not need to pay for the service. Secondly, students might not feel the required level of ownership over the infrastructure changes happening on campus. It is the nature of their relationship with the accommodation facilities that they are usually there for one year (sometimes up to three) and then they move on away.

The introduction of new technology will require adaptation and familiarization, which are usually time consuming depending on the technology. Alongside everything else there are context specific differences which manifest in diverse ways in UEA's small pilot site and for example at a housing project or in public building. ICE project brings the experience, through its own pilots and external pilots, which enriches knowledge development. These challenges are discussed and contextualised further in the next subsection.

2.2. Use of technical solutions: a compromise to reach for a good acceptability

Beyond the success of the technical implementation of the solutions presented earlier in this report as well as throughout Work Package 3, the necessity remains to discuss further various compromises that are essential to balance performance, reliability and project exportability. The extensive research of this Work Package and its coordination with Work Package 5 make a novel proposition in which technical solutions and their own limitations do not stand in isolation of the public, the people whom these technologies are ultimately built to serve.

To begin with the technical considerations themselves, one might start with performance improvements. Identifying ways in which the implemented systems deliver deeper decarbonisation, the answer usually lies in the detailed tailoring of each system to serve the specific characteristics of the community at which it was installed. Higher performance in that sense often comes as a result of improved system efficiency and improved matching to environmental parameters. However, it is these approaches that may deliver, besides the desired performance, some less positive consequences as increasing efficiency leads to lack of redundancy. Even if that sounds initially positive, in reality it can pose a threat to reliability when, for any reason, there is any perturbation from the expected conditions. The wider the range of conditions a low carbon energy system is designed to operate and deliver in, the worst its performance is going to be. Take for example a battery storage system in combination with solar panels. The system can be sized to deliver adequate energy to an island for 80% of the time. For the rest of the time, it might deliver, or it might not, depending on the weather. It is possible to design the system in a way to make it deliver energy for 100% of the time but that will require significant oversizing of all of its components. This will increase the system's redundancy, the number of components that are actually not used for most of the time and exist only to serve in extreme conditions. Such designs come at a great cost and therefore in the real world compromises need to be made between performance and reliability. Furthermore, the better a system is designed to fit within a specific environment, the less likely it is that it will be suitable for a variety of other environments, reducing therefore its exportability. The vast variability of renewable energy resources across different locations and the local conditions need to be approached flexibly in order to allow for system manipulations and exportability.

In that regard the ICE methodology provides for a flexible framework where the solutions applied in the demonstration sites have been selected for their suitability for these locations and their circumstances. That is a characteristic and benefit of the ICE approach which allows it to be transferrable as it does not dictate for one type of technology or one type of operational regime but rather seeks to find what is suitable for each isolated territory.

First, it is important to customise smart energy solutions that can reflect individual needs, values, priorities and capabilities. Given the unique characters of students living on campus, they do not participate in the programme to get lower bills. However, many other motivations are relevant. In particular, the value of smart services includes comfort, convenience and gaining control over the energy consumption. Therefore, a thorough understanding of consumer needs is vital to enable future participations.

Second, to enable the large-scale demand-side sources in the future, novel technical solutions are required. For example, at UEA, students do not pay for their energy bills therefore lacking motivation to participate in demand-side related programmes from an economic perspective. Developing new interactions between energy users and smart technologies is complex, so it makes sense to prioritize alternative pathways. There might be a better way to achieve decarbonisation if technological solutions do not rely on active user engagement and successful domestication. In that sense, improved automation within student-led parameters will be helpful in enabling participation and high standard of comfort without requiring consistent engagement with the technology.

Last but not least, throughout the study, we found an ongoing 'value-action gap', which highlighted the need for a new understanding of whole systems that avoids oversimplifying models of behaviour change. Focusing on more than just individuals, their attitudes or behaviours, or just technologies is part of this process. A more complex relationship between energy users, technologies, and institutional modes of governance should be emphasized instead.

The ICE project' thinking has received multiple international influences to deliver the best possible solutions for the FCE area. One of these external experiences is from the TILOS project, from the Tilos Island in Greece. Tilos project (funded by the EU Horizon 2020 programme) has delivered specific low carbon innovations for an isolated territory, the Tilos Island in Greece. Specifically, the island has been equipped with low carbon energy generation technologies, solar panels and a wind turbine. These have become the primary sources of renewable energy production on the island. In addition to that, a large-scale community-based battery has been installed on the island to provide electrical energy storage when there is a surplus production. This energy can then be used to supply the island when there is energy production deficit. Moreover, houses of the Tilos Island community have been equipped with upgraded power control systems that enable operation of a demand side management system for highly consuming appliances. For Tilos these are appliances for heating and cooling (predominantly heat pumps and electric radiators) as well as water heaters. Tilos offers a different paradigm to those encountered in ICE project in that it has a cable connection to a few other small Greek islands. Before the TILOS project, the island had been supplier exclusively via this cable connection which is still available. That means that there is a good degree of redundancy in the system which increases reliability. Lessons from TILOS project that are useful to the FCE area are to ensure that heating is taken into consideration. Heating is an important part of household energy use but is often disregarded in regions where it is provided by a different network, such as a the gas network or where it relies on oil boilers and is completely independent to electricity (which is seen as closer linked to decarbonisation). A second important lesson has been to ensure that a significant part of the interventions will be directly linked to consumers. This is necessary as it is virtually the only way to guarantee localised buy-in and acceptability for the new technologies.

Regarding smart grid experiments in Ouessant (control of radiators and information objects), we were able to show that from a technical point of view the solutions proposed meet the specifications initially planned. However, at the level of use, we have seen that the use by users is not full.

For the radiator control solution, the design phase took place at the end of 2020, the 2nd confinement period in France, and therefore no trip to Ushant was made. An exchange of information took place digitally but proved ineffective because the information was not transmitted to the staff of the Town Hall. In general, municipal staff must manage daily tasks at a steady pace, with the additional particular context of containment linked to COVID-19.

It is also completely understandable that adding the design and deployment of new solutions outside the usual scope is not a priority, or even an additional burden. This perception can lead to a rejection in practice of the experiment, whereas in principle the inhabitants of Ouessant are overwhelmingly in favour of energy transition actions (see deliverable 5.2).

For the experiments that took place in Ushant, an a posteriori analysis also shows that there was a lack of time for communication and discussion with the various stakeholders. This lack of communication is also a direct consequence of the remoteness of the island (6 hours minimum return trip plus working time on site), but also the particular context of COVID-19 which has further limited exchanges.

Similar challenges have been observed with the heating system controls at UEA. Characteristically, the challenge at UEA was not so much lack of access by the researchers on campus, since that is located essentially in the same area. However, due to pandemic restrictions, the campus has not been used as normal and access overall was even completely banned for a long time. In addition to that the students had to attend their classes online therefore many of them did not stay on campus and instead stayed in other towns and in some occasions even in other countries.

Therefore, even though the technical specifications of the intervention were achieved getting consistent use was less straight-forward. Besides the pandemic that probably has had and will have impacts on similar implementations, as has been shown in this report and in deliverables T5.1.1 and T3.3.1 rich level of user engagement has been achieved overall. This has resulted in several useful observations and lessons that can be learnt for future interventions.

At the initial stage, several students involved in the intervention mentioned that they did not operate the SHT although some configuration of the smart control technology was completed during installation. There were several reasons that caused the inaction, including

- The timing of installation did not require significant heating services (early autumn), which led to lack of interests in the technology by the students.
- The new life experience (of moving to UEA campus, away from their family) presented significant challenges to some students, who were busy adapting to the new environment and less willing to test the system.
- The features of the SHTs were complex, which left it unclear for students to know the useful function of the system. Given the complexity in the SHT, it would be a time-consuming activity for students to fully engage with the system, not to mention their fully packed schedule with other events at the university.

Nevertheless, participants with technical expertise appreciated the practical and cognitive aspects of learning to use the SHT at the initial stage. They were willing to try the more advanced functions of the system, such as the setting automated rule profiles and the timers schedule whilst away from their rooms.

After the initial stage of experiments and trials, students tended to use simpler forms of use rather than progressively using the advanced functions in the middle of the project. Most of them stopped using the more advanced functions but switched back to the basic functions of the SHTs such as manual control. Similar to their experience at the initial stage, students highlighted that the design of the SHT was complex and confusing and in general not user friendly. One other negative experience was the lack of sufficient instructions from the in-house maintenance team of the Estates Department. In addition to the negative experiences in the adoption of SHTs, students highlighted some areas to improve. They also mentioned an integrated approach to improve the performances of the SHTs, which means better coordination among the SHTs, boilers and radiators.

UEA's two Living Labs' occupants were able to utilize specific system features to an increasing extent in the medium-term, however usage of smart home technology was extremely limited in the final weeks of the intervention. As a result, although living labs made significant energy savings (when compared against control flats) prior to the Christmas break, energy consumption increased dramatically at the end of the heating season.