Improving building energy efficiency through user behavior change driven by co-created ICT interface

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Abstract

The consumption of buildings is strongly influenced by the behavior of its occupants. Therefore, it is important to make users aware of their consumption and help them reduce it. The THE4BEES project presented in this contribution aims (1) to raise users' awareness of building energy consumption and (2) to optimize comfort and energy efficiency through better user-building interaction. The designed method gives an important role to the user, while increasing use and acceptance, which is sometimes difficult to achieve with fully automatic solutions. To achieve this, a user-building interface (ICT application on a tablet) was developed. This tool provides occupants of two monitored offices with information on their electricity and heating consumption, comfort indicators (temperature and air quality), light control and hints & tips on how to improve their behavior. The implemented architecture system is multiprotocol in order to communicate with sensors and actuators of any type and any manufacturer. A 32 weeks measurement campaign has led to a significant reduction in the electrical consumption of lights and electrical appliances. Air quality in the working environment was also improved thanks to the user interface. This research highlighted that including occupants early in the design process of a user-building interface that meet their expectations is a good way to inform them and make them realize the impact of their behavior on the energy consumption.

La consommation des bâtiments est fortement influencée par le comportement de ses occupants. Il est donc important de sensibiliser les utilisateurs à leur consommation et de les aider à la réduire. Le projet THE4BEES présenté dans cette contribution vise (1) à sensibiliser les utilisateurs à la consommation d'énergie des bâtiments et (2) à optimiser le confort et l'efficacité énergétique grâce à une meilleure interaction entre les utilisateurs et les bâtiments. La méthode proposée donne un rôle important à l'utilisateur, tout en augmentant l'utilisation et l'acceptation, ce qui est parfois difficile à réaliser avec des solutions entièrement automatiques. Pour ce faire, une interface utilisateur (application TIC sur tablette) a été développée dans le cadre de ce projet. Cet outil fournit aux occupants de deux bureaux surveillés des informations sur leur consommation d'électricité et de chauffage, des indicateurs de confort (température et qualité de l'air), un contrôle des lampes et des conseils et astuces pour améliorer leur comportement. Le système mis en œuvre est multi-protocole afin de pouvoir communiquer avec des capteurs et actionneurs de tout type et de tout fabricant. Une campagne de mesure de 32 semaines a conduit à une réduction significative de la consommation électrique des lumières et des appareils électriques. La qualité de l'air dans l'environnement de travail a également été améliorée grâce à l'interface utilisateur. Cette recherche a mis en évidence que le fait d'inclure les occupants dès le début du processus de conception d'une interface utilisateur qui répond à leurs attentes est une bonne façon de les informer et de leur faire prendre conscience de l'impact de leur comportement sur la consommation d'énergie.

1. Introduction

About one third of the total primary energy resources is consumed by buildings [1]. To meet the expectations of the objectives of the Energy Strategy 2050, buildings are increasingly energy-efficient but there is often a gap between the planned energy consumption of a building and what is actually monitored [2] [3]. Part of this gap is generated by the building's use, and therefore by the users' behavior which is a significant uncertainty affecting the effectiveness of building [4] [5]. Users adapt to their environment and adapt their environment to improve their comfort [6]. For example, if the user feels like it is too cold, then he will either put on a jacket or increase the heating setpoint. These kind of behaviors strongly influence the consumption of buildings [7]. Note that the lack of information related to energy consumption as well as poor interaction between users and buildings is observed in many cases [8]. Therefore, it is important to make users aware of their consumption and help them reduce it. From a building automation perspective, one can differentiate devices that make the building autonomous (i.e. sensors and actuators) to the ones that enable interactions between the users and the building (interfaces).

The THE4BEES project presented in this contribution aims (1) to raise users' awareness of building energy consumption and (2) to optimize comfort and energy efficiency through better user-building interaction. Users, and more specifically employees, are not especially aware of the energy consumption of the building in which they work. They also don't know how to act to reduce the energy consumption. However, occupants will not remain in a situation of discomfort and it is essential to inform them of the impact of their behavior on the energy consumption. Furthermore an employee does not pay the electricity/heating bill and does not directly benefit from consumption reductions; therefore, it is essential to find other ways to motivate him [4].

This situation can be improved by a well-performing interface providing occupants with information on their building (environmental parameters sensors, lighting and HVAC systems) [9]. This will make it easier for users to establish a connection between their behavior and energy performance. Creating a user-building interface with features that improve user's comfort and health is one of them. It is a good way to rise the occupants' awareness and interest by promoting energy saving behavior at the workplace [10]. The proposed design method gives an important role to the user, while increasing use and acceptance, which is sometimes difficult to achieve with fully automatic solutions [8].

2. Experimentation environment

The monitored environment takes place in an old industrial hall completely transformed in 2015, called Blue Hall. It is mainly composed of offices and laboratories, which represent 2'360 m^2 of useful surface. Only offices and laboratories are actively heated and cooled. The occupants can adjust the set temperature of each room individually. The inner courtyard as well as the circulation surfaces are protected from the outside by a polycarbonate envelope and are tempered by the heat loss from the regulated rooms and passive solar gains. This concept significantly reduces the heating and cooling consumption of the Blue Hall while maintaining the indoor courtyard temperature above 15°C in winter and below 30°C in summer. Note that the heating and electricity bills are calculated in relation to the area rented to each entity present in the building. This choice of billing does not push tenants to make efforts at the consumption level of their office since their savings are distributed among all tenants. Common areas are available to tenants, such as meeting rooms or a shared cafeteria equipped with microwaves, refrigerators and a coffee machine. Despite this, similar equipments are installed in some offices, which logically increases the building's consumption.

The employees are quite young (about 40% of them are 19-30 years old and about 60% are 31-65 years old) and a majority are men (70%). Most of them have a high level of education (architects, engineers and university students).

The experiment proposed by this research was conducted in two offices (A and B) in the Blue Hall. Two large offices (65 m^2 each) were chosen to test the design methodology on two representative samples of occupants, generating group synergies and allowing the comparison of two distinct target groups. The occupation is almost identical in both offices (about 10 employees for 5 FTEs) and the type of activity of the employees is comparable (office work). Both offices are equipped with sensors, illustrated in the Figure 1, for monitoring and recording the data listed in Table 1.

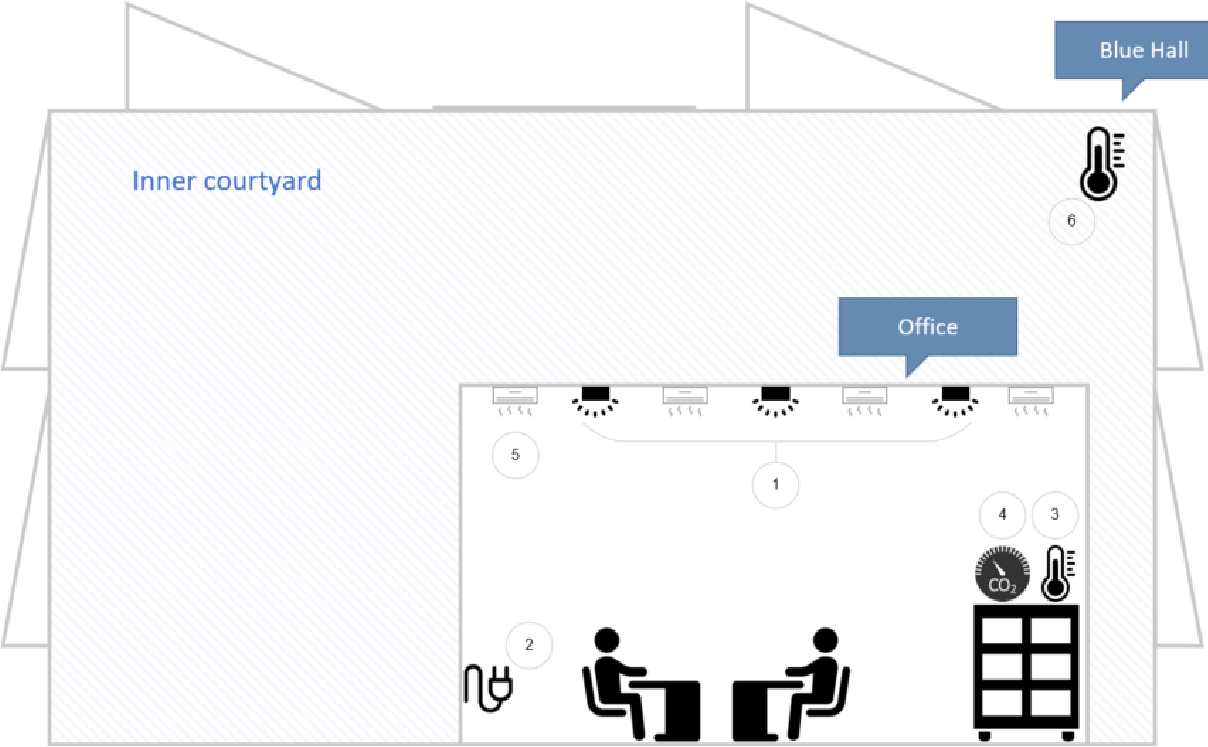

Figure 1 *Experimentation environment with sensor locations (1: lighting power and energy, 2: electrical outlet power and energy, 3: temperature, 4: CO_2 level, 5: heating system power, 6: courtyard temperature).*

Data	Unit	Sensitivity	Sampling	Position	Sensors
Door opening detection	Boolean	-	event	Offices A and B	NodOn EnOcean Door and Window Sensor
Windows opening detection	Boolean	-	event	Offices A and B	NodOn EnOcean Door and Window Sensor
Lighting energy	Wh	1 Wh	15 minutes	Offices A and B	ABB B23 111-110
Lighting power vs time	W	1 W	15 minutes	Offices A and B	ABB B23 111-110
Electrical power vs time of specific appliances	W	1 W	4 seconds	Offices A and B	Z-Wave SmartSwitch Gen5
Total electrical power vs time of electronic devices	W	1 W	15 minutes	Offices A and B	ABB B23 111-110
Electrical energy of appliances	Wh	1Wh	15 minutes	Offices A and B	ABB B23 111-110
Air quality detection (CO_2)	ppm	1 ppm	1 minute	Offices A and B	Amphenol T6713
Office temperature	°C	0.1 °C	1 minute	Offices A and B	ABB Mini KNX premium
Heating/cooling system power	W	100 W	15 minutes	Offices A and B	Siemens UH50-C21-00
Inner courtyard temperature	°C	0.1 °C	5 minutes	Inner courtyard	ABB 6108/08-500

Table 1 *List of recorded data with measurement characteristics, position of sensors and sensors' references.*

3. Methodology

3.1 Co-creation lab

This research proposes to develop an ICT interface to make the building occupants aware of their energy consumption and give them the information they need to reduce it. A challenge is to make this tool understandable by users and accepted. Like the current trend of the design thinking including users in firms' processes to help companies better address their customers' latent needs, this research includes the building occupants from the beginning of the project [11]. The co-creation process aims to (1) identify the real needs of users and the improvement potential of their workspace, (2) determine the useful information to be transmitted by the interface and in what form it should appear, (3) involve occupants in the design of the interface to facilitate its adoption and catch their interest. To achieve this, several interactions with the occupants were organized through co-creation labs (CC-Labs) promoting group exchange and synergy or personal surveys to gather user feedback. The different phases of the co-creation process are illustrated in Figure 2.

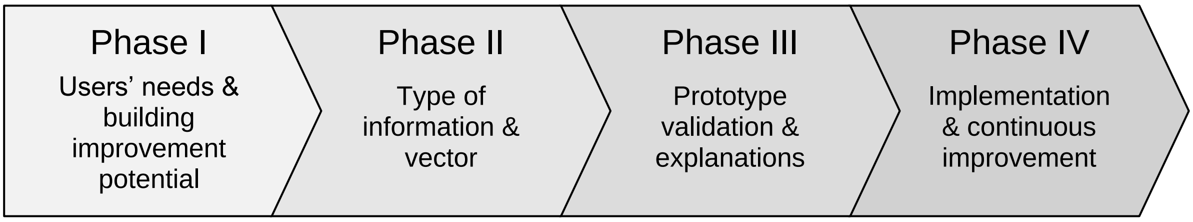

Figure 2 The four phases of the co-creation process of ICT interface design implemented as part of the project.

The first phase is about the identification of users' needs concerning their work environment. The goals of the first CC-Lab were to think about the present energy consumption of the building, gather ideas, needs and opportunities in the field of energy consumption through technical or behavioral changes. This first step highlighted some building improvement potentials that could be exploited by an ICT interface coupled to sensors and actuators. The user's main interest is to improve his comfort and health before saving energy. Providing an interface that does both is a way to catch the user's attention while making him aware of the energy savings he is able to achieve by changing his behavior.

Once the areas of improvement have been identified, the second phase seeks to define what information is relevant to be communicated, in what form and on what medium. Too much information displayed on the interface affects the user's understanding. It is important to transmit only the information which seems relevant and sufficient to him. The way that the information is displayed is also crucial. There are many ways to display the same information: a numerical value or a colour code, an instantaneous value or a history of values, an absolute value or a trend with regard to a reference value, etc. User input is required to choose the most appropriate way to display the information and thus ensure that they will interpret it correctly. After these first two steps, it was possible to design a first version of the interface. The interface was designed by the occupants of the building but it must be understandable for future users who were not present during the first two stages of the co-creative process.

The third phase consists in presenting this beta version to the users and get feedback on possible improvements to make it more intuitive, easier to read and use. It is essential to take into account comments and advices collected at this stage to later present an interface that meets users' expectations. Co-creation requires time from the participants of the different CC-Labs. If they do not feel listened, they might be frustrated and will not use the interface.

Finally, the fourth and last phase of the co-creation process begins at the implementation of the alpha version of the interface. User feedback is still required to enable continuous improvement of the interface. This step is used to detect and correct possible bugs, to add or modify features desired by users. This will keep their attention and keep the interface attractive. Generally speaking, this co-creation process should not appear binding. CC-Lab participants should benefit from it, for example by providing them with explanations on how the building works or on how to improve their work environment.

3.2 Improvement potentials

The interface must meet a need to be effective, useful and used. The first phase of the co-creation process detailed in the previous chapter describes the search for building potential improvement and users' needs. The occupants of the Blue Hall were invited to a workshop conducted using the World Café method [12] to first discuss the building's strengths and weaknesses and then to reflect on improvement opportunities. If some requests could not be met by an ICT interface, such as the desire to modify the envelope of the building to enjoy more natural light and thus save energy, some points were in line with the project's framework. The occupants found it unfortunate that they only had access to the annual consumption of the entire building. They wanted a clear and detailed feedback of their office consumption. Some wanted the office light switches to be moved next to the front door. Indeed, once towards the door and knowing that the automatic regulation will turn off the light later, people did not make the effort to cross the office to press the buttons. The lack of mechanical office ventilation was also a concern for the occupants. Some, who did not ventilate their offices sufficiently suffered from recurrent headaches. The lack of air quality measurement to inform people when it is necessary to open windows was highlighted. Some tenants complained about a lack of information and knowledge on the building automation and settings and users' possibilities to interact with the building. Parallel to the implementation of the dashboard, it was necessary to provide this type of information to users, so they understood how to act on their work environment and the impact of their actions. Workshop outputs coupled with available measurements allowed to identify four areas for improvement: (1) better lighting management, (2) better electrical devices management, (3) air quality improvement by opening windows and (4) better heating/cooling control.

3.3 System architecture

Recording the measurements, providing near real time feedback to the user and enabling him to control the lights requires a reliable system architecture adapted to the existing building. This system architecture implemented for this project is detailed in Figure 3.

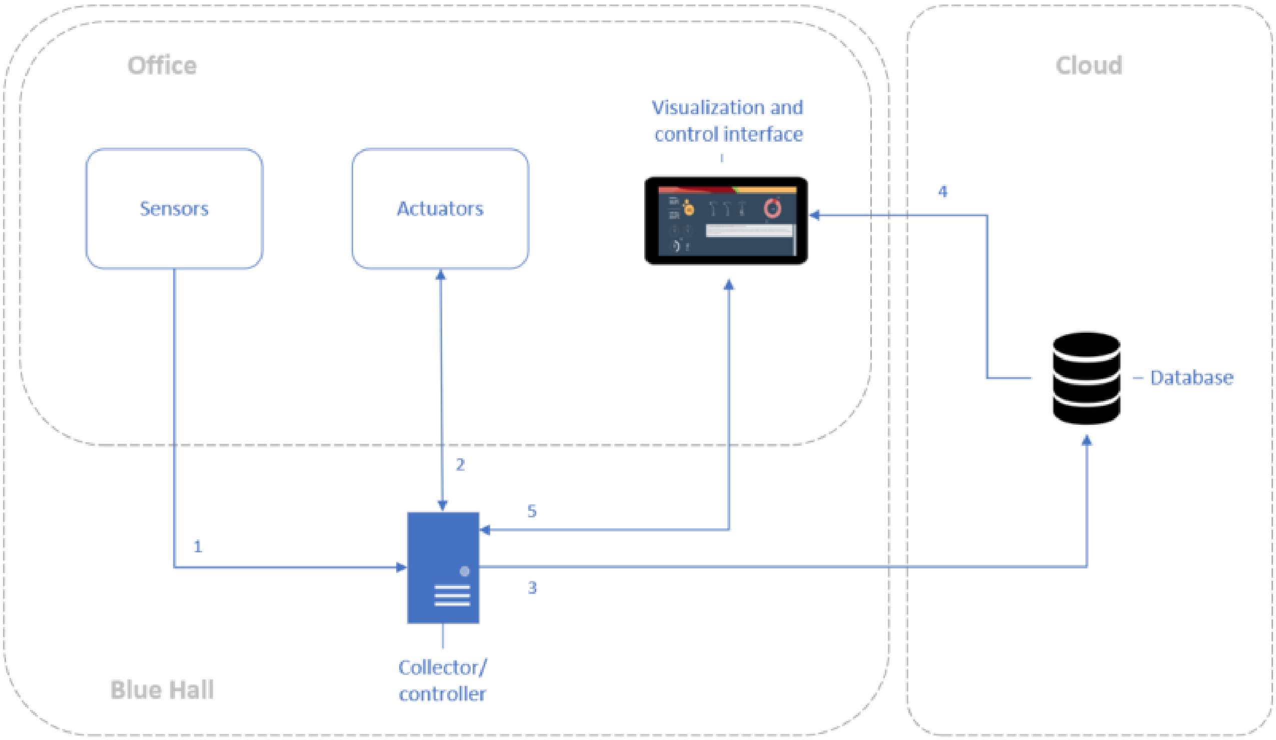

Figure 3 System architecture with the arrows representing the data streams.

The sensors of the monitored offices described in Table 1 as well as the controllable lights (actuators) are connected to a collector/controller, which is the core of the system. This collector/controller is hosted by a server located in the Blue Hall and its functions are to collect the data from the sensors (1 in Figure 3) and control the light system of each office (2). It is multiprotocol in order to communicate with sensors and actuators of any type and any manufacturer. In the case of this research, offices' sensors use different protocols: KNX for the light/electrical system, Z-Wave to monitor the electrical power of specific appliances, EnOcean to detect the opening/closing of the windows and doors, M-Bus/Modbus for the heating system and finally the Arduino-based “sensor box” to monitor the temperature and CO_2 level in the offices. There are two possibilities to retrieve the data from the sensors. Some of these sensors return data to the collector at each state change (for example windows opening detection) while others must be polled by the collector to collect values according to a defined timestamp.

Then, the collected measurements are directly transmitted to a cloud database for storage (3) [13]. Communication with the database is carried out via a REST API. The server also hosts local storage in case the database is not accessible, for example in case of network failure. The collector will then store this data locally until the database is up again. The user interface is then updated via recent data stored on the database (4). The interface is hosted on a web server accessible by a URL and displayed on a tablet installed next to the office door. This location allows occupants to keep an eye on the interface every time they enter or leave the office.

Finally, for the light control via the interface, the requests go directly through the collector/controller (5) which then forwards them to the lights (2). Actuator control does not go through the database to minimize latency. The light intensity data is transmitted directly to the interface in order to make the display on the tablet as responsive as possible.

3.4 Interface design

The designed interface, shown in Figure 4, is organized into four parts. The information displayed on the interface is obviously specific to the office in which it is located.

A. Comfort and heath

The temperature inside the office and in the inner courtyard is displayed. By knowing the inside and outside temperature of the office, users can make the decision to open the windows rather than to adjust the set temperature of the office if the situation is favourable.

The CO_2 level of the office is also displayed using an icon designed by an occupant during a CC-Lab. Because a numerical CO_2 value is not meaningful for non-air quality specialists, the indicators changes colour depending on the CO_2 level (green = ok, orange = open the windows soon, red = open windows now). Because users do not always have an eye on the interface located next to the door, it is important to take into account the variation of the CO_2 rate. If it increases too quickly, it is necessary to warn users before exceeding the recommended limit. By this anticipation, the interface compensates the reaction time of the users. It is also possible to see the historical variation over the last 24 hours (see Figure 5) of CO_2 level by clicking on the icon.

B. Lighting control

Three buttons allow users to individually turn on/off the three rows of LEDs in the office by clicking on the light icon. An added value of this tool is to locate these switches near the door, which is favourable for frequent switching on/off of lights and which was not the case before the implementation of the interface. A circular slider is available to adjust precisely the illumination level, which was difficult to do with the installed mechanical buttons. Finally, a button allows the user to switch off all the lights at once. It is possible to expand the lighting control panel with the “expand” button located in the centre to be more precise when adjusting the illumination level.

C. Energy consumption

Three gauges display the lighting, electrical and heating power consumption. Maximum values displayed by these gauges must be defined in relation to the regular consumption of the office. It is not advisable to display numerical power values, as it is not very meaningful for the average user [14]. However, the interface still displays these numerical values on the occupants' request. Indeed, most users in this experiment have a high education level and are comfortable with raw values.

One of the purposes of measuring electrical consumption is to inform occupants about the office's residual consumption, i.e. the energy wasted by certain electrical appliances that are continuously connected. No colour code was used on the power consumption gauges (light and outlets). The interface cannot provide judgment on the consumption needs and should not return a negative message to the user that consumes a lot out of necessity of his task.

The third gauge allows occupants to know if the heating system is heating or cooling. There is a colour code for the heating/cooling system (red for heating and blue for cooling). Coupled with the temperature indicators, users have necessary information to adapt the setpoint temperature and manage the windows opening if the situation is favourable. Historical variations on 24h of the heating/cooling power is available by clicking on the gauge. The user can see the influence of the setpoint temperature on the consumption of the office and adjust it to reduce the consumption during the night for example. Historical variation of lighting and electrical power are also.

The pie chart on the right shows the proportion of all the electrical consumers combined. On request of the users, it is possible to display on this pie chart the consumption of a specific appliance, such as a coffee machine or a fridge, on this pie chart. This representation allows users to visualize the main sources of electrical consumption in the office.

D. Message window

This part is used to display all the tips/messages to the occupant. There are four types of messages: alert (red), warning (orange), success (green) and standard messages (grey). This service is also used to send a message to the users following a more in-depth analysis of the results and not necessarily visible by the user directly on the tablet. Messages can be either general for the two offices or specific to one.

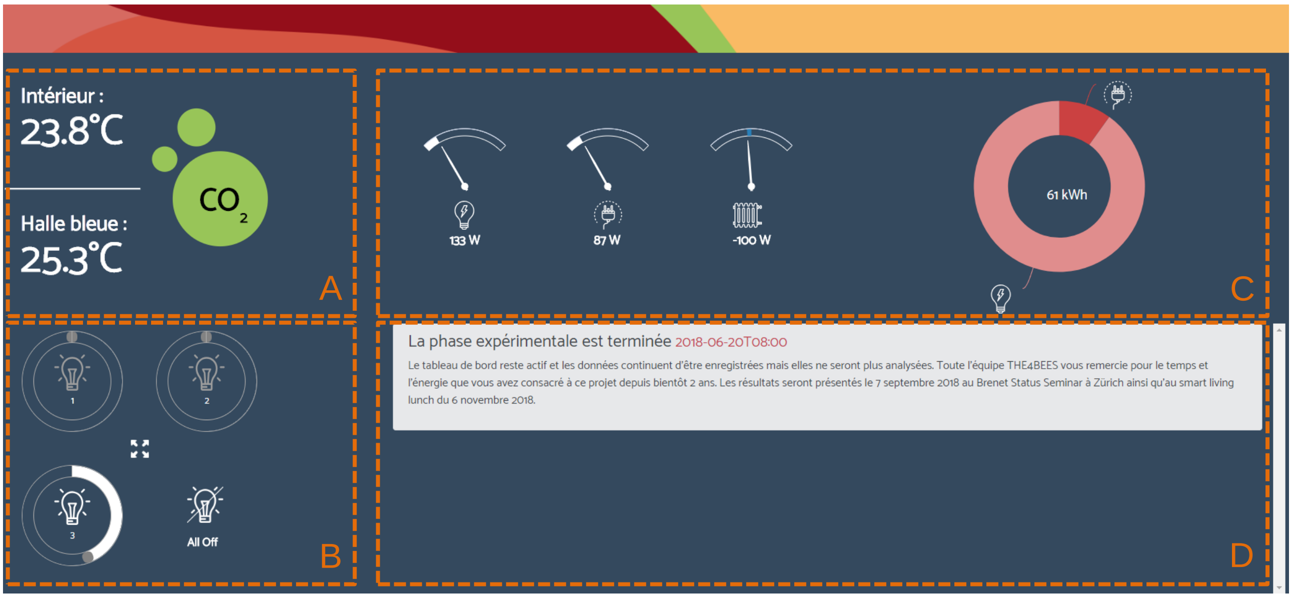

Figure 4 *Main menu of the developed interface with comfort indices (A), lighting control (B), instantaneous and proportional electrical consumption (C) and messages window (D).*

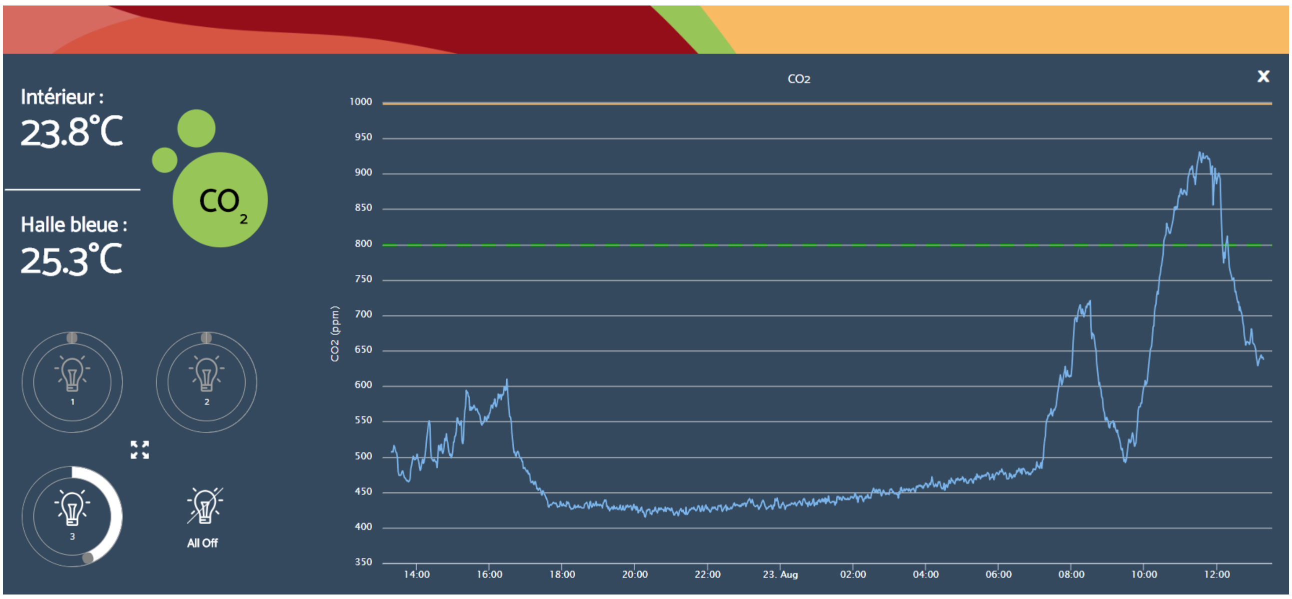

Figure 5 *One submenu with historical measurement on 24 hours of the CO_2 level of one office with the recommended threshold limit at 1000 ppm (orange).*

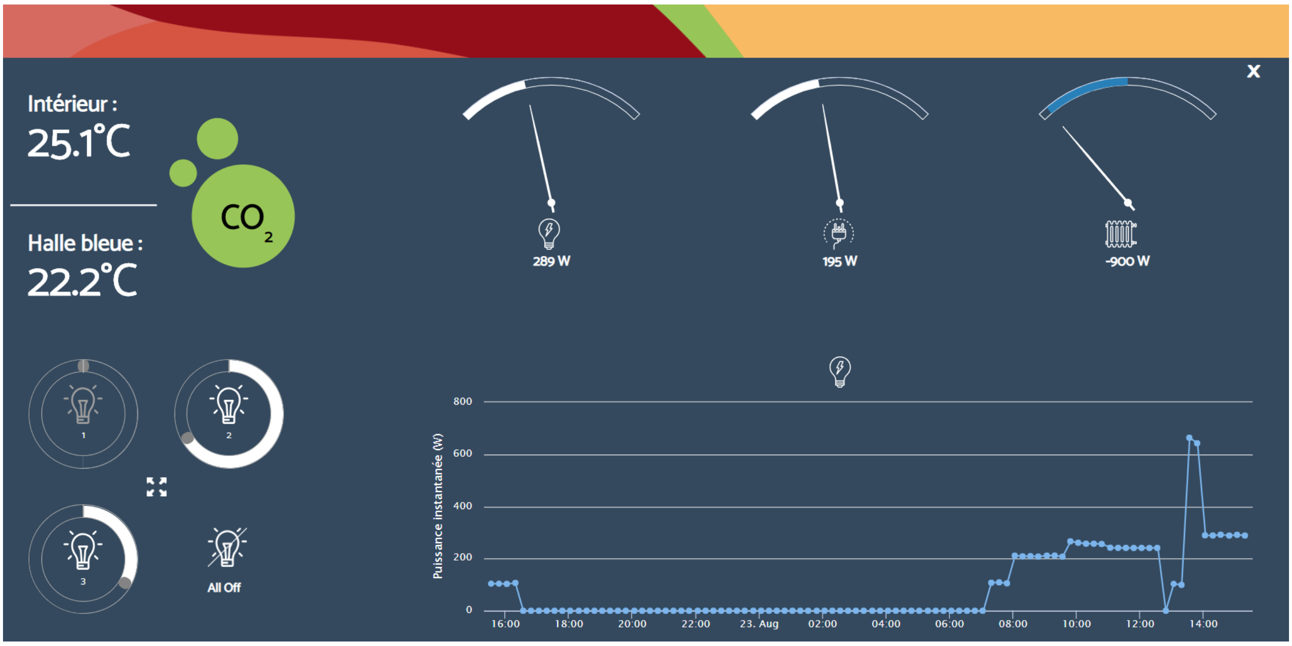

Figure 6 *One submenu with historical measurement on 24 hours of the lighting power consumption of one office.*

4. Results

4.1 Energy consumption

Baseline

The electrical consumption of both offices (light and outlets) was recorded for one year before leading to changes in occupant behavior. The datasets recorded during the trial phase, after triggering behavior changes via the interface, can be compared to this baseline. It is also interesting to compare the consumption of the two offices before implementing the interface. As mentioned before, the occupation is almost identical in both offices and the type of activity of the employees is comparable (office work). However, there are clear differences in electrical consumption between offices (see Table 2). Indeed, office B consumes 29% more light than office A and 73% more electrical outlets. This difference represents a 41% difference on the annual electricity bill. This result clearly shows the consumption uncertainties of two identical offices in the same building. These uncertainties depend mainly on (1) equipment, (2) office layout and (3) occupant behavior.

Yearly consumption	**Office A**	**Office B**
Lighting consumption (kWh/year)	1'084	1'402 (+29%)
Electrical outlet consumption (kWh/year)	406	702 (+73%)
Electricity consumption cost (CHF/year)	268.20	378.70 (+41%)

Table 2 *Electrical consumption of both offices recorded during one year (from 1.12.16 to 1.12.17) with an electricity purchase price of 0.18 CHF/kWh.*

Lighting consumption

The weekly average of daily lighting consumption during work days (excluding weekends and public holidays) was chosen as the representative indicator for the analysis. Since most employees work part-time, the week should be considered as the time base during which the occupation can be estimated constant. The variation of this daily consumption during the trial phase is shown in the Figure 7. Table 3 compares the daily consumption during the last month of the trial phase (after 32 weeks of awareness) with the reference consumption recorded before the implementation of the interface in the offices.

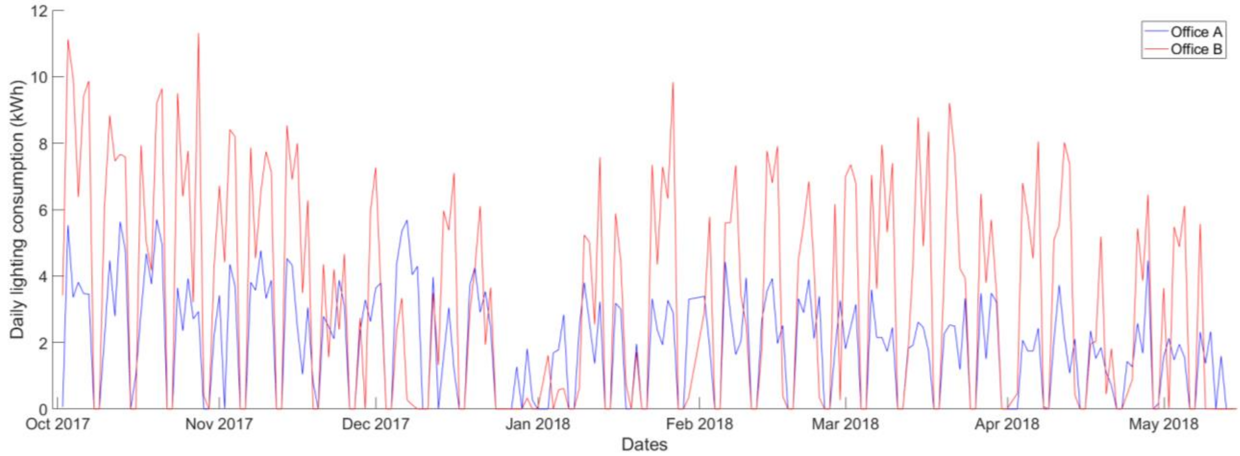

Figure 7 *Daily lighting consumption in kWh of offices A (blue) and B (red) during the trial phase since the interface implementation.*

Time period	Office A	Office B
'Baseline' daily lighting consumption (kWh)	4.44	5.57
'End of trial phase' daily lighting consumption (kWh)	1.94	4.30
Lighting consumption reduction (%)	56%	23%

Table 3 *Lighting consumption comparison of both offices between the baseline and the end of the trial phase.*

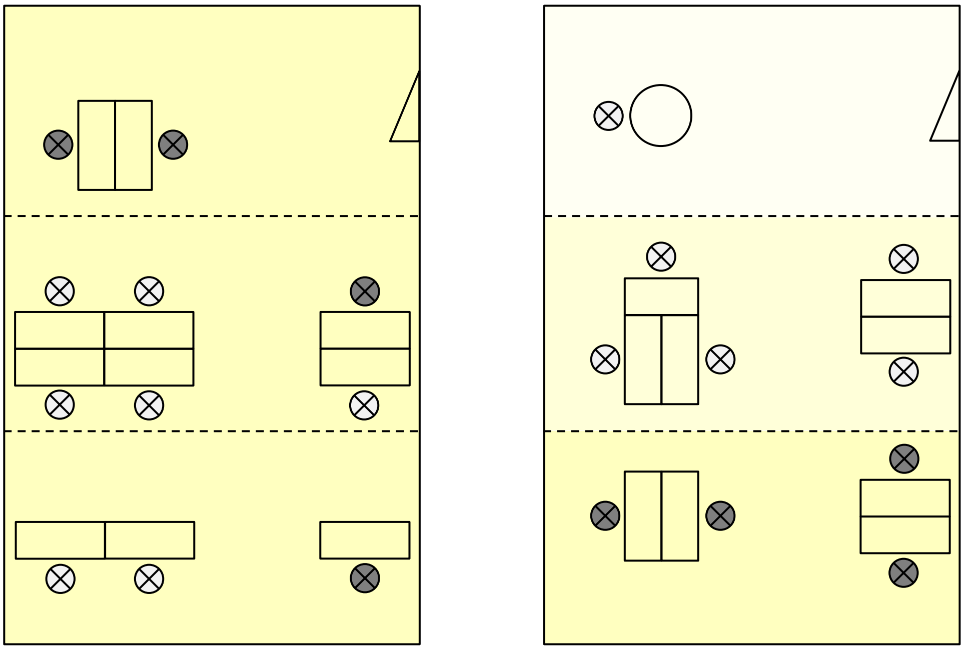

Figure 8 *Workplace locations in the office A before (left) and after (right) the reorganization during the trial phase with dark points representing the frequent users workplaces (≥ 0.6 FTE per person) and clear points for occasional users workplaces (≤ 0.5 FTE per person). The dash lines delimit the areas illuminated by the 3 LED strips. The colour intensity is proportional to the average light consumption of each zone.*

These measures indicate that offices A and B have reduced their lighting consumption by more than half and about a quarter respectively. To achieve this, the occupants reorganized the work places in office A, as shown in the Figure 8. Therefore, the most frequent employees are grouped in a third of the office so that they no longer need to turn on the three rows of lights continuously. The middle part is occasionally illuminated while the third near the door is almost always switched off. Users also reduced light intensity more often thanks to the interface that simplified the handling. The layout of office B has not been modified, but its occupants bought individual LED office lamps, which consume less energy than the rows on the ceiling. The rows of light on the ceiling continued to be used because of the automatic switching on of the lights. Some users did not find it comfortable to work only with a desk lamp. The awareness campaign also convinced users to turn off the lights more regularly when they were no longer needed (e.g. during breaks, when leaving work at the end of the day). The fact that the reduction is more pronounced in office A also comes from the fact that the light buttons were already positioned towards the door in office B. This change greatly improved comfort in office A with no real added value for office B.

Electrical outlet consumption

The weekly average of daily electrical outlet consumption during work days (excluding weekends and public holidays) was chosen as the representative indicator for the analysis for the same reasons as those mentioned above for light consumption. Table 4 shows two distinct baselines. The first was recorded during the months of April and May 2016, when office B was still equipped with desktop computers, while the second was measured during the 2 months preceding the implementation of the interface with only laptops in both offices.

Time period	Office A	Office B
(a) 'Baseline 1' daily electrical outlet consumption (kWh)	1.84	3.34
(b) 'Baseline 2' daily electrical outlet consumption (kWh)	1.68	1.65
(c) 'End of trial phase' daily electrical outlet consumption (kWh)	1.06	1.45
Electrical outlet consumption reduction (a, c) (%)	43%	57%
Electrical outlet consumption reduction (b, c) (%)	37%	12%

Table 4 *Electrical outlet consumption comparison (only during work days) of both offices between the baselines and the end of the trial phase. Baseline 1 was recorded during April-May 2016 and Baseline 2 was recorded during the two months preceding the trial phase.*

The power consumption of the two offices is relatively low and does not make it possible to make large savings. The variation of this daily consumption during the trial phase, visible in the Figure 9, shows that more electrical appliances remain on in office B. The minimum daily values measured in office B are higher than the minimum daily values in office A. No significant behavioral changes were observed in the use of the coffee machine, kettle and fridge in office B. It should be noted that some employees in office B have given up their second screen to be satisfied only with their laptop to work. Even if the residual consumption of office A increases slightly from March 2018 (due to additional equipment related to their work), its occupants managed to reduce their consumption by 43%. They removed two coffee machines and a kettle and made more use of the common coffee machine in the building's cafeteria. They also plugged their computer equipment into the power strips in order to turn everything off more easily at the end of the day.

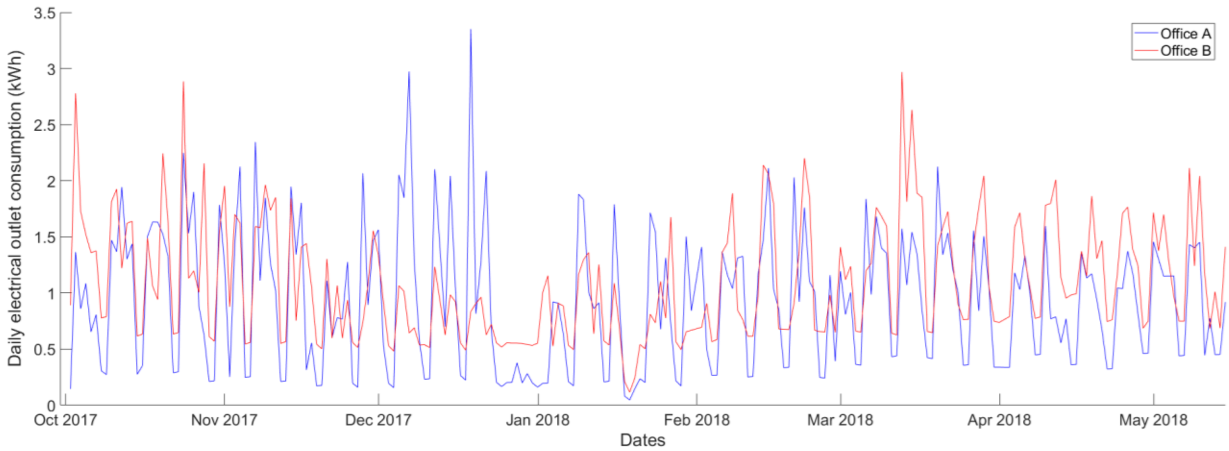

Figure 9 *Daily electrical outlet consumption in kWh of offices A (blue) and B (red) during the trial phase since the interface implementation.*

4.2 Comfort and health

Air quality

Before providing occupants with a CO_2 indicator, one of the two offices regularly exceeded the recommended threshold of 1000 ppm for several hours per day, especially during cold periods when they were less likely to open windows. Sometimes, the CO_2 level was so high at the end of the day that the infiltration through the offices walls and windows were not enough to bring it back below the recommended limit on the next morning. The employees started their work day with poor air quality. Figure 10 shows the significant influence of the interface on the office window opening management. Once warned, occupants knew when to ventilate and were able to keep CO_2 level below a reasonable limit. Both offices found the CO_2 indicator relevant and appreciated the way this information was displayed on the dashboard. This functionality was a major request during the CC-Labs due to the lack of mechanical ventilation in offices. The fact of using a design proposed by a user seems to be much appreciated.

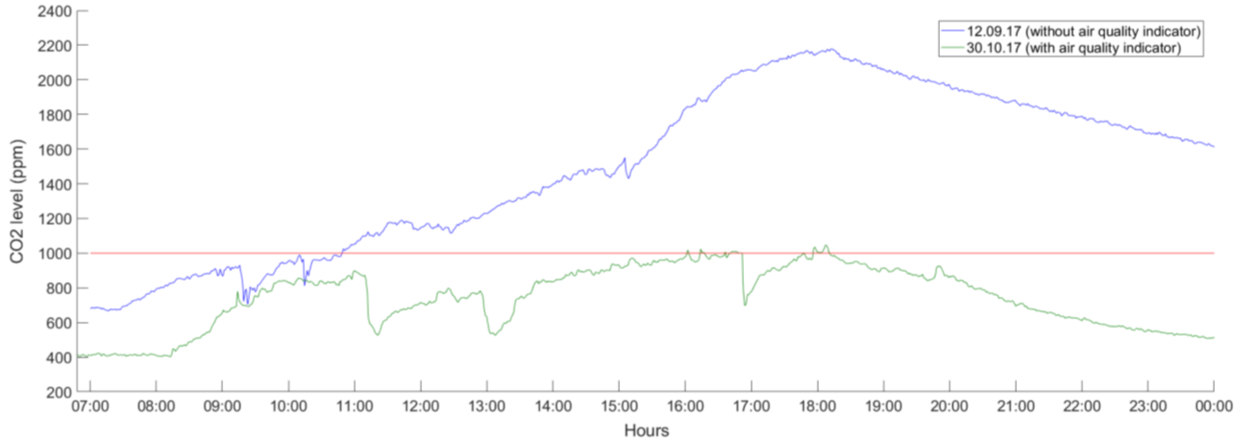

Figure 10 *CO_2 level variation on 24h before (blue) and after (green) the interface implementation with the recommended threshold limit set to 1000 ppm (red).*

Heating/cooling control

Unfortunately, for the time being, this study cannot characterise the change in user behavior with regard to the control of the heating/cooling of the office, nor quantify its impact on consumption. Due to technical limitations, the office setpoint temperature cannot be recorded. Furthermore, the heating consumption measurements taken during the trial phase cannot be compared with the previous winter's data because the heat meter was only recently installed.

According to users' feedback, some employees modified the office setpoint temperature when leaving in the evening to avoid consuming all night. During the day, priority is clearly the air quality, comfort and health. Users open windows to decrease CO_2 without paying attention to heating consumption.

4.3 User feedback

The aim of the THE4BEES project is to reduce the consumption of buildings through the behavior of their occupants. It is therefore necessary to check whether the trials can reduce the consumption of buildings, but also whether they modify the behavior of their occupants. While the data acquired by a range of well-chosen sensors allow a quantitative interpretation of building consumption and user comfort, they do not accurately describe the behavior of users and tell nothing about their feelings and impressions. Two surveys were sent to the occupants of the two monitored offices. They replied to the first one about two months after the beginning of the trial phase and the second was completed at the end of the trial period.

The intermediary survey was about:

- The participants' level of knowledge about their consumption before the implementation of the interface;
- Their view on the co-creation phase;
- Their appreciation of the services offered by the interface (the relevance of the information, the way it is displayed, the frequency of use);
- Their impression of having changed or not their behavior since the beginning of the trial phase.

Before the trial phase began, few participants had an idea of the office consumption. This result was expected, although surprising for tenants in an eco-district. It reflects the need to inform occupants about their consumption. Despite their lack of knowledge about their general consumption, they all felt like they could reduce it, especially at the level of the lights. It means people are convinced that there is a potential for energy reduction. This first survey shows that the co-creation process is successful.

This questionnaire showed that people change behaviors more easily to improve their comfort than to reduce their consumption. In fact, most of them claim to have clearly changed their habits in terms of window opening to improve air quality, while the change is less significant in terms of lighting and electricity consumption. This survey indicates that the dashboard must have the goal to improve the comfort of users so that they can use it and be made aware of their consumption.

The final survey asked the occupants of both offices for their opinion on:

- The device chosen to display the interface;
- The acceptance of this new tool at work;
- The means of enhancing this interface at the end of the experimental phase;
- Its influence within the work group and the repercussions of this awareness at home.

Following the CC-Labs discussions, a common dashboard was installed in each office. The aim of this solution was to create a synergy between the occupants of each office, to generate group discussions and common decisions and above all not to be intrusive (no individual notification). This survey shows that 70% of occupants still believe that the common dashboard is the best option. Some users want to have access to a web version of the dashboard to have access to information and control of the office lights and check the CO_2 level from their workstation. Only one thinks that a mobile application would be more suitable than a dashboard.

The decision taken during the co-creation phase therefore seems to have been the right one at the end of the trial phase. It was important to assess the constraint induced by the means put in place to reduce office consumption and improve occupant comfort. A solution that is very efficient but annoying for users will not be appreciated and accepted. All surveyed users, without exception, found the trial phase not restrictive. If the majority of them do not wish to receive notifications or alerts in general, 38% of users would like to be alerted by email or mobile app when the CO_2 level exceeds a critical threshold and 23% wants to receive personal notifications about heating and cooling management.

Regarding synergies, this survey shows that the project generated discussions within both offices. The intention to install a common dashboard to create a group dynamic around the project theme seems to have worked. In addition, it is interesting to note that half of the surveyed occupants said that this trial phase at their workplace had an influence on their behaviors at home.

5. Conclusions & recommendations

This research highlighted that including occupants early in the design process of a user-building interface that meet their expectations is a good way to inform them and make them realize the impact of their behavior on their energy consumption. Investing time and being involved in the co-creation phase motivates employees to use the tool they contributed to design. Despite a relatively low initial electricity consumption of both offices, results showed a significant decrease in office electrical consumption. The office air quality was also greatly improved thanks to the ICT tool. It should be underlined that the measured consumption reductions (up to 56% for light and around 40% for electrical appliances) far exceed results reported otherwise in the literature. The particular context of the Blue Hall offices and building, the type of activities carried out in these premises and the sociological profile of the employees explains these scores.

This work proved that through the co-creative approach:

- Users have been involved in the project;
- Users understood the information displayed on the interface;
- The occupants of the monitored offices felt that they had actively contributed to the project and succeeded in improving the situation;
- Employees felt no particular constraints in using their workplace.

Surveyed users also believe that the co-creation process has a major influence on the efficiency and the good results of the experiment. It is therefore not recommended to reuse the dashboard as it was designed for the offices of the Blue Hall in another building. The co-creation process must be repeated to highlight users' needs and the building's own potential for improvement.

Since the end of the trial phase, the solution has been deployed in another office of the Blue Hall. It would be interesting to deploy it in even more offices to validate the obtained results on a larger sample. Maintaining the interface active over several years will also make it possible to evaluate the influence of such a tool on the long term.

In parallel with this study, the other partners of the THE4BEES project carried out similar experimentations in six other pilot buildings. Among these buildings there are schools, rental buildings, alpine huts and another workplace. It would be interesting to compare the influence of different co-creation processes and different IT tools in the context of other buildings and users.

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