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Experimental setup and testing of an in-field system for real-time occupant feedback

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Abstract. Thermal comfort and air quality in buildings have been found to be the 2nd and 5th largest sources of complaints among occupants in modern office buildings. In building operation, the determination of control set-points is normally based on a combination of theoretical models and feedback from occupants. The feedback is most often unstructured and based on face-to-face information transfer, costing time for building operators and with no possibility for systematic learning over time. In practice, operating temperature ranges as small as 1-2°C are usually adopted in order to prevent complaints from occupants in office buildings. Research has however shown that narrow temperature ranges do not result in higher occupant satisfaction, and several researchers have proposed that control of buildings should be done based on continuous subjective feedback from the occupants in the building. This article covers the design and proof of concept for a non-intrusive system for continuous occupant feedback in offices. The system consists of a feedback terminal for capturing day-to day overall satisfaction with indoor climate, a smart phone based system for capturing personal comfort thresholds, and physical measurements of room temperature and CO_2 level. Longitudinal tests were conducted in selected rooms in two buildings near Oslo in Norway, measuring a total of 20 office desks in regular use over 3-5 months. The findings indicate that this simple and inexpensive system collects information about the occupant's perception of the indoor climate. Further work must be done to give this information value for building control and learning.

1. Introduction

Thermal comfort and air quality in buildings have been found to be the 2nd and 5th largest sources of complaints among occupants in modern office buildings [1]. In building design, the optimization of these parameters is normally based on theoretical models and guidelines for predicting the comfort and satisfaction of groups of occupants. In building operation, the same models are combined with practical experience and feedback or complaints from occupants in real-time to achieve optimal performance of the building. The feedback from occupants is however seldom systematically logged or used in systematic learning [2]. Studies of facility management practices in existing office buildings have shown that in buildings designed using the above mentioned approaches, in practice, operating temperature ranges as small as 1-2°C are adopted in order to prevent complaints from occupants [2–4]. These demands and practices lead to a high need for installed heating and cooling capacity, high power peaks, and high energy use. At the same time, field studies find that narrower temperature bands do not lead to higher satisfaction with the thermal environment. In one study [5], operating temperature ranges were compared to user satisfaction with different temperature conditions. It was revealed that there was no detectable difference in the satisfaction levels of office workers in buildings with wide temperature bands than in those with narrow bands. The authors claim that this is due to the fact that individual differences in neutral temperature, due to physical differences in metabolism, clothing, activity level, posture etc., are larger than the building temperature dead-bands, and that the variety among occupants is larger than what is assumed by the classical thermal comfort theory. The main tenet of the adaptive model is that building occupants are not just passive recipients of their building's internal thermal environment, but rather play an active role in creating their own thermal preferences [6]. It has been found that users on average tend to be more satisfied with buildings where they can open windows or in other ways control their own thermal environment, even though the actual thermal conditions were no better in these buildings [7]. These studies conclude that a common static "neutral temperature" is not necessarily the most satisfactory condition for people in real buildings, and that physiological and psychological factors play an important role in addition to the physical conditions. Looking more closely at the recommendation of Arens et. al. from 2010 [5], and noticing the rapid development of digital technology such as Internet of things, cloud computing and machine learning, one may ask if this technology could be utilized to achieve the recommendation. The technological evolution has made advanced ICT functionality reachable, affordable and possible to implement into a context suitable for real-time occupant control. The objective of this research has been to develop and demonstrate the usefulness of a system for non-intrusive real-time feedback from occupants regarding indoor climate. This paper describes the experimental setup, results and recommendations for further research and development. It must be seen only as a proof of concept and verification of workflow, as limited data set were not eligible for statistical testing. Aim is at this point not to come out with an evidence based verification of the system functionality.

2. Method and system design

2.1. Choice of system architecture and data sources

The goal of the system is to be non-intrusive, provide real-time data and give a best possible representation of the subjective preferences and satisfaction levels of the occupants. The chosen system should also be possible to install in a real building, only using low cost and commercially available technology. According to these goals, it was decided to design a system which collects real-time data on three levels; *physical measurements, occupant complaints (individual preference)* and *total satisfaction.* Physical measurements of basic indoor climate parameters are already in use and easily available in most modern commercial buildings. Occupant complaints will also automatically come forward, as long as occupants are not content with indoor climate conditions or they are given the possibility to control them. However, no available information source for occupant satisfaction was identified, and such information does not seem possible to obtain without asking the occupant to specifically provide the information. In order to collect the information with minimum intrusion to the occupants, the concept of single-button feedback terminals was chosen. Such terminals have in recent years had a large success in satisfaction measurement in retail and airports due to low cost, low customer intrusion and sufficient accuracy [8,9]. The tests were conducted as longitudinal blind tests in two real office environments. If the occupants asked, they were informed that the equipment was related to investigations into the indoor climate, and that they should use it as they wished. They were not told that the tests focused on their use of the equipment. Eight of the occupants were asked about their experience with the use of the system at the end of the test period.

2.2. Physical measurements

Physical measurements were conducted with a Testo160 IAQ Wi-Fi Data Logger, in combination with built in sensors in the building automation system. The built-in sensors were checked prior to the experiments, and found to have an accuracy of +/- 1°C.

2.3. Digital complaints

The goal of the system is to be non-intrusive, digital, affordable, and provide real-time data. The feedback solution also needs to have a low threshold for user interaction, require no prior knowledge for use, and be able to provide location specific information. For these reasons, a solution using a web page tailored for smartphones was used in combination with unique QR codes printed and attached to each work desk. The users did not need to download anything, but could scan the QR code with their smartphone and reach a webpage with buttons to complain about "Too cold", ”Too hot", "Bad air" or "Draught". They could also leave a text message. On the first visit the user was asked to enter age and gender, and a unique user number was stored using cookies. No other personal information was collected. See Figure 1.

2.4. Satisfaction terminal
There are two main types of feedback terminals commonly used in retail and airports; one uses physical buttons with smiley faces and the other is based on a tablet where similar icons are shown on the screen. A tablet solution was chosen, where a tablet mounted on a floor-stand displayed a full screen webpage with the question "How satisfied are you with the indoor climate today?" and five smiley icons. Once pressed, the screen showed the message "Thank you!". See figure 2.

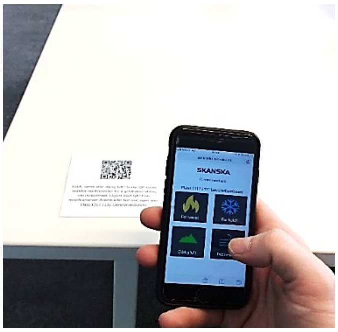

Figure 2. Smartphone complaint feature with QR code.

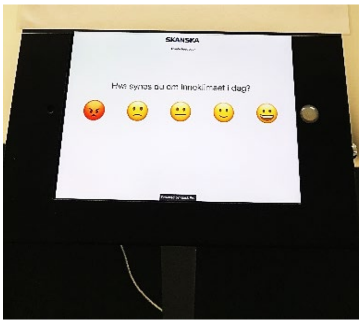

Figure 1. Tablet feedback terminal.

2.5. Test buildings
The system was tested in two different office spaces near Oslo in Norway. *Space 1* is a team office space with eight workspaces in the Skanska main office in central Oslo. The space sits on the third floor of a modern office building with Passive house and BREEAM Excellent certifications. The building was completed in January 2017. It has a full HVAC system with variable air volume ventilation and no operable windows. *Space 1* is on the north side of the building with very little solar irradiation. The room is intended for quiet concentrated work, and occupants normally sit and work quietly in the room for several hours at a time. The workspaces are free seating, "first come, first served". Temperature and CO_2 concentration were measured at one point in the room. QR codes for occupant complaints were attached easily visible on each desk. A tablet computer showing the satisfaction feedback screen was placed by the door, facing outwards (visible both to occupants entering and leaving). The test period was from April 4th 2018 until December 15th 2018. *Space 2* consists of three singular offices and one nine-person team office at the Montessori Upper Elementary School in Drøbak, about a 40 minute drive south of Oslo. The rooms make out the teacher office wing of the school, and sit on the ground floor facing northeast. The office spaces are personal where each teacher has their own desk. The building was completed in February 2018 as the world's first school building satisfying the energy demands of the Powerhouse collaboration, meaning that the building should pay back the embodied energy of building materials through a surplus of produced energy through the lifetime of the building. The building satisfies Passive house standard and utilizes demand controlled displacement ventilation and night time ventilative heating. There are several operable windows in each room, but no daytime heat sources. Temperature was measured at one point in each room. QR codes for occupant complaints were attached clearly visible on each desk. A tablet computer showing the satisfaction feedback screen was placed by the door, facing outwards (visible both to occupants entering and leaving). The test period was from August 15th 2018 until November 12th 2018.

3. Results
3.1. Time-series representation
Dashboard windows tracking the variables in time are shown below. The representations give an impression of the occupants' comfort and satisfaction in the building. This is an example of how to display the information, when more data is collected a more condensed form will be appropriate with statistical indicators. Some correlation can be seen between temperature and total satisfaction with indoor climate in the data. See figures 3 and 4.

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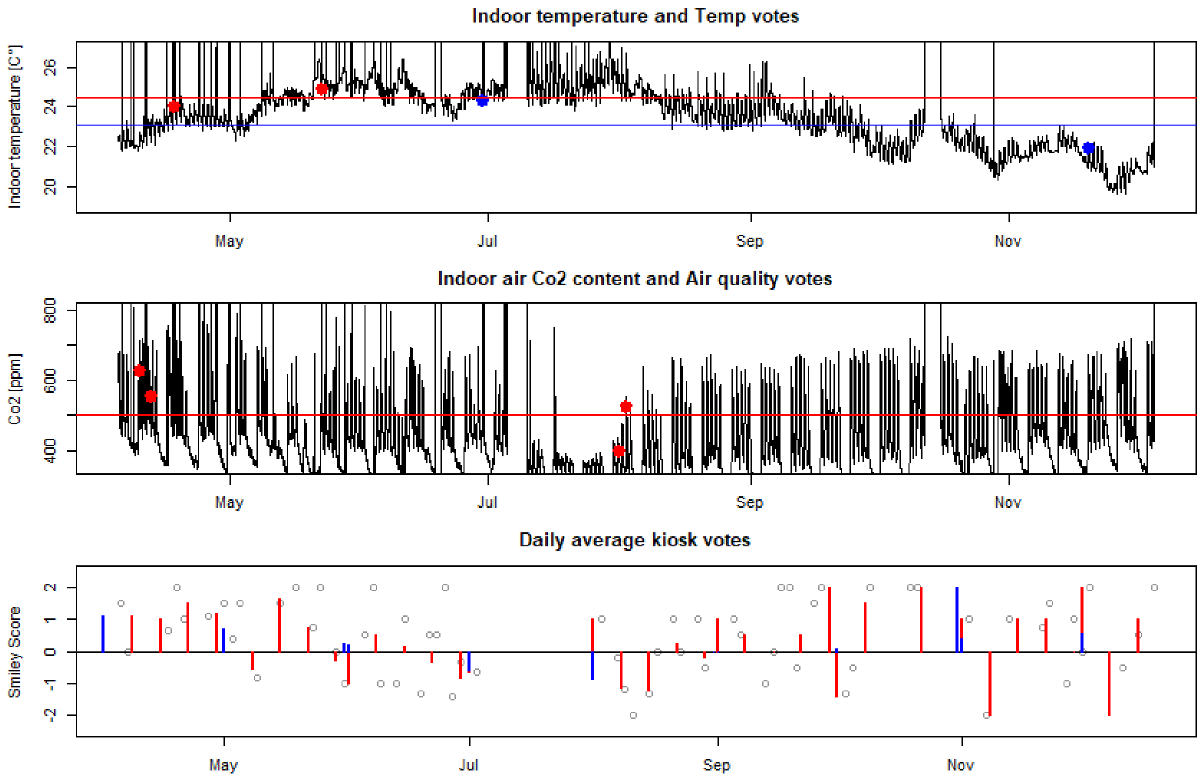

Figure 3. Time series plot of Space 1. Top two plots show temperature and CO_2 in office at 15-minute intervals. Blue dots where occupants have made a digital complaint about "Too cold". Red dots where complaint "Too hot" and "Bad air in middle plot. Red and blue lines are mean of dots. Bottom plot shows 2-day mean of satisfaction votes (circles) from "Angry" = -2 to "Happy" = 2. Red bars are weekly mean, blue bars are monthly mean.

3.2. Satisfaction terminal key data

Distribution of votes is shown in figure 5. Number of daily votes is shown in figure 6. In Space 1, the total number of votes was 173 and the mean score was 0.57. In Space 2 the total number of votes was 576 and the mean score was 0.81.

3.3. Occupant experiences

The following relevant statements were logged after asking 8 of the occupants about their experiences with the system:

- I was not familiar with use of a QR code, and had trouble using the complaint feature on the desk.
- I did not see the point in using the complaint feature as no changes were made to my environment when I used it.
- The feedback terminal was not working, or responded slowly when I tried it.
- I only use my smartphone for calls or text messages, and I don't know how to use the camera or QR code.
- I saw some students playing with the feedback terminal and adding angry votes.
- My smartphone does not have internet reception right now, and I can't make a complaint.

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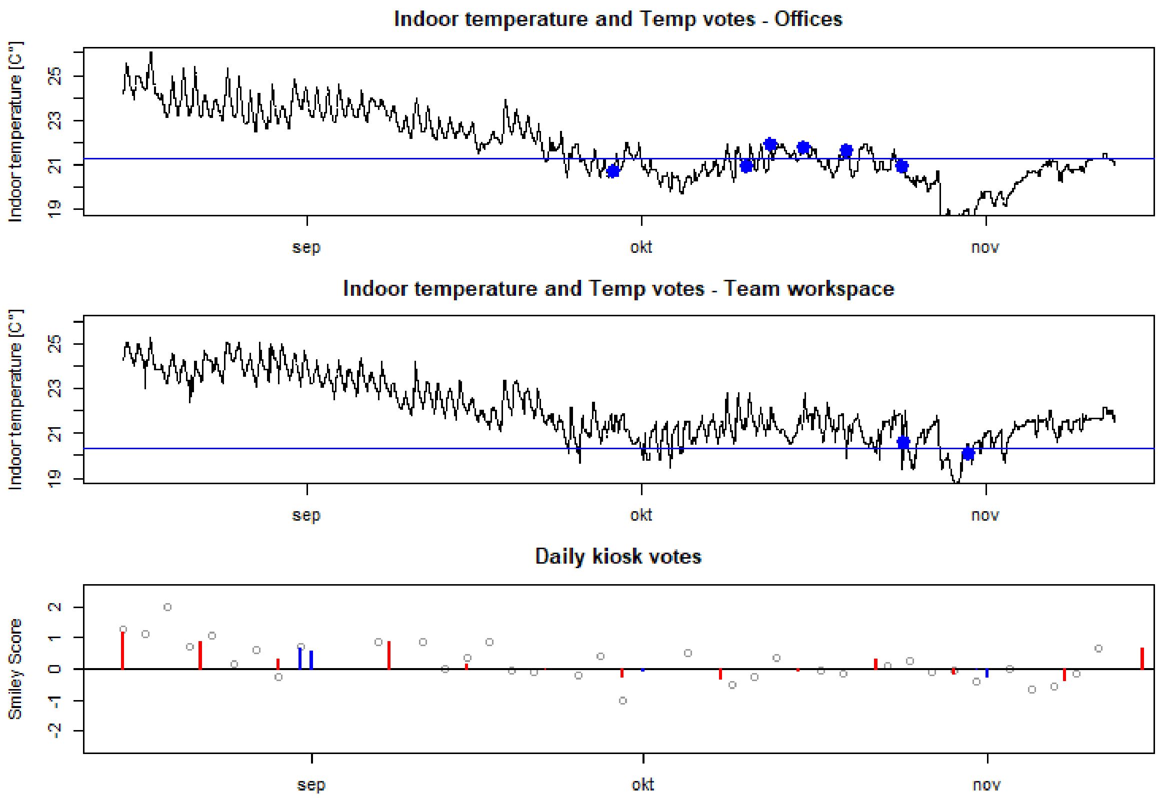

Figure 4. Time series plot of Space 2. Top two plots show temperature at 15 minute intervals in offices and open team workspace. Blue dots where occupants have made a digital complaint about "Too cold". Red dots where complaint "Too hot". Red and blue lines as "mean complaint temperature for hot and cold. Bottom plot shows 2-day mean of satisfaction votes (circles) from "Angry" = -2 to "Happy" = 2. Red bars are weekly mean, blue bars are monthly mean.

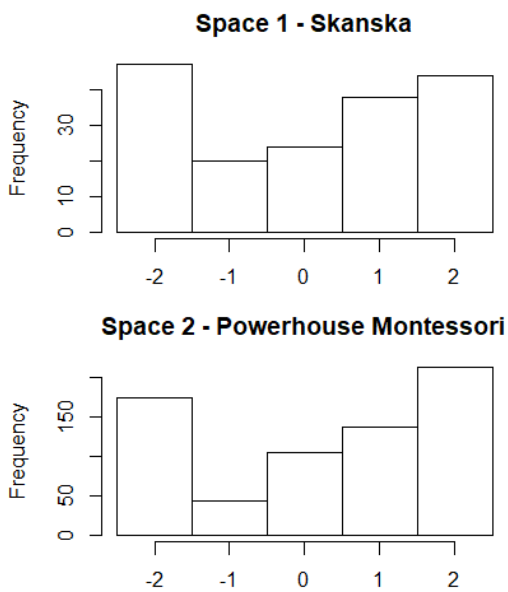

Figure 5. Distribution of button presses. From "Angry" = -2 to "Happy" = 2.

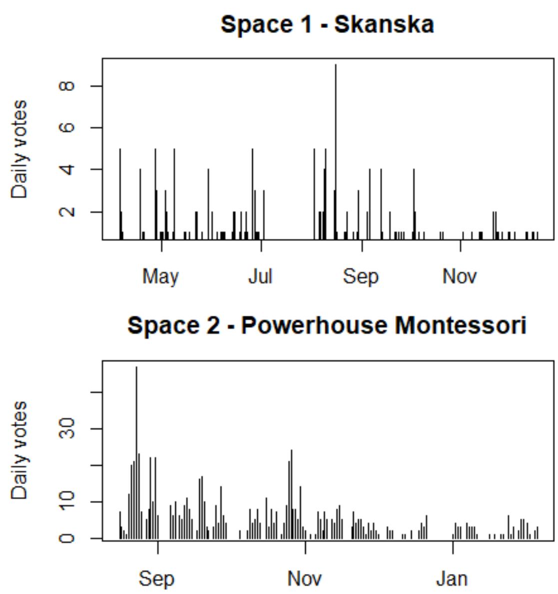

Figure 6. Daily count of votes for entire test period.

4. Discussion

The number of daily votes is low for both spaces, and it was necessary to generate two-day means to get visualisations that can show a trend rather than just scatter. Data from Space 2 shows a more clear trend than those from Space 1, due to a higher number of daily votes. There seems to be a correlation between room temperature and mean satisfaction rate for Space 2, where low indoor temperatures result in lower satisfaction. The distribution of votes is similar for the two spaces, with more votes on the extremes ("Happy" / "Angry"), than the others. Reasons for this are not known, but it could be that occupants with a "clear standpoint" are more likely to vote than those who are less engaged. The daily count of votes seems to show a high participation in the start, and thereafter a slight general decline over the test period.

5. Conclusions and further work

The results show that a non-intrusive system for real-time occupant feedback, using the data sources described, may be able to gather useful information for building design and operation. The system was tested as a field blind test and used by normal building occupants in two very different office spaces. The occupants made use of the system in both buildings, and the data gathered was sufficient to produce visualizations which give an impression of the complaints and total satisfaction. The system should however be developed further in respect to:

- A simpler and more user-friendly complaint alternative is needed, that does not involve QR codes and preferably not smartphones.
- Complaints should give a physical response to the user.
- Measures should be taken to increase the number of daily votes at each feedback terminal.

Further tests should be done with the system, benchmarking mean satisfaction votes to other types of satisfaction measurements. The system should also be tested with deliberate interventions to the physical environment to better test the correlations between physical environment, complaints and mean satisfaction vote. Future tests should be done with larger occupant populations to each kiosk.

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