# Influencing user behavior in office buildings through a co-creation process in order to achieve better energy efficiency and comfort

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**Abstract**. Providing users with relevant information raises their awareness on the influence of their behavior on the energy consumption and comfort in their workspace. A user-building interface was developed as part of this research through a co-creation process. It provides the occupants of monitored offices with information on their electricity and heating consumption, comfort indicators (temperature and air quality), light control and hints and tips on how to improve their behavior. This contribution describes the methodology used to improve the behavior of users in a pilot building and the results of a 32-week measurement campaign.

*Keywords:* Building efficiency, comfort, behavior improvement, ICT application, co-creation process, workspaces.

## 1. Introduction

Today, despite efforts to build more efficient buildings, a significant discrepancy is often observed between the anticipated consumption and the consumption measured once the building has been carried out [1-2]. If this performance gap can be partly explained by the approximate assumptions about the performance of some building components or building technology [3], it is also strongly influenced by the behavior of its occupants [4-8]. Studies analyze the correlation between the building's energy performance and the comfort of its occupants [9-10]. Some other show that poor interactions between users and buildings and a lack of information on energy consumption are observed in many cases [11]. Therefore, it is important to make occupants aware of the consumption of their building and help them reduce it.

In this context, the THE4BEES project, supported by the European Regional Development Fund via the Interreg Alpine Space program, has demonstrated and evaluated the potential for improvement through a co-creation process involving users in the design of a dedicated human-building interface and a test phase over a long period in workspaces [12].

## 2. Experimental set-up and methodology

### *2.1. Experimentation environment and improvement potentials*

The behavioral study conducted in this research requires the collection of data from a representative sample of occupants in a monitored space. This study is based on the monitoring of an open-space office in the Blue Hall, a recent building equipped with sensors and actuators connected to a data acquisition system [13].

The Blue Hall is a former industrial hall, located in Fribourg, Switzerland, completely renovated in 2014. It now hosts 2’360m$^2$ of offices and laboratories. The energy concept of the building provides that only the offices are passively ventilated and actively heated and cooled. The space of the inner courtyard, including the corridors that allow circulation between the rooms, is tempered by the heat losses of the rooms as well as by passive solar gains. A system regulating the openings in the building envelope, on the facade and roof, maintains a satisfactory air quality in the building and prevent overheating in the summer. Thus, the temperature of the inner courtyard, on which the premises are located, is maintained between 15°C and 35°C during the year.

Using existing workspaces as a test environment allows to conduct a measurement campaign under real work conditions and to provide reliable and stable baseline due to the existing habits of the occupants. The knowledge, questions and expectations of the occupants made it possible from the beginning of the process to establish the potential improvements in terms of energy and comfort classified in Figure 1.

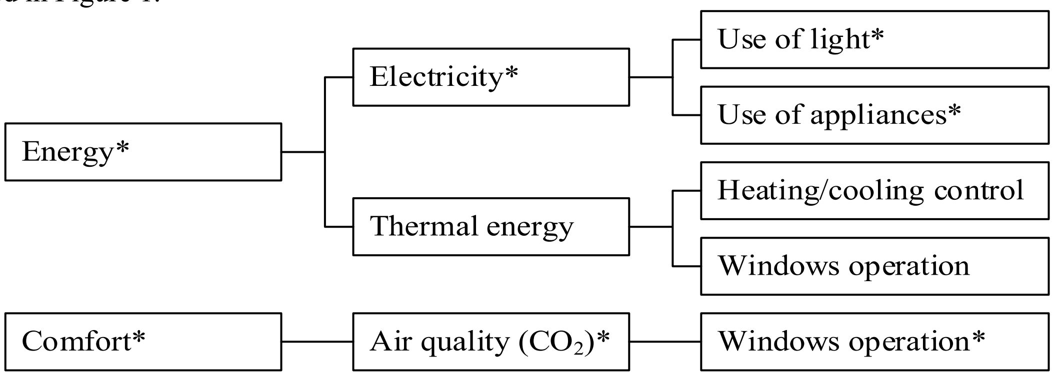


**Figure 1.** Improvement action areas and systems considered in the study including those detailed in this contribution (*).

*2.2. Co-creation process*

In order to improve the participants' degree of acceptance of change, a collaborative co-creation process was initiated [12]. In addition to identifying the most appropriate potential improvements for the occupants and their office, this process also led to the development of an ICT interface to make the building occupants aware of their energy consumption and give them relevant information to reduce it [14]. Building occupants identified a common interface per office as a useful solution to encourage discussion and promote synergies among employees.

*2.3. Measurement campaign*

The project was carried out in two phases. A first 8-month phase (from 02.02.17 to 02.10.17) was devoted to the co-creation of the ICT interface in collaboration with future users, the installation of missing sensors in the monitored office and the collection of a baseline data before influencing the behavior of the occupants. This baseline would then be used to quantify the impact of their behavior changes on their consumption and their level of comfort. The second phase was a 32-week measurement period (from 02.10.17 to 13.05.18) following the installation of the interface in the monitored office. It was used by a group of about 10 engineers and/or university students for 5 FTEs. During this measurement campaign, the interface's functionalities were gradually unlocked and adapted according to user feedback in order to keep their attention and promote the use of the tool.

## 3. Results

### *3.1. Lighting consumption*

The week was chosen as a representative time base to minimize the impact on the results of a fluctuating occupancy rate generated by part-time employees. Figure 2 shows the drastic reduction in light consumption during workdays (excluding weekends and public holidays). During baseline, this consumption decreased until summer and then increased until the interface was installed. This phenomenon can be explained by natural light. Due to the office's location in the building, this influence is weak but not negligible. The summer holiday period also affects the occupation of the office and can influence this measurement.

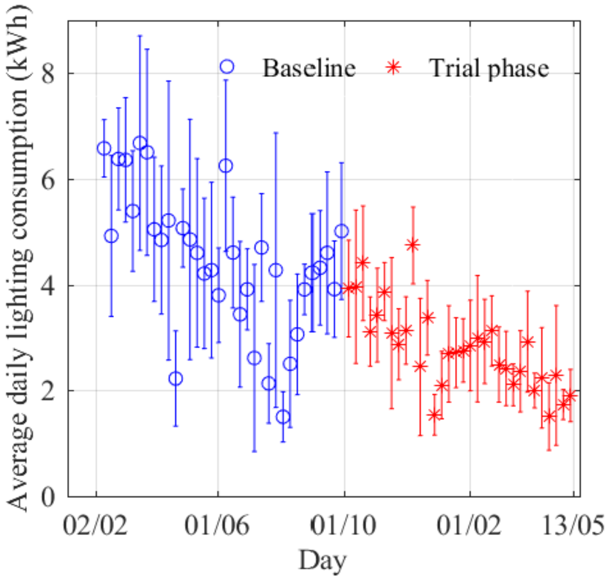


**Figure 2.** Weekly average of daily lighting consumption during workdays in kWh with standard deviation during the baseline and the trial phase.

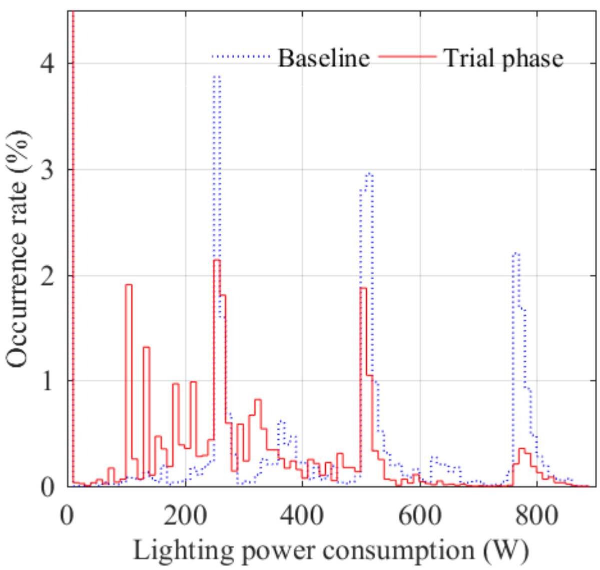


**Figure 3.** Occurrence rate of lighting power consumption measurement every 15 minutes in Watt with 72.5 % of zero values during the baseline and 74.9 % during the trial phase.

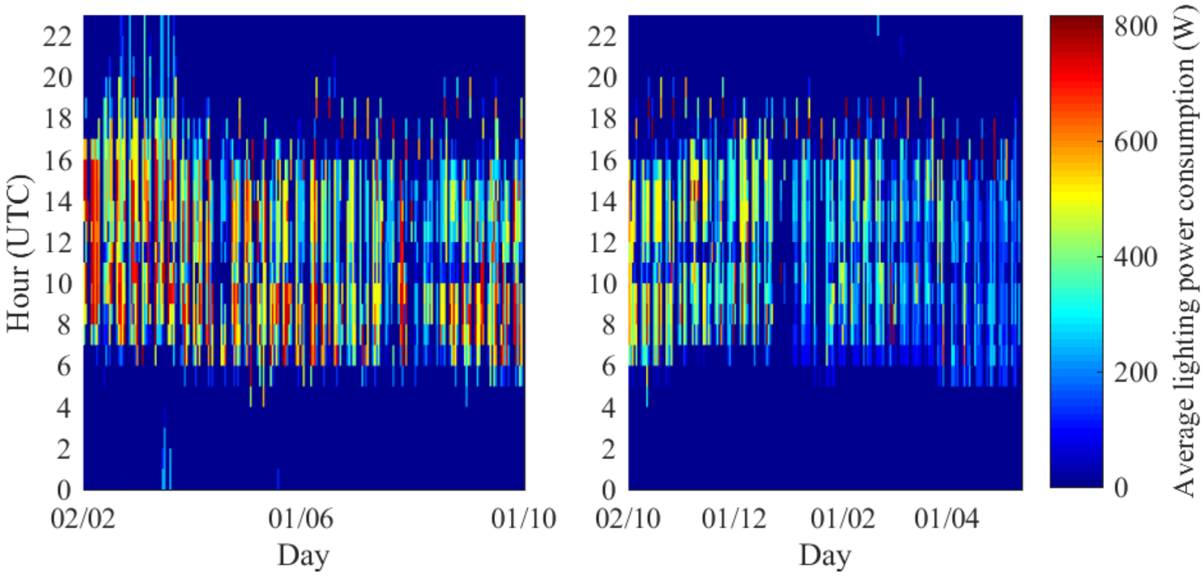


**Figure 4.** Hourly average of lighting power consumption in Watt in the monitored office during the baseline (left) and the trial phase (right).

During baseline, the light actuators were not located near the office door. In addition, occupants found that the dimming was not intuitive and rarely dimmed the light. Figure 3 shows that the interface located near the door encourages users to dim the light more regularly. By adjusting the light intensity more regularly according to their activities, users reduce the maximum level lighting time of the lamps (2 LED strip lights of 6 meters per lamp to about 20W/m) induced by the automatic regulation of the three LED lamps of the office.

This change in occupants' behavior is also visible in Figure 4 showing the daily evolution of the hourly lighting power consumption average before and after the interface installation. These maps show that employees have not adjusted their work hours to reduce the time of day when light is needed but have significantly reduced their light consumption during work hours. A notable change in occupants' behavior concerns the adjustment of lamps at the beginning of the day. The consumption peaks generated by the automatic switching on of the lamps upon almost disappeared during the trial phase. The peaks visible at the end of the day once a week can be explained by the intervention of the cleaning service. The people in charge of cleaning the office were not included in the co-creative process and did not pay attention to the interface.

The overall reduction in light consumption is also due to the reorganization of workplaces based on employee attendance rates as shown in the Figure 5. The most frequent employees grouped their workplaces in the same third of the office in order to benefit from the light of a single lamp. This change of habit allows them to switch off the other two thirds of the office more regularly, which are only occasionally occupied and do not require as much light.

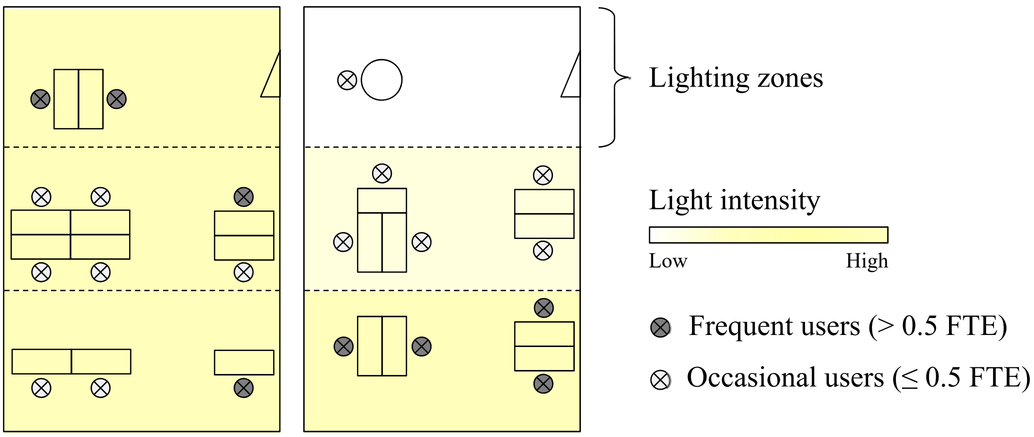


**Figure 5.** Evolution of office spatial organization before (left) and during the trial phase (right).

The lighting consumption could be further reduced during the last four weeks of the trial phase by removing the automatic regulation of the lamps. This research shows that through a co-creation process and 28 weeks of awareness raising through the interface, office occupants are able to do without the automatic switching on and off of lamps and, as a result, further reduce their light consumption. Without automatic regulation, there is a risk of over-consumption at night or during the weekend. Ideally, the automatic switch-on should be removed, but the automatic switch-off should still be left in place in case users forget to turn off the lights.

### *3.2. Electrical outlet consumption*

The interface was also intended to raise awareness among occupants on the electrical consumption of the various devices in their offices. The relatively low initial electrical consumption limits the saving potential. However, Figure 6 shows a slight reduction in electrical consumption. The measurements collected show that occupants turned off their computers, monitors and coffee machines more regularly and were more careful not to leave appliances plugged in at night. While some have tried to do without their additional screen, it was easier to motivate users to use their devices more efficiently than to convince them to do without certain devices completely.

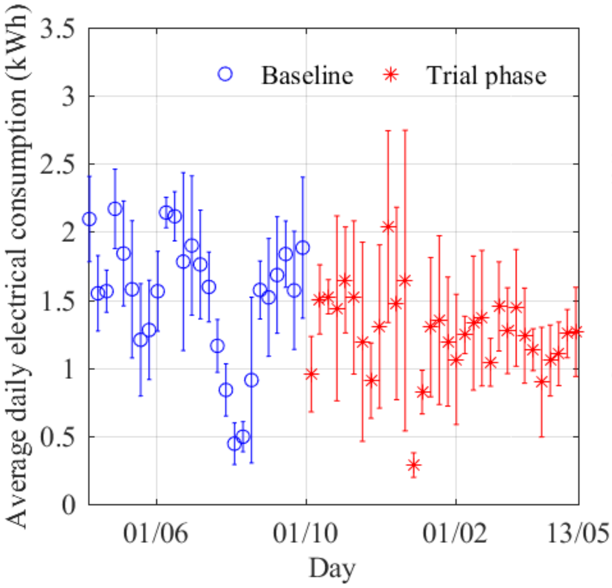


**Figure 6.** Weekly average of daily electrical consumption in kWh with standard deviation during the baseline and the trial phase.

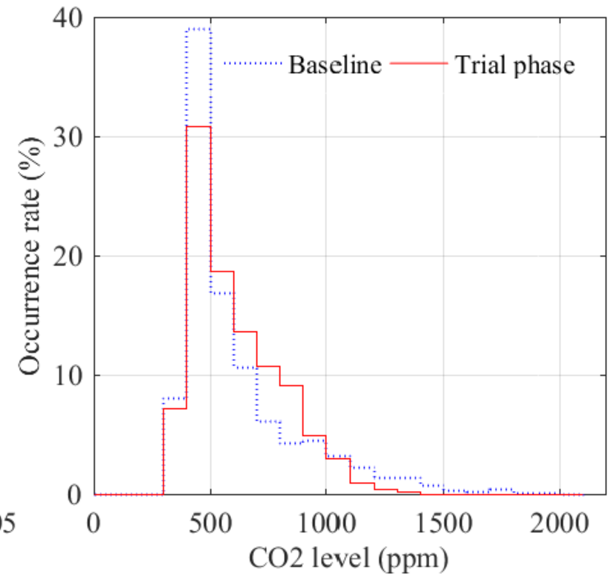


**Figure 7.** Occurrence rate of hourly average of $CO_2$ level measurement in ppm during the baseline and the trial phase.

### *3.3. Air quality improvement*

The analysis of air quality is limited to the $CO_2$ level. Figure 7 shows that the occurrence rate on 24 hours of a $CO_2$ level measurement higher than 1000 ppm is lower after the installation of the indicator. By integrating these graphs, 10.5% of the values measured during the baseline exceeded the recommended limit of 1000 ppm. Sometimes it happened that passive ventilation was so insufficient that employees started their work day with poor air quality. Once the interface was installed, this ratio decreased to 4.6%.

During this measurement campaign, it was observed that occupants left windows open more easily when the temperature difference between the office and the inner courtyard was small. During the cold season, users managed window opening by finding a trade-off between thermal comfort and air quality. Temporal analysis of the measurements shows that users are able to keep the $CO_2$ level below a certain recommended limit if they have access to an indicator.

## 4. Conclusions and recommendations

This research highlights the influence of the occupants' behavior on the electrical consumption of lights and devices as well as on the indoor air quality in an open-space office. To trigger a change in the occupants' behavior, they were involved in a co-creative process that led to the development of an ICT interface dedicated to their work environment. This tool was designed to provide users with comfort indicators, but also to make them aware of the impact of their behavior on their consumption.

The results presented in this contribution show a significant reduction in light consumption partly due to an office layout reorganization triggered by the co-creation process. Despite a relatively low electrical consumption of various devices, an improvement in the occupants' behavior could still be observed. Finally, the air quality of passively ventilated office was improved during the 32-week measurement campaign.

Recommendations for further research include: (1) ensure a robust and reliable data acquisition system to prevent data loss and (2) monitor a wider panel of offices with, for example, different types of activities, a variable number of users, etc. The results presented in this contribution apply only to a specific context. Their scope is therefore limited, but the methodology used as well as the analyses and representations could be useful in other studies.

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