Comparing tangible and graphical interface of occupant voting system: Preliminary results of experimental field study in an office

Donya SHEIK KHAN*[1], Mian BREUM[1] and Jakub KOLARIK[1]

[1] Technical University of Denmark, Civil Engineering, Kongens Lyngby, Denmark
* *Corresponding author: dskh@byg.dtu.dk*

ABSTRACT

Occupant voting systems (OVS) collect real-time votes on occupants' perception on the indoor environment. The votes are applied to improve building control to achieve low energy consumption and improved occupant satisfaction. For achieving these, occupants need to use the OVS frequently. Few studies investigated whether the OVS's interface influence voting frequency.

The study in this paper compared a tangible OVS interface (TUI), designed as a panel of buttons, to a graphical OVS interface (GUI), designed as a smartphone app. The study was conducted as a within-group in-field experiment in an office space with fourteen participants over four weeks. The results showed that when the participants could only vote with one of the interfaces, they casted equally the same amount of votes on the TUI and GUI. When the participants could freely choose between the two interfaces, they voted more with the TUI because it was accessible and easier to use.

INTRODUCTION

In the recent two decades, a growing interest within the research community has emerged on occupant voting systems (OVS) for collecting occupant feedback on indoor environmental quality (IEQ) in buildings. OVS is typically applied as a tool to collect real-time votes on how occupants perceive the thermal environment. Most studies on OVS have demonstrated how the collected occupant votes can be applied to determine a temperature setpoint used in controlling the heating, ventilation and air-conditioning (HVAC) in buildings (Sheikh Khan et al., 2020). Furthermore, studies have shown that OVS can provide energy savings of 10% – 30% and improve occupant comfort with 30% – 60% compared to conventional (fixed temperature setpoint) control strategies (e.g. (Feldmeier & Paradiso, 2010; Jazizadeh et al., 2014; Lam & Wang, 2013; Winkler et al., 2016)).

To achieve the aforementioned improvements, occupants need to use OVS frequently; how frequent depends on, e.g., the number of votes required by the control algorithm to reliably determine occupants' comfort temperature range. In most studies on OVS, e.g., (Jazizadeh et al., 2014; Konis & Annavaram, 2017; Shetty et al., 2015)), researchers actively reminded study participants to vote, or the OVS was designed to emit a discrete sound for reminding participants to vote. However, one study (Petersen & Pedersen, 2016) noted that participants experienced "survey fatigue" due to too frequent prompting (every half hour over ten days). Therefore, frequent prompts or reminders are not necessarily suitable, especially if the OVS is intended for long-term deployment in buildings. Consequently, some studies deployed more subtle methods of getting occupants to vote, e.g., by handing out information flyers (Sanguinetti et al., 2016), providing dashboards to see voting statistics (Mathur et al., 2015) and designing interactive devices that light up according to the current indoor condition (Rittenbruch et al., 2015). However, mainly the study by Rittenbruch et al. (2015) explored whether the OVS interface impacted occupants voting behaviour. They discovered that the tangible OVS reminded and encouraged the participants to vote as it was situated at their desk. This was in contrast to the mobile application of the OVS that participants had to remember to use (Rittenbruch et al., 2015). However, no previous studies have been found that directly compare a tangible OVS interface to a graphical OVS interface (S. Lee & Karava, 2020; Sheikh Khan et al., 2020).

The objective of the study presented in this paper was to compare a tangible user interface (TUI) based OVS to a graphical user interface (GUI) version of the OVS to answer the following research questions:

1. Did study participants cast more votes with the TUI based OVS compared to the GUI based?
2. Which of the OVS did occupants mostly prefer to use, and what was their reason?
3. What did the study participants experience regarding the functionality and design of the TUI and GUI based OVS?

The deployed OVS in this research study was denoted TiAQ (Thermal and indoor Air Quality) and was developed to allow occupants to provide continuous feedback from occupants in office spaces. TiAQ was initially designed as a tangible panel of five buttons. For the present study, it was also designed as a mobile application (GUI) for smartphones. The research questions were investigated through a field experiment in which TiAQ was deployed in an open plan office space with fourteen participants over four weeks.

METHODS

Study design

The study was carried out as a within-group experiment (Lazar et al., 2017). It was conducted at an open plan office space (Figure 1) in a nine-story office building in Denmark. A total of fourteen participants were selected as they had previous experience with TiAQ and volunteered to participate in this study. The experiments were conducted over four weeks in October 2019. Before the experiment, the study design and duration were explained to the participants via flyers. The participants were divided into groups of eight, assigned Group 1 (G1) and Group 2 (G2), as shown in Figure 1. The participants were instructed when and how to use the GUI or the TUI based TiAQ. Table 1 shows the study design of the field experiment. In week 1, G1 was instructed to use only the GUI based TiAQ, and G2 was instructed to use only the TUI based TiAQ closest to their seating area. In week 2, this was reversed. There was a break from the study in week 3. In week 4, participants could freely choose the interface to use every time they wanted to vote. Through the whole study, the participants could freely discuss the details and their experiences related to the interfaces among each other.

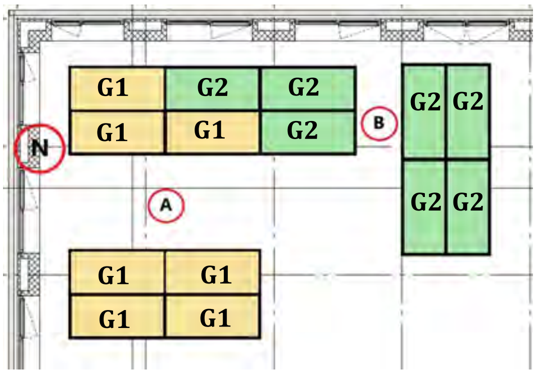

Figure 1. Participants' desks and the seating arrangement of the groups. TiAQ was located at spot A and B. An indoor environment sensor was located at spot N at 1.5 m height above the floor.

Table 1. Study design for the within-group field experiment.

Week	GUI	TUI
1	G1	G2
2	G2	G1
3	Break	
4	G1 and G2 (Free choice of interface)	

Structured questionnaires were developed explicitly for participants using either GUI, TUI or both. They were distributed to all participants at the end of each week. The questionnaires asked the participants about how often they were at their workstation, how often they used the TiAQ, their reason for using it, their experience using it and which interface of TiAQ they preferred for long-term use.

The indoor environment was monitored with a commercial, wireless Internet of Things (IoT) device with Sensirion SHT20 temperature sensor (± 0.3 °C) and relative humidity sensor (± 3%) and NDIR CO_2 sensor (± 50 ppm). The ventilation airflow, inlet temperature and outdoor temperature were collected with the building management system (BMS), and the number of minutes of sunshine per hour was collected from the online weather archive of the Danish Meteorological Institute (DMI, 2020). These measurements were denoted as confounding variables as they could affect participants' decision to vote and the number of votes they would cast.

OVS design: TUI and GUI based TiAQ

The TUI based TiAQ allowed participants to vote on their here-and-now experience of the indoor environment using the following five buttons: "Too Cold", "Too Warm", "Draught", "Stuffy" and "Fine" (Figure 2a). The buttons used the Zigbee communication protocol to transmit data to an internet-connected gateway, which further sent the data to the gateway provider's IoT platform. As the platform only saved data for a short time, data was automatically sent via Application Programming Interface (API) to a secondary platform for long-term storage. The buttons distinguished if users provided a single, double or long push. The secondary platform was set up to only log a value of "1" regardless of how the button was pushed. The GUI was developed with Shiny-Rstudio (Rstudio, 2020) and set up to look similar to the TUI based TiAQ (Figure 2b). The GUI based TiAQ was accessed by scanning a QR code provided to participants via information flyers (Figure 3). The participants were further instructed to save the GUI link as a shortcut on their smartphone home-screen to use the GUI like an app. Via the GUI interface, participants could push the "black button" (Figure 2b), which led them to a dashboard showing real-time data on the total number of votes cast with both interfaces over a week and the daily temperature and relative humidity in the monitored space. The dashboard was also developed with Shiny-Rstudio. The group, which was only allowed to use the TUI, accessed the dashboard either using an URL or scanning another QR code provided via the flyers (Figure 3).

Data processing and statistical analysis

The dataset of occupant votes from each interface and indoor environmental parameters was processed according to the steps below:

1. Only data from Monday to Friday 5.00-18.00 in week 1, 2 and 4 were included in the data analysis.
2. The total number of votes per day for each interface was calculated as the sum of votes cast on all buttons.
3. The daily mean of the measured indoor environmental parameter for each week was determined.
4. Two datasets were prepared for the total number of votes per day, i.e., one dataset for data collected

in week 1-2 and a second dataset for data collected in week 4.

Two-sided hypothesis tests (significance level, α = 0.05) were used to investigate if the daily total number of votes for each interface was the same. The tests were used for answering the first research question.

The Shapiro-Wilk and Levene's test showed that the datasets were normally distributed and had homogeneity of variance (i.e., the variance of each compared group was nearly equal), respectively. Thus, the paired t-test and one-way, repeated-measures ANOVA were used for hypothesis testing.

The package Rstatix (Kassambara, 2020) for the statistical software R studio (R Core Team, 2020) was used for both data processing and analysis of the votes and the measured indoor environmental parameters.

Descriptive analysis was used to analyse and present the responses from the questionnaires to answer the two latter research questions. The responses from week 1 and 2 were grouped so that they presented the responses of participants who had used either GUI or TUI, e.g., responses from G1 in week 1 were grouped with responses from G2 in week 2 as they both had used GUI.

Figure 2. (a) Top: TUI based TiAQ. (b) Bottom: GUI based TiAQ. The text in the presented figures has been translated from the original language (Danish) to English.

Figure 3. Example of one of the flyers distributed to the participants in the first week of the study. Text is in Danish.

RESULTS

Hypothesis tests

Before the main hypothesis tests were conducted, the daily means of measured indoor parameters for week 1 and 2 were compared to determine whether there was a significant difference in indoor conditions between the two weeks. The two-sided paired t-test was applied on all indoor parameters. The mean and standard deviation for the daily mean of measured parameters were provided in Table 2.

Table 2. Mean and standard deviation of the daily mean of measured parameters.

Parameter	Week 1	Week 2	Week 4
Ventilation airflow [l/s]	427 ± 46	459 ± 80	385 ± 13
Indoor CO_2-level [ppm]	583 ± 31	564 ± 33	575 ± 19
Indoor relative humidity [%]	44 ± 6	46 ± 5	53 ± 1
Indoor temperature [°C]	23.2* ± 0.3	22.5* ± 0.04	22.6 ± 0.1
Outdoor temperature [°C]	10 ± 2	10 ± 3	12 ± 1
Sunshine [min]	8 ± 8	17 ± 10	3 ± 2
Ventilation inlet temperature [°C]	20.9 ± 0.4	20.9 ± 0.9	20.4 ± 0.3

The sample size for each parameter per week was n = 5.
* Significant, $p < 0.05$

The tests showed that only the indoor temperature was significantly different between week 1 and 2. Furthermore, a linear regression analysis revealed that the daily mean indoor temperature did not significantly affect the daily total number of votes ($F(1,18) = 1.07$, $p = 0.31$). Thus, it was concluded that none of the measured indoor parameters had a significant confounding effect on the daily total number of votes.

The difference between interfaces for the daily total number of votes collected in week 1 and 2 was tested with a one-way, repeated-measures ANOVA, and the daily total number of votes collected in week 4 was tested with a paired t-test. Figure 4 shows the daily total number of votes for each interface for week 1-2 and 4.

The analysis revealed no significant difference between the TUI and GUI for the daily total number of votes in week 1-2 ($F(1,9) = 1.55$, $p = 0.25$). On the contrary, a significantly higher number of votes were cast with TUI than GUI ($t(4) = -7.53$, $p = 0.002$) for the votes collected in week 4. The analysis yielded the same conclusion when specific vote types were excluded from the total voting poll, e.g., when the total number of votes per day only included votes cast on "Fine" or "Too Warm" and "Too Cold".

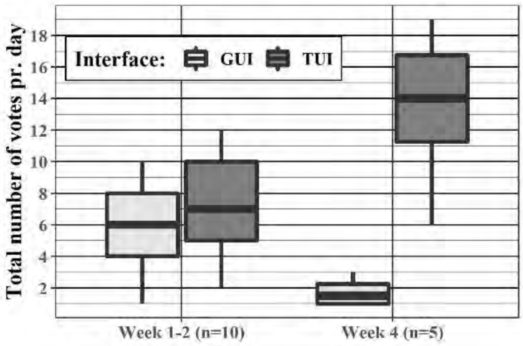

Figure 4. Boxplot of the daily total number of votes for each interface for week 1-2 and 4. n is the sample size for each interface.

Questionnaire responses

A total of 8 out of 14 participants (57% response rate) answered the questionnaire related to the use of GUI. A total of 7 out of 14 participants (50% response rate) answered the questionnaire related to the use of TUI and the questionnaire related to the use of both interfaces. The respondents had an age between 21 to 60 (n=7), and most of them were present during all days of the study.

The respondents who used the GUI in week 1 and 2 used it either every day (n=4) or at least every second day (n=3). At least 5 respondents who used GUI agreed to the following: The guidance presented on the flyers were easy to follow, they did not need help to find the GUI, it was easy to scan a QR-code and to vote with the GUI. Most of the respondents who had used the GUI answered that the reason they forgot to vote with the GUI was that the experiment was too short for making voting with the GUI a habit (n=5) or that the GUI was not physically "present" in the space (n=4). The respondents agreed that they used the GUI based TiAQ when they noticed a change (n=6) or became dissatisfied (n=5) with the indoor environment or when a colleague reminded them to vote (n=4). Fewer respondents agreed that they were reminded to vote when they saw the dashboard (n=3), the app icon of the GUI on their smartphone home-screen (n=2) or when a colleague voted (n=2). The respondents agreed that it was easy to know and understand what they voted on (n=7), the icons in the GUI were intuitive (n=7) and the text was readable (n=6). However, only 4 respondents agreed that it was easy to access the GUI based TiAQ on the phone, whereas 3 respondents disagreed. Overall, 5 respondents agreed that the GUI based TiAQ was quick and easy to use, whereas 2 respondents did not agree. Finally, the respondents either answered "yes, definitely" (n=3) or "yes, maybe" (n=4) to use the GUI based TiAQ to collect occupant votes on IEQ in the office space. Some of the respondents commented that they would forget to vote with the GUI during a busy working day or simply forget to use it as they were not used to using smartphone apps at work.

The respondents who used the TUI in week 1 and 2 used it every day (n=6). The respondents agreed that they used the TUI based TiAQ when they noticed a change in the indoor environment (n=4), a colleague reminded them to vote (n=4) or saw a colleague vote (n=4). Fewer respondents agreed to the statement that they voted when they were dissatisfied with the indoor environment (n=3) or that they saw or passed the TUI (n=3). Only 1 respondent agreed that the dashboard reminded them to vote. All respondents (n=7) agreed that it was easy to know and understand what they voted on with the TUI, that the TUI was accessible, quick and easy to use for voting and the text on the TUI was readable and the icons were intuitive. Finally, the respondents answered "yes, definitely" (n=6) to have the TUI based TiAQ for collecting occupant votes on the indoor environment at the office.

The questionnaire related to the use of both TUI or GUI collected after week 4 showed that most respondents (n=5) used the TUI, and only 1 respondent used the GUI or both. They answered that they selected the particular OVS because it was easier to access (n=5), generally easier to use (n=4) and easier to use because the duration of the experiment was short (n = 2). Most respondents answered that they would prefer to use the TUI (n=6) instead of GUI (n=2) based TiAQ to collect votes on IEQ in the office space.

DISCUSSION

According to the results in week 1-2, the study participants did not cast more votes with the TUI based TiAQ than the GUI when they were only allowed to use one of the interfaces. This was also supported by the responses from the questionnaire showing that most participants used either interface every day. In week 4, when the participants could freely choose between the interfaces, the daily total number of votes was significantly higher for the TUI based TiAQ than the GUI. The questionnaire also showed that most participants voted with the TUI instead of GUI.

In general, the results from the questionnaires showed that the participants voted with either interface when they noticed a change, became dissatisfied with the indoor environment or when a colleague reminded them to vote. The dashboard or seeing the app icon on the phone acted as a reminder for participants using the GUI. Seeing a colleague vote on the TUI or noticing or passing the TUI acted as a reminder for participants using the TUI. This suggests that having the TiAQ available in the space, the device itself might act as a subtle reminder. Additionally, participants stated in the questionnaire that they forgot to use the GUI as it was not physically "present". However, participants remarked that they missed a mechanism to remind them to vote for both interfaces. Furthermore, most participants emphasised that the study period was too short for making voting with the GUI a habit.

All participants using TUI in week 1-2 agreed that it was accessible, quick and easy to use for voting. There was a mixed opinion among participants regarding how easily accessible the GUI was. It was unclear whether these participants voted by accessing the GUI with the QR-code or using the shortcut app on their smartphone home screen. Participants said yes to use either interface for voting in week 1-2, but in week 4, most participants preferred to vote with the TUI instead of GUI. Since the participants had a relatively short timeframe to get accustomed to vote with the GUI, the easy/quick access to the TUI might have made it more preferable than the GUI.

Related studies that compare the performance, application and participants' experience of TUI and GUI based OVS are limited to the study by Rittenbruch et al. (2015). They deployed a GUI and TUI based OVS device for two weeks at an office space in a university building and conducted a qualitative study to evaluate participants' experience and use of OVS for IEQ assessment. They reported that their TUI based device was inconspicuous. Specifically, participants forgot to use the device unless they noticed the device on their desk, became uncomfortable or aware that their indoor condition changed, and when they were reminded by the subtle buzzing mechanism or the subtle sound of other participants submitting a vote with the device. They also discovered that 7 out of 11 interviewed participants reported they used the GUI based (mobile app) OVS, which was designed to allow for more direct and precise input than the TUI. However, the participants needed to be specifically reminded to use the GUI compared to the TUI. The authors concluded that participants perceived the GUI as extended functionality to the TUI based device rather than a replacement. Other research studies on OVS that evaluated the interface and application mainly used GUI. For example, Sanguinetti et al. (2017, 2016) developed a GUI based OVS for deployment at a university campus, which could be accessed via a widget through the university web page and as a web app that could be installed on the phone for easier and quicker access. They discovered that the different platforms could engage different stakeholders, e.g., the university staff had a low engagement with the OVS until the web app was developed and deployed. Contrarily, Mathur et al. (2015) concluded based on a one-month pilot study at an office building that participants voted on average 57 times on the tablet based GUI, placed near, e.g., coffee machines in the office building, compared to the mobile application, which only 4 participants installed. The majority of participants reported that they would not install the app on their personal phone due to participants concern that their vote could be linked to their name and used by their employers to rate their performance. The authors pointed out that making the OVS only available as an app could exclude participants not able to or did not want to install the app, thereby reducing the overall "trust" in the OVS output as it would only represent the votes by those with access. Additionally, Lassen and Josefsen (2019) experienced in their study that some participants did not know how to scan a QR code and that connectivity problem with the internet impeded the participant to cast a vote with the OVS app.

One study (Price et al., 2018) was identified, outside of the research field related to OVS, which could be compared to the present study. Price et al. (2018) compared a TUI and GUI device called Painpad designed as a panel of buttons for hospital patients for rating their pain level. The authors concluded that the TUI based Painpad was preferred by most participants than the GUI based Painpad. They argued that this was because participants were mostly older people who were not familiar with or used to touch-screen devices. They also noted that as older people have drier skin and thus lower skin conductance, conductive based touch-screen are less responsive to their touch, thereby making interaction more difficult. Generally, most research studies on TUI and GUI, outside of the research field of OVS, mainly focused on tasks or interaction aspects that were far more complex than casting a vote. For example, some studies focused on how TUI could help children learn programming (Horn et al., 2009) or increase children's engagement by making a task, such as solving a puzzle, more fun (Xie et al., 2008). Other studies compared how TUI or GUI affected, e.g., participants' cognitive abilities to manipulate objects in space (Huang, 2004) and their dexterity to write with hard (TUI) or soft (GUI) buttons (S. C. Lee & Zhai, 2009). Zuckerman and Gal-oz (2013) and Cheng et al. (2011) reviewed and compared different research studies on TUI and GUI. They concluded that the studies' different design and context led to contradicting results on whether TUI was better than GUI and vice-versa. Instead, Zuckerman and Gal-oz (2013) suggested it would be of greater interest to evaluate which context TUI and GUI would benefit. For example, TUI has shown to be suitable for task performance that requires several participants to collaborate (Shaer, 2009; Zuckerman & Gal-Oz, 2013). Contrarily, tasks in which scaling in size and number is required, e.g., when creating an architectural model of a building, GUI can be more efficient because virtual objects can be easily scaled and changed compared to physical objects (Shaer, 2009). These main points can also be transferred to the research field of OVS, in which GUI based OVS have the benefit of being easily scaled and distributed to many participants, like in the study by Sanguinetti et al. (2017), and have the flexibility of being upgraded and changed (Shaer, 2009).

In summary, the limited research studies comparing TUI and GUI OVS demonstrated that the accessibility of the OVS, regardless of its interface, was an important functionality for making participants vote, e.g., (Lassen & Josefsen, 2019; Mathur et al., 2015; Sanguinetti et al., 2016). This is also supported by the results of the present study suggesting that it was more feasible for occupants to vote with the TUI than the GUI because of the easy and quick access participants had to it. This was not related to the interface per se but because TiAQ was physically located in the office space, i.e., as a stand-alone device with no restriction or prerequisites to be accessed and used by participants. Thus, a future study should instead compare a tablet/touch-screen GUI based version of TiAQ with the TUI based TiAQ to investigate the GUI and TUI functionalities of a stand-alone device. Additionally, few other limitations are noted for the present study as follows. Firstly, participants in the present study had prior experience with the TUI based TiAQ. Nevertheless, participants also had prior experience with smartphone apps in general. Thus, the concept of using an app for voting was not expected to require a skillset the participants did not already possess, especially since the participants were below 60 years old and expected to be accustomed to smartphones. Secondly, the experimental period was short, and the number of study participants was low. Thus, the results should be evaluated as preliminary results and act as inspiration for future studies investigating the application of TUI and GUI based OVS.

CONCLUSION

The present study demonstrated that participants of a 4-week field experiment in an office space did not vote more with a tangible OVS than an app-based version of the OVS. However, participants used the TUI based OVS significantly more than the GUI based OVS when they could freely choose among either interface. Participants likely preferred TUI over GUI because it was easily accessible. Nevertheless, they also noted that the study period was too short to make voting with the GUI based device a habit. The findings of the present study cannot be generalised. Thus, the preliminary results were intended to inspire future research to explore how the interface of OVS can affect occupants voting behaviour and, in the end, the ability of OVS to achieve energy saving and improved occupant satisfaction with the indoor environment.

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