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Method for monitoring and collecting real-time subjective comfort data

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SAMENVATTING

In Nederland is een Binnenklimaatlabel ontwikkeld voor de operationele fase van kantoren. Het verwijst naar een in 2021 geactualiseerd Programma van Eisen (PvE). Het Binnenklimaatlabel combineert drie verschillende gegevensbronnen. Het gebruikt continue monitoringgegevens van temperatuur, vochtigheid, CO_2 en fijnstof ($PM_{2.5}$) gemeten door sensoren in een beperkt aantal representatieve kantoorruimten. Verder wordt elk jaar een onderzoek uitgevoerd onder alle kantoorgebruikers. En om de drie jaar wordt een inspectie ter plaatse uitgevoerd door een gecertificeerde inspecteur. Alle gegevens worden verzameld in een dataplatform dat algoritmen bevat om elk jaar automatisch het gebouwlabel te bepalen.

Het jaarlijkse onderzoek naar subjectief comfort wordt uitgevoerd met de Healthy Building Index tool. Deze online tool is gebaseerd op de vragenlijst van het EU-project OFFICAIR. Het beoordeelt complexe factoren zoals tocht, waargenomen licht en geluid en gebruikt een zevenpunts-schaal. Normaliter wordt het slechts eenmaal per jaar in elk kantoor gebruikt, wat als nadeel heeft dat seizoensinvloeden verloren kunnen gaan en er geen directe koppeling met monitoringgegevens kan worden gemaakt.

Het doel van onze studie was een instrument te ontwikkelen dat continu feedback verzamelt over het waargenomen comfortniveau van kantoorgebruikers op een minimaal hinderlijke manier. Een van de belangrijkste aspecten was het ontwikkelen van een strategie om mensen te triggeren en te motiveren om hun momentane comfortbeleving door te geven. Deze subjectieve gegevens zouden in toekomstige updates van het label kunnen worden gebruikt om dynamisch inzicht te krijgen in het waargenomen comfortniveau wanneer sensorgegevens afwijkingen rapporteren.

In de zomer van 2022 is een pilotstudie uitgevoerd in een bestaand kantoorgebouw in Zuid-Nederland. Gebruikersfeedback werd verzameld met zowel losstaande stemkastjes als QR-codes geplaatst op tafels in de kamers. De stemkastjes waren voorzien van een korte vraag, zoals "Hoe tevreden bent u met de temperatuur op uw werkplek?". Na twee weken werd de vraag gewijzigd om vier andere comfortaspecten aan de orde te stellen: geluid en akoestiek, licht, luchtkwaliteit en controle. Dezelfde vragen, maar dan in één keer gesteld zonder de controlevraag, werden gesteld via een QR-code die gebruikers konden scannen en die hen vervolgens naar een speciale website leidde.

Uit de analyse van de verzamelde resultaten bleek dat vooral de stemkastjes interessant waren, gezien het aantal reacties. Dit was waarschijnlijk te danken aan de gemakkelijk toegankelijke manier om feedback te geven. De stemkastjes lijken een redelijk inzicht te geven in het gemiddelde ervaren binnenklimaat in vergelijking met de jaarlijkse enquête met de Healthy building index tool. Zowel de stemmen van de stemkastjes als de QR-codes hadden echter geen duidelijke relatie in vergelijking met de verwachte temperatuurbeleving volgens ISO 7730 en de verwachte perceptie van de luchtkwaliteit op basis van de CO_2-meetgegevens op het moment of de twee uur voordat de stem werd uitgebracht. Dit zou het belang kunnen benadrukken van directe feedback van de gebruiker, aangezien de tevredenheid van de gebruiker niet alleen met fysieke sensorgegevens kan worden voorspeld.

De eerste verklaring voor de zwakke relatie zou kunnen zijn dat in het kantoorgebouw de fractie van de tijd dat de temperatuur of de luchtkwaliteit, uitgedrukt als CO_2, buiten de comfortcondities valt, vrij beperkt is.

De tweede verklaring zou kunnen zijn dat het waargenomen binnenklimaat door meer variabelen wordt beïnvloed dan werd gemeten. Bijvoorbeeld zonnestraling of tocht kunnen ook van invloed zijn. En de stemmen kunnen ook worden beïnvloed door persoonlijke factoren die geen verband houden met de fysieke omstandigheden binnenshuis. Als mensen bijvoorbeeld niet genoeg geslapen hebben, gestrest zijn, zich ergeren aan een collega, kan dat ook een trigger zijn om op de rode knop te drukken.

Een derde verklaring zou de plaatsing van het stemhokje kunnen zijn. De stemkastjes bij de ingang van de kantoorvleugels gaven de gemiddelde stemmen van personen die in verschillende gesloten kantoorkamers zaten in combinatie met andere personen die in het landschapskantoor zaten. Het fysieke klimaat kan tussen deze personen verschillen.

De vierde verklaring zou de veronderstelling kunnen zijn dat mensen de comfortvraag boven het stemhokje niet lezen en dus wellicht op een ander comfortaspect stemmen. Bijvoorbeeld, de vraag boven het stemhokje is "Hoe tevreden bent u met de temperatuur?" en dat er gestemd wordt op basis van ontevredenheid over het geluid.

Een interessante vaststelling is dat bij het gebruik van de stemkastjes voor alle onderzochte comfortaspecten doorgaans de uiterste waarden van de schaal werden gekozen, namelijk "zeer ontevreden" en "zeer tevreden". Bij de QR-codes voor luchtkwaliteit is de "neutrale" waarde prominenter gekozen. Terwijl voor de temperatuur met de QR-code ook de extremen meer favoriet lijken te zijn. De voorkeur voor extreme stemmen kan verband

houden met de eenvoudige en gemakkelijke interface die meer stemmen kan opleveren wanneer ongemak of comfort wordt ervaren.

Aanbevelingen

Op basis van de gemeten temperaturen en CO_2-concentraties kan het comfortniveau in de testruimte als redelijk tot goed worden beschouwd. Desondanks leverden de stemkastjes een hoog rapportageniveau op. Dit suggereert dat het gebruik van stemkastjes een aantrekkelijke manier is om zelfgestuurde comfortfeedback te leveren. Wij bevelen daarom aan de volgende twee verbeteringen te onderzoeken.

1) Herhaal het onderzoek in andere kantoorgebouwen

Om verder te bevestigen dat de stemkastjes een goede indruk geven van het ervaren comfort is het nodig om aanvullende vergelijkingen te doen met de Healthy Buildings Index in andere kantoorgebouwen, bij voorkeur gebouwen met een breder spectrum van temperatuur en CO_2-concentraties. Zowel het gemiddelde als de verdeling van de stemmen moeten worden vergeleken met de resultaten van de vragenlijst. In dit onderzoek kan het interessant zijn om korte interviews te houden waarom mensen het stemhokje hebben gebruikt. En of hun stem verband hield met de bijgevoegde comfortvraag of dat het feedback was over een ander aspect.

2) Plaats de stemknoppen direct bij de werkplek

In de huidige opzet zijn de meeste stemkastjes bij de ingang van de kantoorvleugels geplaatst. Dit heeft wellicht veel feedback opgeleverd. Het was echter moeilijk om de stemmen in verband te brengen met de objectieve sensorgegevens. Dit kan te wijten zijn aan het feit dat elke kantoorvleugel bestond uit verschillende gesloten kantoorkamers in combinatie met een landschapskantoor. Daarom gaf het stemkastje een gemiddelde van een kantoorvleugel of zelfs een gemiddelde score van een verdieping. Door de stemknoppen direct bij de werkruimte te plaatsen zou een hogere correlatie met de objectieve sensorgegevens kunnen worden verkregen. Ook zou het interessant kunnen zijn om meer aandacht te besteden aan (kantoor)gebouwen met extremere klimaatomstandigheden.

3) Gebruik stemknoppen gekoppeld aan een touch screen

In de huidige opzet was boven de stemknoppen een A4 met de comfortvraag bevestigd. Het was de vraag of mensen op deze vraag reageerden of dat ze feedback gaven op een ander comfortaspect. Het idee is om dit verder te onderzoeken door de stemknop te koppelen aan een scherm waarmee vervolgvragen getoond kunnen worden. Welk comfortaspect: geluid, licht, temperatuur of luchtkwaliteit. En als bijvoorbeeld op temperatuur wordt gedrukt of de temperatuur te laag of te hoog is. Als het stemkastje op een centrale plaats is geplaatst, kan het interessant zijn om mogelijkheden toe te voegen om aan te geven voor welke ruimte de stem geldt. Op die manier kan een gedetailleerder inzicht worden verkregen, vergelijkbaar met de Healthy Building Questionnaire. Verschillende prototypes van de lay-out moeten worden getest om een optimale opstelling te verkrijgen die aantrekkelijk is voor de gebruiker om feedback te geven en om zoveel mogelijk informatie over het zelf ervaren binnenklimaat te verkrijgen.

SUMMARY

In the Netherlands, an Indoor Climate Label has been developed for the operational phase of offices. It refers to a 2021 updated Program of Requirement (PoR). The Indoor Climate Label combines three different data sources. It uses continuous monitoring data of temperature, humidity, CO_2 and fine particulate ($PM_{2.5}$) measured by sensors placed in a limited number of representative office rooms. Furthermore, every year a survey is carried out of all office users. And a certified inspector carries out an onsite inspection every three years. All data are collected in a data platform that contains algorithms to determine the building label every year automatically.

The yearly survey for subjective comfort is carried out with the Healthy Building Index tool. This online tool is based on the questionnaire from the EU project OFFICAIR. It assesses complex factors such as draft, perceived light and noise and uses a seven-point scale. Normally it is used only once per year in every office, which has the drawback that seasonal influences may get lost, and no direct coupling with monitoring data can be made.

Our study aimed to develop a tool that continuously gathers feedback on the perceived comfort level of office users in a minimal nuisance manner. One of the most important aspects was determining a strategy to trigger and motivate people to provide their momentary perceived comfort. This subjective data could in future updates of the label, be used to gain dynamic insight into perceived comfort level when sensor data reports anomalies.

During the summer of 2022, a pilot study was conducted in an existing office building in the South of the Netherlands. User feedback was gathered with self-standing vote boxes and QR codes placed on room tables. The vote boxes were equipped with a short question, such as “How satisfied are you with the temperature in your workplace?”. After two weeks, the question was changed to address four other comfort aspects: noise and acoustic, light, air quality and control. The same questions, but then asked all at once but without the control question, was asked via a QR code that users could scan, which then directed them to a dedicated website.

Based on the analysis of the results gathered, the vote boxes proved interesting, given the number of feedback samples. This was probably due to the easily accessible way of giving feedback. The vote box data seems to give a reasonable insight into the average perceived indoor climate compared to the yearly survey with the Healthy building index tool. However, both the votes of vote boxes and QR codes did not have a clear relation when compared with the expected temperature sensation according to ISO 7730 and the expected air quality perception based on the CO_2 measurement data now or the two hours before the vote was casted. This might emphasise the importance of direct user feedback, as user satisfaction cannot be predicted with physical sensor data alone.

The first explanation for the weak relation might be that in the office building, the fraction of time that the temperature or air quality expressed as CO_2 is outside the comfort conditions is rather limited.

The second explanation might be that the perceived indoor climate is influenced by more variables than were measured. For example, solar radiation or draught can also have an impact. And the votes can also be influenced by personal factors unrelated to the physical indoor conditions. For example, if people don’t have enough sleep, are stressed, or are annoyed by a colleague, that may also be a trigger to push the red button.

A third explanation might be the placement of the vote box. The vote boxes placed at the entrance of the office wings gave the average votes of persons sitting in several closed office rooms in combination with other persons sitting in the landscape office. The physical climate may differ between these persons.

The fourth explanation might be the assumption that people do not read the comfort question above the vote box and thus might vote for another comfort aspect. For example, the question above the vote box is “How satisfied are you with the temperature?’ and the vote is casted based on dissatisfaction with noise.

An interesting observation is that in using the vote boxes for all studied comfort aspects, the extreme ranges of the scale were typically selected, being “Very dissatisfied” and “Very satisfied”. With the QR-codes for air quality, the ‘neutral’ value is more prominently chosen. While for the temperature with the QR-code also, the extremes seem to be more favorable. The preference for extreme votes might relate to the simple and easy interface that may trigger more votes in case discomfort or comfort is experienced.

Recommendations

Based on the measured temperatures and CO_2 concentrations, the comfort level in the test office can be considered reasonable to good. Despite this, the vote boxes delivered a high level of reporting. This suggests

that using vote buttons is an attractive way to deliver self-triggered comfort feedback. We, therefore, recommend investigating the following two improvements.

1) Repeat the research in other office buildings.

To further confirm that the vote boxes give a good impression of the perceived comfort, it is necessary to do additional comparisons with the Healthy Buildings Index in other office buildings, preferably buildings with a wider spectrum of temperature and CO_2 concentrations. The average and the votes' distribution should be compared with the questionnaire results. In this research, it may be interesting to have short interviews about why people have used the vote box. And whether their vote was related to the attached comfort question or it was feedback on another aspect.

2) Place the vote buttons directly in the workspace.

Most of the vote boxes in the current set-up have been placed near the entrance of office wings. This might have generated much feedback. However, it was challenging to relate the votes with the objective sensor data. This might be because each office wing consisted of several closed office rooms in combination with a landscape office. Therefore, the vote box gave an average of an office wing or even an average score of a floor. A higher correlation with the objective sensor data might be obtained by placing the vote buttons directly in the workspace. It also might be interesting to focus more on (office) buildings with more extreme climate conditions.

3) Use vote buttons connected with a touchscreen.

In the current set-up, an A4 with the comfort question was attached above the vote buttons. Whether people responded to this question or gave feedback on another comfort aspect was questionable. The idea is to investigate this further by connecting the vote button to a screen with which follow-up questions can be shown. Which comfort aspect: noise, light, temperature, or air quality? And if e.g., the temperature is pressed, whether the temperature is too low or too high.

Further, in case the vote box is placed at a central location, it may be interesting to add possibilities to mark the location to which room the vote is applicable. This way, a more detailed insight can be obtained comparable to the Healthy Building Questionnaire. Several prototypes of the layout need to be tested to obtain an optimal setup that is attractive to give feedback by the user and to retrieve as much as possible information about the self-perceived indoor climate.

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1 INTRODUCTION

The objective of task 3.1 is to develop a method to assess occupants' comfort and health levels in real-time in the operational phase of buildings, based on monitoring building data and self-reported data of occupants. This method could be added to the Indoor Climate Label initiated by Binnenklimaat Nederland. This label is based on the Program of requirements Healthy offices (PvE Gezonde kantoren, 2021[1]).

In sub-task 3.1.1, we developed methods to continuously measure perceived comfort data to assess complex factors such as air quality, thermal comfort, light, noise, and control in the workplace.

One of the most important aspects was determining a strategy to trigger and motivate users to self-reporting data based on their perceived comfort. The subjective data can be used to gain dynamic insights when sensor data reports indicate anomalies or when sensors fail to measure the source of discomfort. In-situ methods, including the location and type of displays, were determined to collect subjective data minimally intrusively. They require a minimum perceived effort by their subjective comfort levels.

Two methods for direct feedback have been compared with the Healthy Buildings Index tool and physical sensor data. The first method for direct feedback was a five-point vote box in combination with a short question. The questions were changed every two weeks. The second method used an app for scanning a QR code. Unica has developed this app. This app asked all four questions about perceived comfort simultaneously, so there was no change of question necessary. A pilot study has been executed in the Spie office building in Son.

The research questions to be answered in this study are:

- How do the vote boxes/QR code data relate to the yearly Healthy building index survey?
- How can we trigger and motivate users to deliver self-reported subjective comfort data?
- What is the effect of the position of the vote box?
- Are the physical sensor data in line with the subjective feedback of the vote box and QR code?

2 CURRENT METHODS FOR SUBJECTIVE COMFORT IN THE INDOOR CLIMATE LABEL

The Indoor Climate Label currently uses a short Healthy Buildings Index tool version. BBA develops the Healthy buildings index tool in collaboration with DGMR. It is an online questionnaire based on the questionnaire developed in the EU project Office Air[2]. It measures the satisfaction of office building users regarding the indoor environment. The survey addresses the following themes: Thermal comfort, Indoor air quality, Light, Acoustic and Personal control. It is a dynamic tool. When a respondent is unsatisfied with a theme, he or she will be asked to elaborate on the cause of dissatisfaction in detail by answering additional questions, see Figure 1.

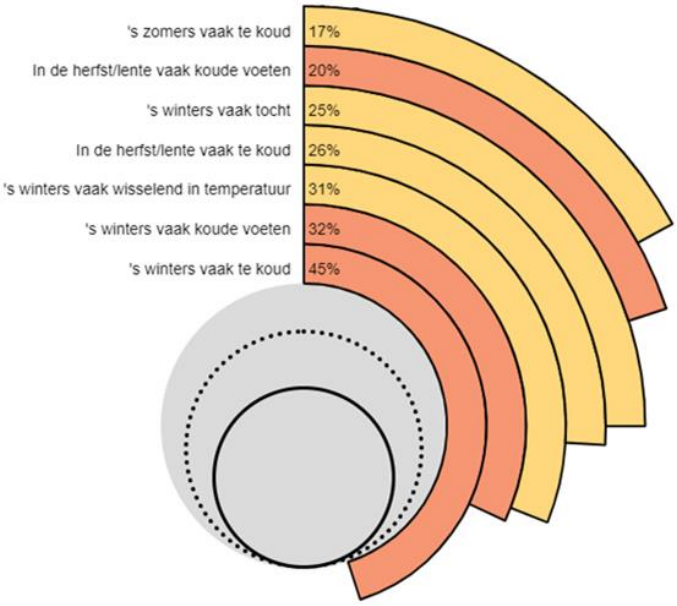

Figure 1: Detailed insight into thermal comfort complaints by answering additional questions with the Healthy buildings index tool.

The tool uses a 7-point scale ranging from 1 = very dissatisfied, 4 = neutral to 7 = very satisfied. See figure 2 for the five main questions. As the vote box and the QR code have a 5-point scale, the questionnaire results have been analysed within this format. This has been achieved by adding up the number of votes in the categories 2. dissatisfied' and '3. somewhat dissatisfied' into the category 'dissatisfied' and by adding up the number of votes in the categories '5. Somewhat satisfied' and '6 satisfied' into the category 'satisfied'.

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Indoor Climate

	Satisfaction						
	Very satisfied	Unsatisfied	Somewhat unsatisfied	Neutral	Somewhat satisfied	Satisfied	Very satisfied
How satisfied are you with the temperature in your workplace?	○	○	○	○	○	○	○
How satisfied are you with the air quality in your workspace?	○	○	○	○	○	○	○
How satisfied are you with the light in your workspace?	○	○	○	○	○	○	○
How satisfied are you with the noise and acoustics in your workspace?	○	○	○	○	○	○	○
How satisfied are you with the degree of control in your workspace	○	○	○	○	○	○	○

Figure 2: Main questions Healthy buildings index tool and a 7-point scale.

3 EXPERIMENTAL SETUP

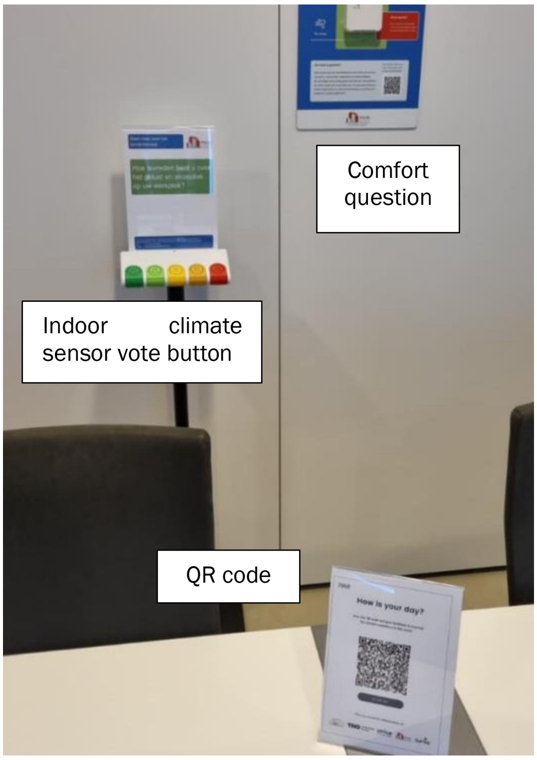
3.1 Introduction

The pilot was conducted from May 2^{nd} to September 16^{th}, 2022. This was during week number 18 to 37. In the pilot, the feedback on the perceived comfort was obtained with vote buttons and a specific comfort question placed next to the wall. This was compared with the feedback obtained with QR codes placed on tables. Further, a comparison was made with indoor climate sensors attached to the wall at about 1.5 m height.

The yearly questionnaire (healthy building index tool) was sent out on July 5^{th} to all building occupants.

The sensors and sensor positions are described in more detail in paragraph 3.3. The sensors were placed according to the 'verification protocol' of the Indoor Climate Label.

On March 29^{th}, 2022, the Spie Building was inspected according to the 'inspection protocol of the Indoor Climate Label.



3.2 Pilot building

The pilot was held in the Spie office building in Son, see Figure 3.

Figure 3: Pilot building with red facade, Spie office building in Son.

In this building, about 200 employees of Spie are working on the first, second, third and fourth floors. The ground floor is used as an entry and restaurant and contains two large meeting rooms. Another company was using the fifth and sixth floors. The floor maps with the sensor locations are listed in Appendix 2.

3.3 Sensor description

3.3.1 Vote box

In total, eight vote/vote boxes were placed in the Spie building. The vote boxes have five buttons; see Figure 4. The locations are indicated in Appendix 2 and Table 1. Once pressed a button, the vote, together with the time and the location, was sent to the Spie central database. All the vote boxes were equipped with one indoor comfort question from figure 2. After two working weeks, this question was changed to a new question. See appendix 1 for the questions and the time scheme for the changes.

Figure 4: Five button vote box with indoor comfort question attached above it.

Table 1: Overview of vote box positions

number	floor	description	name
1	Ground floor	Large meeting room	Meeting room 2
2	Ground floor	Restaurant	Restaurant
3	First floor	Entrance of a mixed open / closed office space	Room 1.16
4	Second floor	Entrance of a mixed open / closed office space	Room 2.22
5	Second floor	Entrance of a mixed open / closed office space	B&O
6	Third floor	Entrance of a mixed open / closed office space	Projects
7	Fourth floor	Entrance of a mixed open / closed office space	ICT
8	Fourth floor	Small meeting room	Room 4.24

3.3.2 QR code based app

Unica has developed a feedback app for indoor comfort. By scanning a QR code with a mobile phone, a webpage with subjective comfort questions is opened. The comfort sensation can be selected by answering four questions (4 clicks). These data, together with the time and the location, were sent to the Unica central database. An important difference with the vote box is that all four questions can be answered simultaneously.

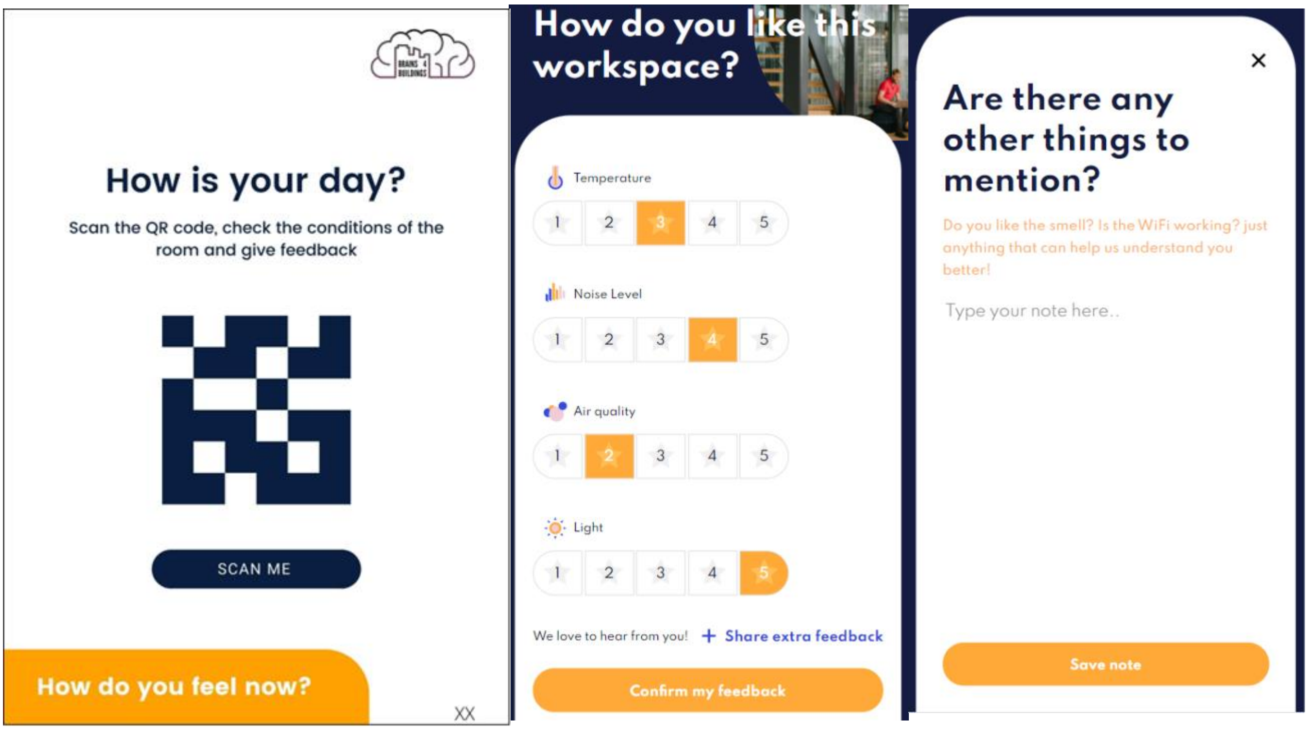


Figure 5: Left QR code placed on a table, right: two screenshots of Unica's five-point scale comfort app after answering the questions (scale: 1= uncomfortable, 3 = neutral, 5 = comfortable).

3.3.3 People counters

Person counters were attached next to doorways to determine the number of occupants in the Spie office at strategic places. In figure 6, the person counter placed at the central entrance on the ground floor is shown. The system consists of an emitter and a receiver. Every time a person passes, the beam is disconnected, and a person is counted. The counter detects the walk direction, this makes it possible to count the actual number of persons present in the building, wing or even in a meeting or office room. The positions of the people counters are listed in Appendix 2.

Figure 6: People counter at the central entrance on the ground floor (the emitter is circled orange).

3.3.4 Indoor climate sensors

In the Spie office building, indoor climate sensors measuring temperature, relative humidity, and carbon dioxide (CO_2) concentration were placed near the vote boxes and QR codes. Before deployment, they were checked by placing them all together in the same room and comparing the measurement data with each other, see figure 7. The maximum temperature deviation between the 32 temperature sensors was 0.25 K.

Figure 7: Indoor climate sensors placed next to each other for calibration.

3.4 Communication

At the start of the study, the building users were informed about the research goal: to develop improved methods for measuring perceived comfort. To promote vote buttons and QR codes, narrowcasting was used in the Spie building to display the results of the last period; see figure 8 for a screen dump. The daily results were calculated as the average value of all vote boxes, expressed on a 10 points scale.

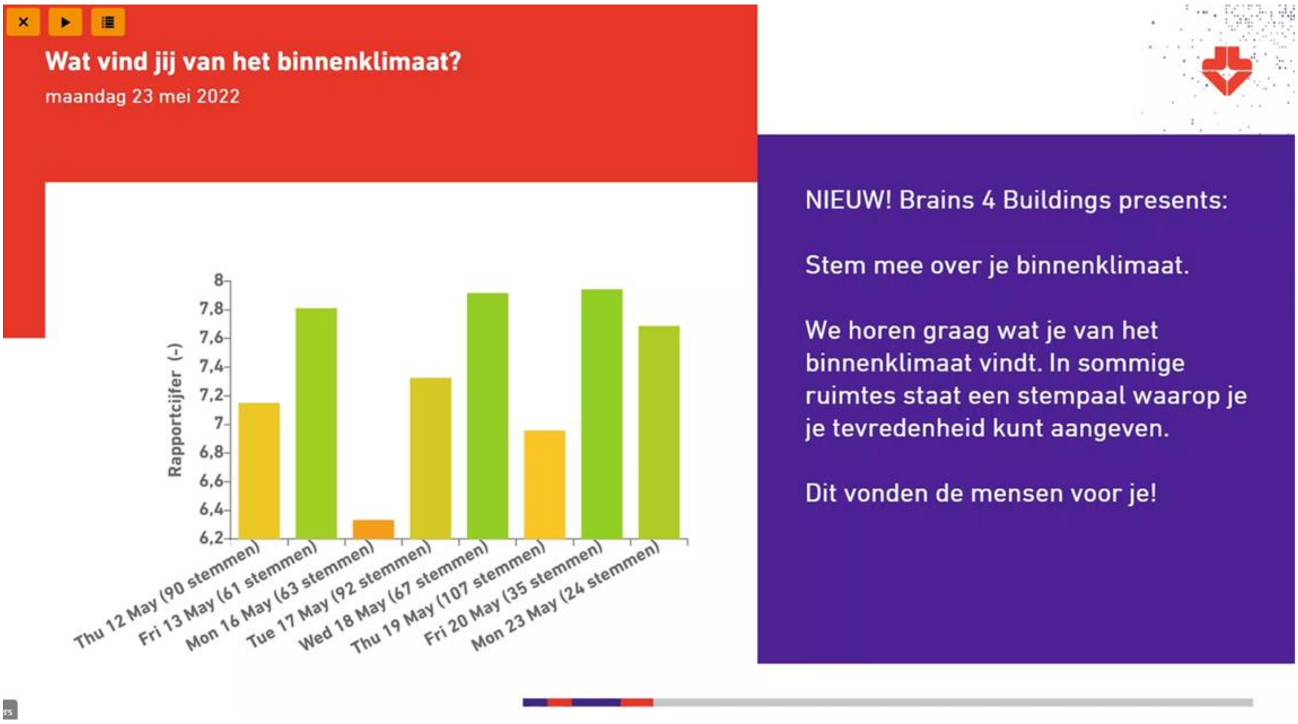


Figure 8: Screen dump of narrow casting.

4 MONITORING RESULTS

4.1 Number of votes per week

Figure 9 shows the number of votes obtained with the 8 vote boxes during the pilot study. In the second week, May 9th to 13th, 2022, the weekly votes collected reached a maximum. After that week, the number of votes slowly declined to about 100 votes per week in the last week. The largest number of votes with the vote boxes were in space 2.22, the Project room and in the space ICT North. The total number over the whole period was 3500 votes. In the office, about 200 persons are working, therefore, at least in week 19, several persons have voted multiple times per day. This may be also the case in the weeks afterwards. It is not known which part of the persons did vote.

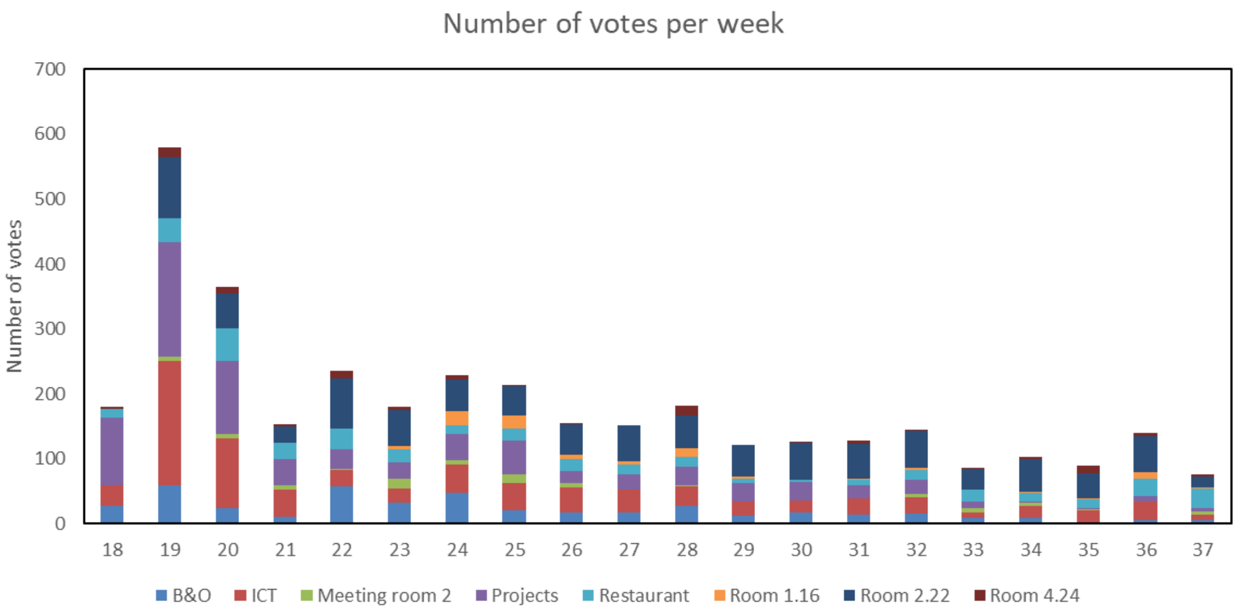


Figure 9: Number of vote box votes per location during each pilot week.

Figure 10 shows the number of votes obtained with the 12 QR codes during the pilot. The total number of votes over the whole period was 51, much lower than the number obtained with the vote boxes. With the QR codes also, a peak was in the first week. Note that although the system was operational for the whole period, not all week's votes were issued via the QR codes. These weeks have been left out of Figure 10. What is interesting to see that after week 20, in most weeks, the votes were casted from one or two rooms. The reason for this is unknown.

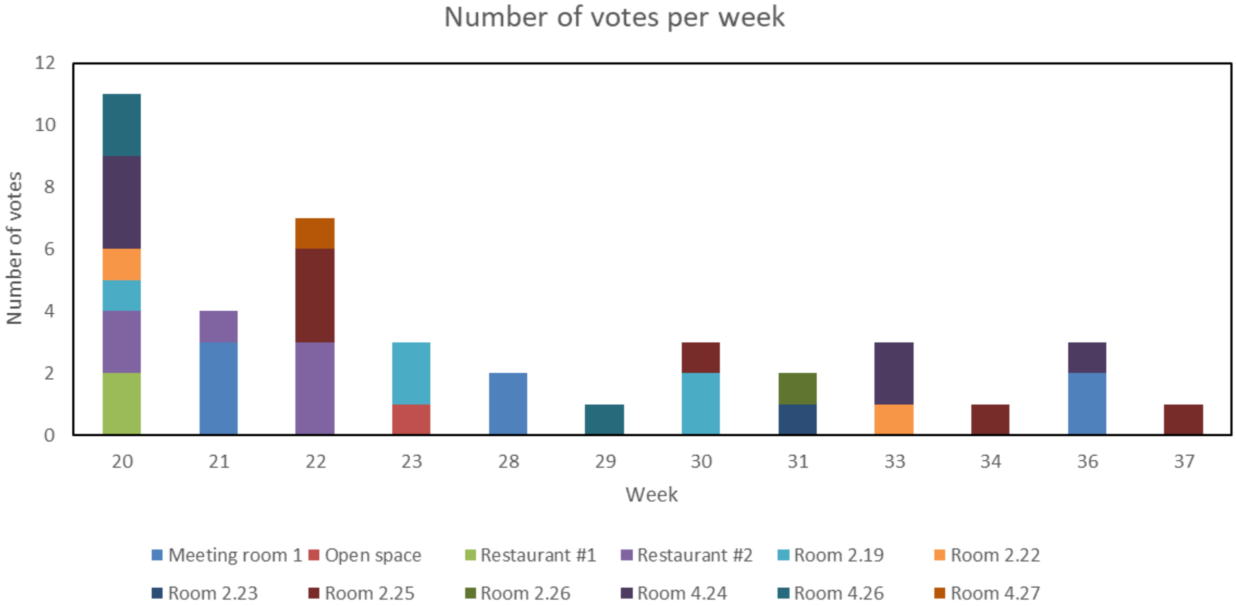


Figure 10: Number of QR-code votes per location during each pilot week.

The online indoor climate label questionnaire (based on the Healthy Building index tool) was deployed in the middle of the monitoring period in week 27 on July the 5th under all building users. In total, 51 persons filled in the questionnaire. This is about 25% of the total office population.

4.2 Effect of location

in Table 2, the number of votes per asked question is listed per location. The first three weeks are omitted to exclude introduction effects. Out of curiosity, people might just have voted without answering the comfort question. The highest number of responses was given in room 2.22. In this part of the building, the Pulse core experts are located. These persons are doing energy and indoor climate analyses for clients. Due to their work, they might have been more motivated to vote. Noise and temperature are the aspects with the highest number of votes. Light and control have triggered the least number of votes.

Table 2: Number of vote box responses per the theme given in different locations after the first three weeks. In bold, the theme with the highest number of responses is indicated.

#	location	1. air quality	2. light	3. noise	4. temperature	5. control
1	B&O	108	35	36	79	47
2	ICT	51	**109**	129	48	73
3	Meeting room 2	27	27	3	12	4
4	Projects	55	105	102	53	25
5	Restaurant	24	21	75	73	57
6	Room 1.16	51	2	4	24	17
7	Room 2.22	**109**	76	**149**	**195**	**171**
8	Room 4.24	21	9	16	24	10
	Total	446	384	514	508	404

Table 3 and 4 list the % of persons passing by and being present in the rooms giving feedback. Here also room 2.22 has the highest response rate regarding the number of persons passing each day. The small meeting room 4.24 has given the highest % people working inside and giving feedback. It might be possible that people have given multiple votes per day and thus the % giving feedback is estimated too high.

Table 3: Share of persons passing giving feedback with the vote box

number	Location	# votes/day	# persons passing / day	% giving feed back
1	B&O	4,0	164	2,4%
2	ICT	5,0	118	4,2%
3	Meeting room 2	1,0	33	3,0%
4	Projects	4,0	110	3,6%
5	Restaurant	3,0	116	2,6%

number	Location	# votes/day	# persons passing / day	% giving feed back
6	Room 1.16	1,0	92	1,1%
7	Room 2.22	9,0	176	5,1%
8	Room 4.24	1,0	22	4,5%

Table 4: Share of persons inside the rooms giving feedback with the vote box

number	location	# votes/day	# persons inside / day	% giving feed back
1	B&O	4,0	13,8	29,0%
2	ICT	5,0	32,6	15,3%
3	Meeting room 2	1,0	4,6	21,7%
4	Projects	4,0	26	15,4%
5	Restaurant	3,0	22,4	13,4%
6	Room 1.16	1,0	11,2	8,9%
7	Room 2.22	9,0	22,7	39,6%
8	Room 4.24	1,0	2	50,0%

The self-reported comfort score with the QR-codes (figure 12) differs more between the different rooms/locations than the self-reported comfort with the vote buttons (figure 11). This may be due to the larger number of votes obtained with the vote boxes. With the QR-codes in some rooms only one vote has been obtained.

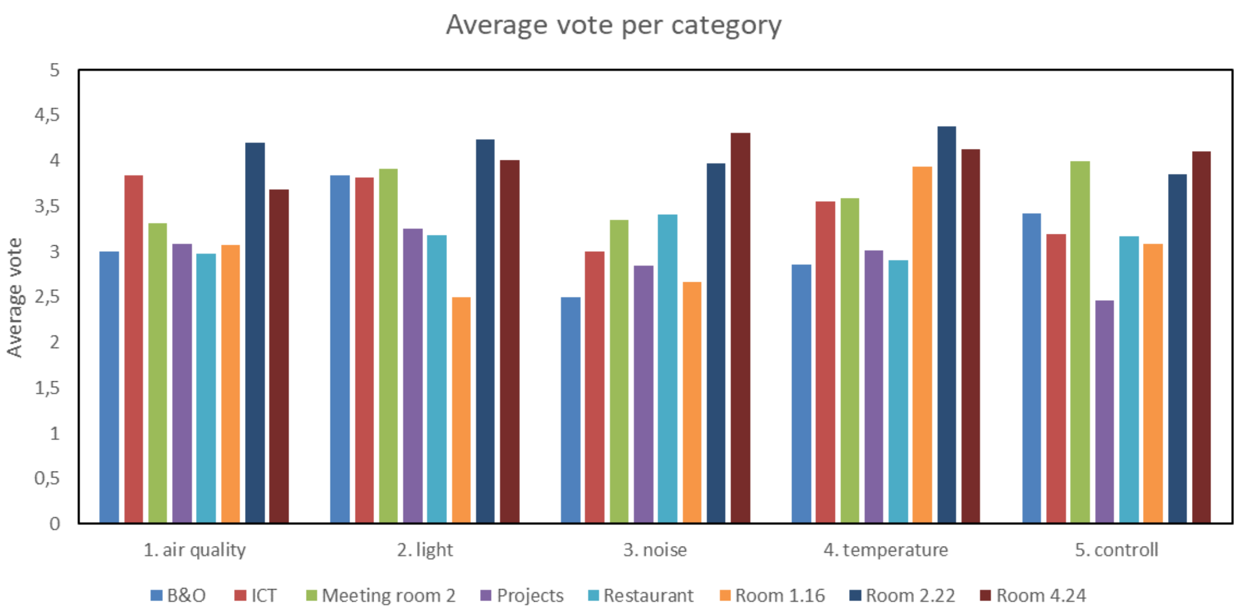


Figure 11: Average score obtained with Vote box per category for the different rooms.

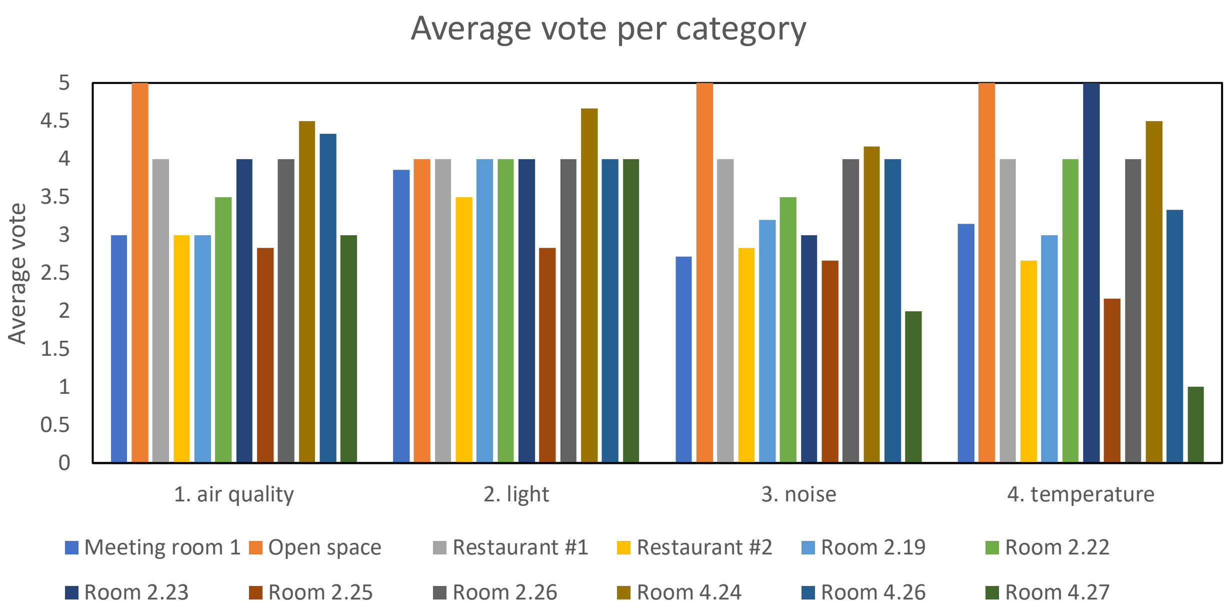


Figure 12: Average score obtained with QR-code per category for the different rooms.

4.3 Comparison of subjective comfort data

Figure 13 compares the average votes obtained with the vote boxes, QR codes and the questionnaire. There are no significant differences between the three methods concerning air quality, noise, and temperature. Small but significant differences (T-test, $p < 0.05$) are found between the light and control scores obtained with the vote boxes and the questionnaire.

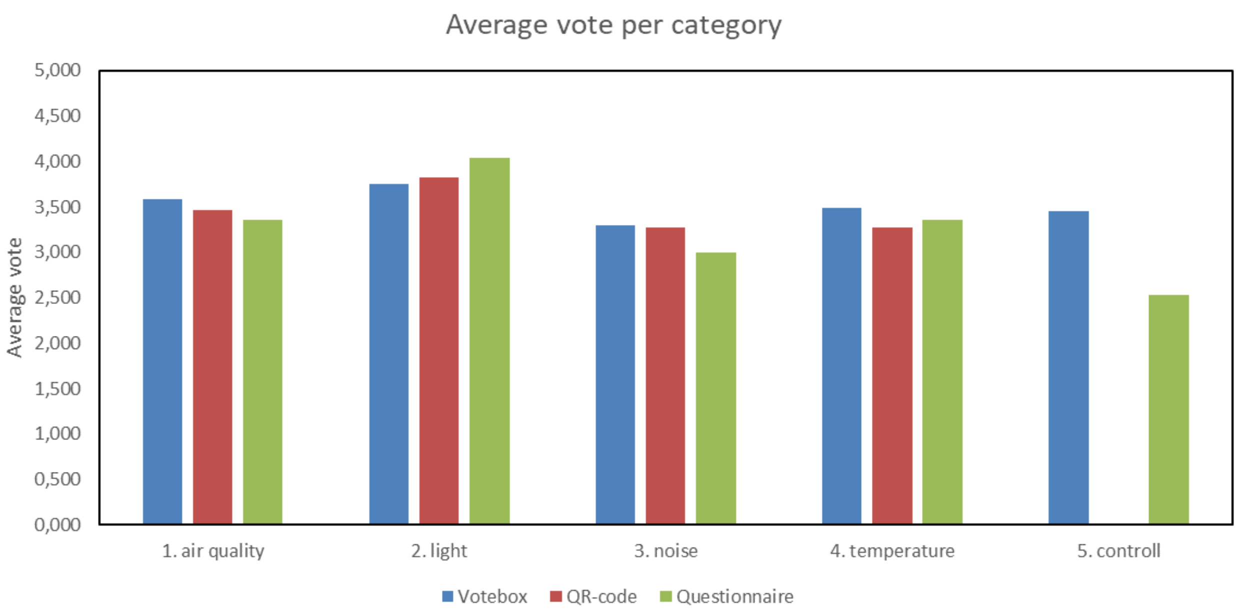
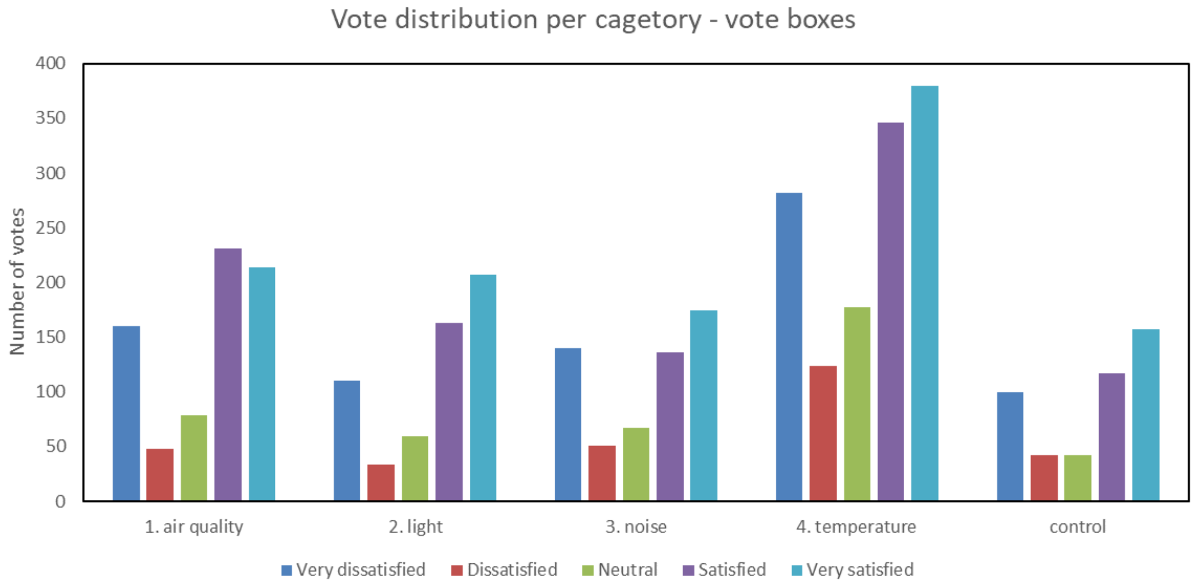
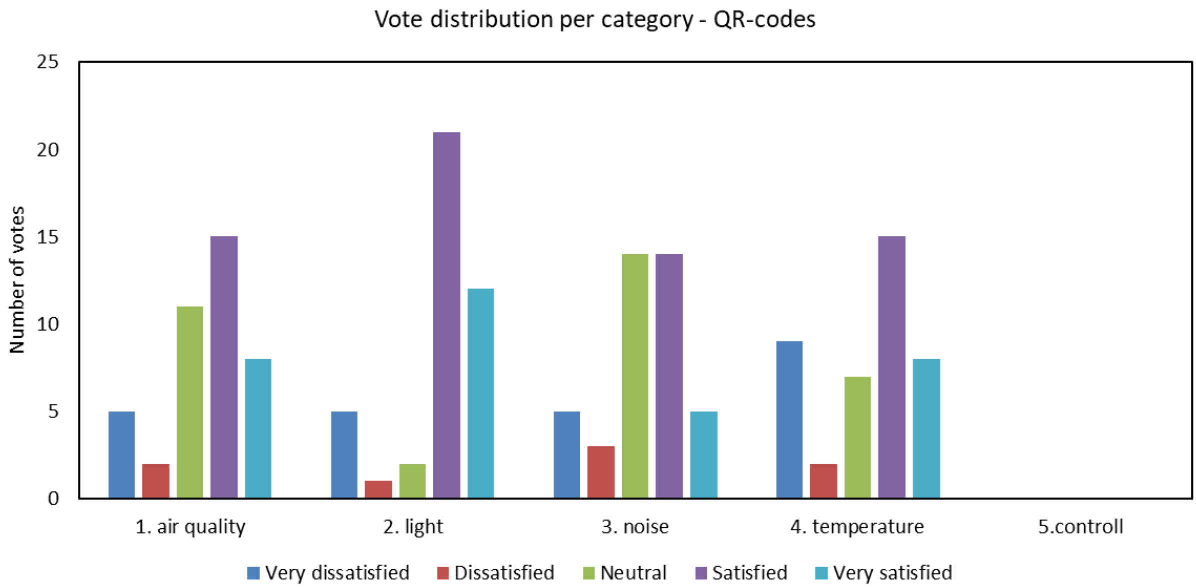


Figure 13: Average votes obtained with the vote boxes, QR codes, and the questionnaire.

The lowest scores have been obtained for control. This is in line with the inspection results. No solar shading is present. The windows can be opened, but only in one position. And the lighting cannot be changed. Although the averages of the four comfort aspects are comparable, the distribution of the votes per comfort aspect for the vote boxes differs from that of the QR code and the questionnaire. With the vote boxes, the extremes of the scale are preferred: 'Very dissatisfied' and 'Very satisfied. With the QR codes and the questionnaire, the 'dissatisfied – neutral – satisfied' values are more often chosen, see Figure 14. The questionnaire originally had a 7-point scale; in Appendix 3, a comparison is made between results on a 5 and 7-point scale. This does not change the conclusion that using the questionnaire, the extremes are rarely chosen





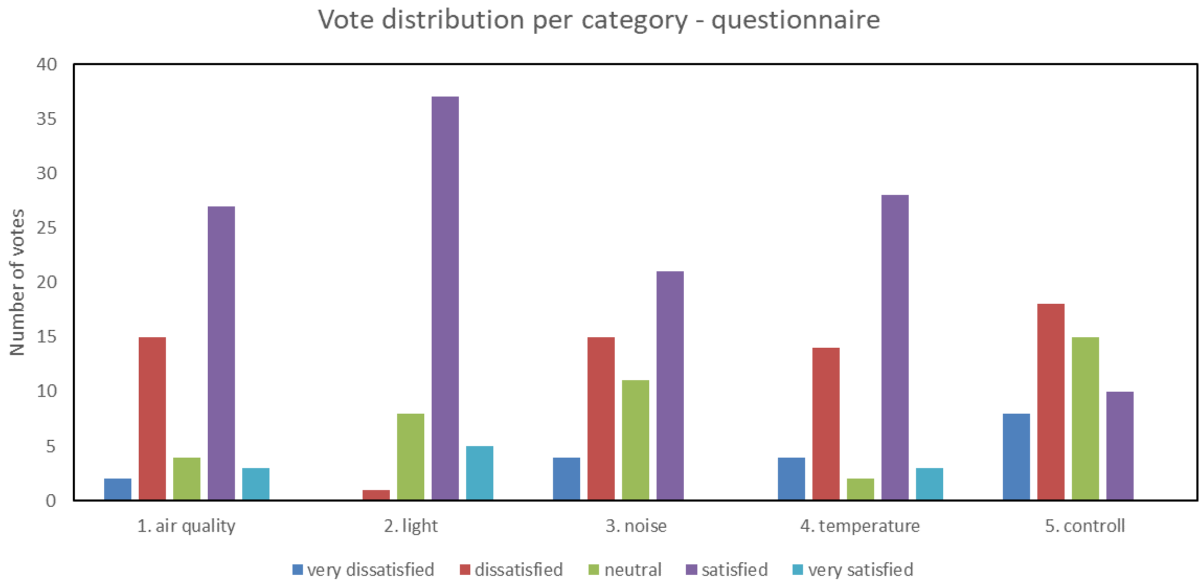


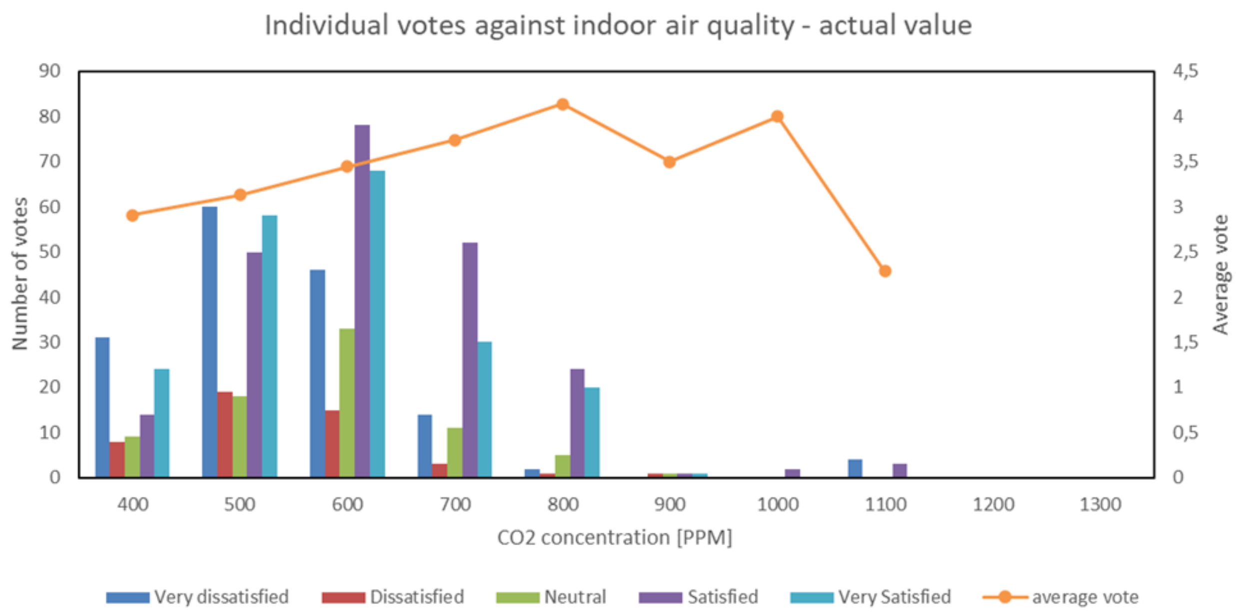
Figure 14: Vote distribution obtained with the vote boxes, QR codes, and the questionnaire.

4.4 Comparison of subjective with objective sensor data

The subjective data obtained with the vote boxes and the QR code can be compared with the objective data for temperature and air quality (CO_2) registered by sensors at the time of the vote or the maximum value during the two previous hours.

Vote boxes

Figure 15 shows no logical relation between the vote box results and the measured air quality. One would expect that at higher CO_2 concentration, the number of votes for 'Satisfied' or 'Very satisfied' would be lower, and the numbers for 'Dissatisfied' and 'Very dissatisfied' would be higher. However, this was not the case. They were going from 400 to 800 ppm the share of 'Satisfied' or 'Very satisfied' votes increased. This can also be seen in the increase in the average vote. The average vote drops at 1100 ppm and, for the maximum during the previous two hours, at 1000 ppm. However, the number of samples is too low to draw solid conclusions. Less than 0,1% of the data, mostly in room 2.22, is above 850 ppm, see figure 16.



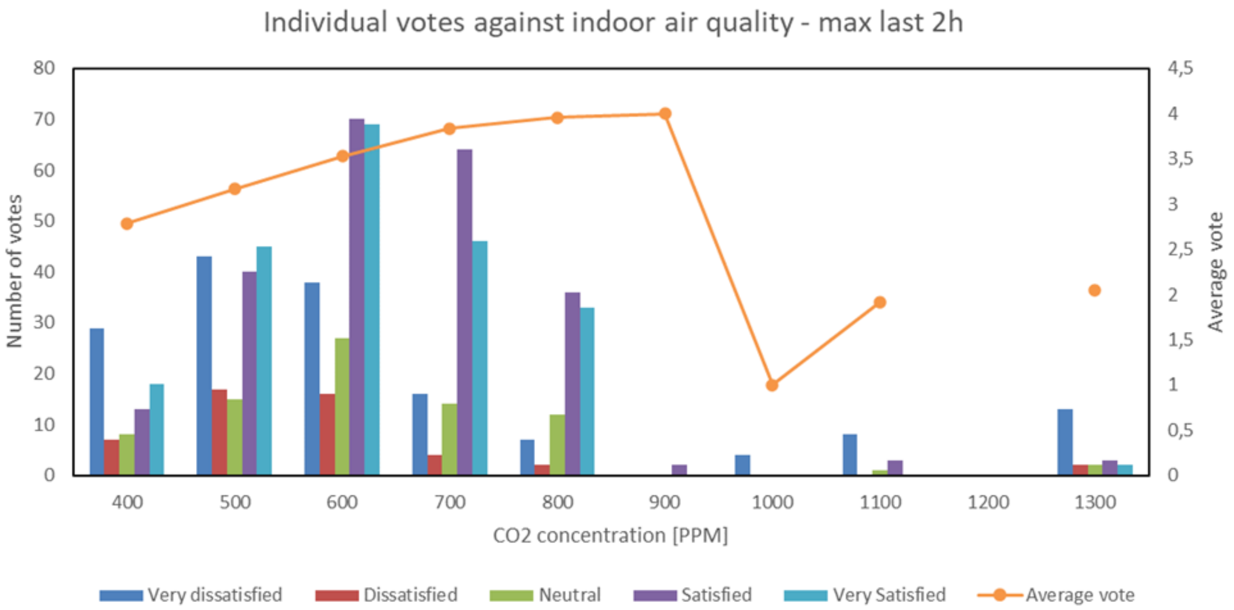
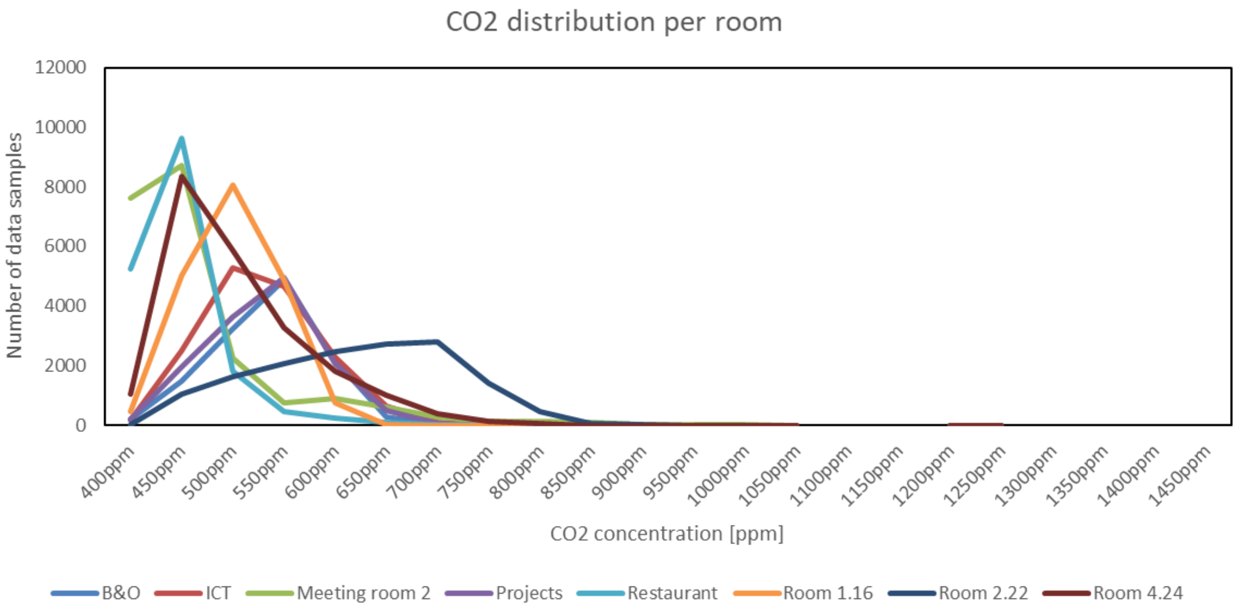


Figure 15: Vote button results concerning perceived air quality as a function of measured air quality. Upper graph: CO_2 value measured at the moment of the vote. Lower graph: votes plotted against the maximum CO_2 value during the previous two hours.



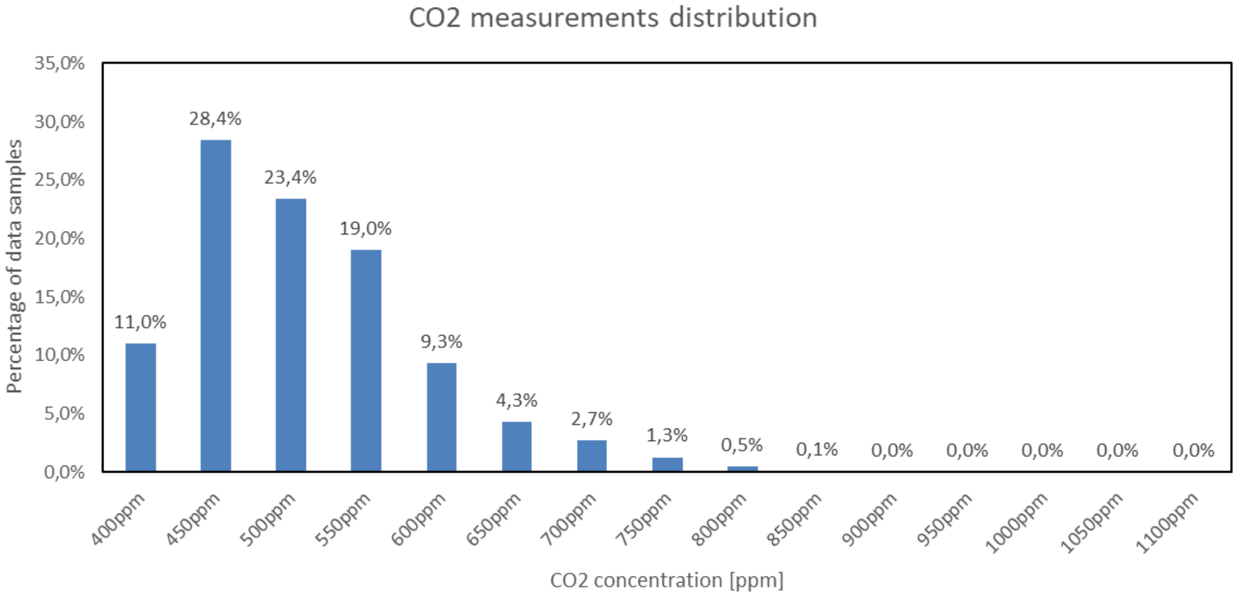
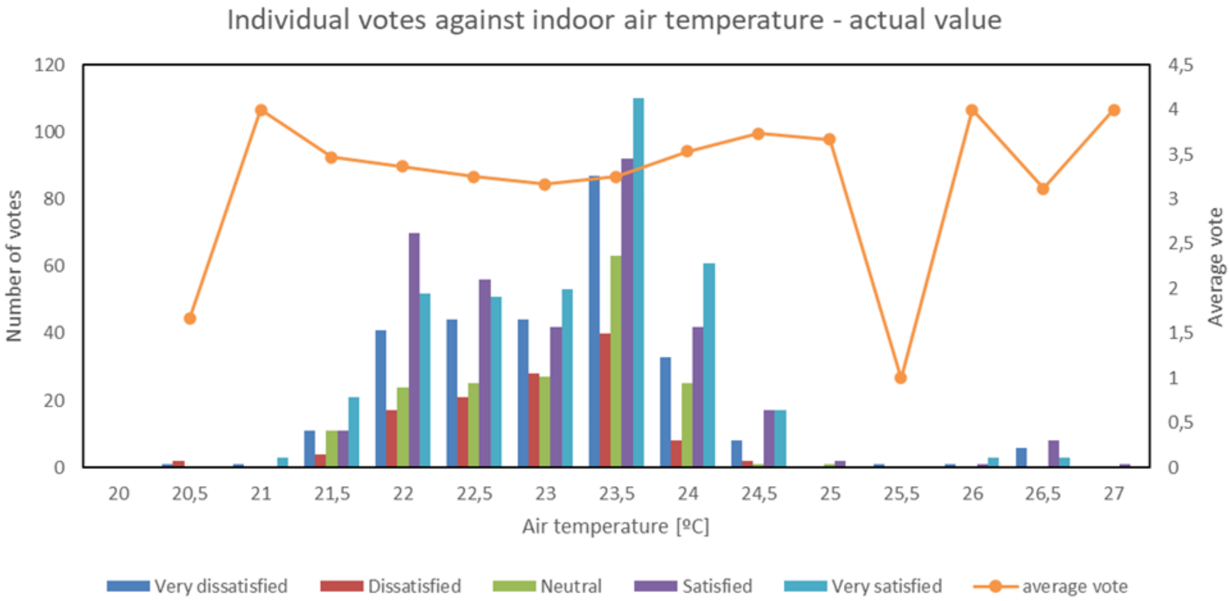


Figure 16: Upper graph: CO_2 distribution per room in monitoring period during office opening times. Lower graph: CO_2 distribution over all rooms in monitoring period during office openings.

According to ISO 7730[3], with summer clothing (0,5 Clo) at 24,5 °C a Predicted Mean Vote (PMV) of zero would be expected for sedentary office activity (1,2 met). Below and above this temperature, an increase of complaints can be expected. At 21 and 27 °C one would expect from ISO 7730 that 30% of the persons are dissatisfied with the temperature. Figure 17 shows no increase in 'Very dissatisfied' or 'Dissatisfied' votes going from 24,5 °C to 21 °C. This can also be seen from the stable average vote for this temperature region.

Below 21 °C the average vote drops. However, the percentage of time that the temperature is below this level is only 1,5 % see figure 18. The exceedance above 27 °C is even below 0,05% of the time. This may explain the low number of votes at the extremes.



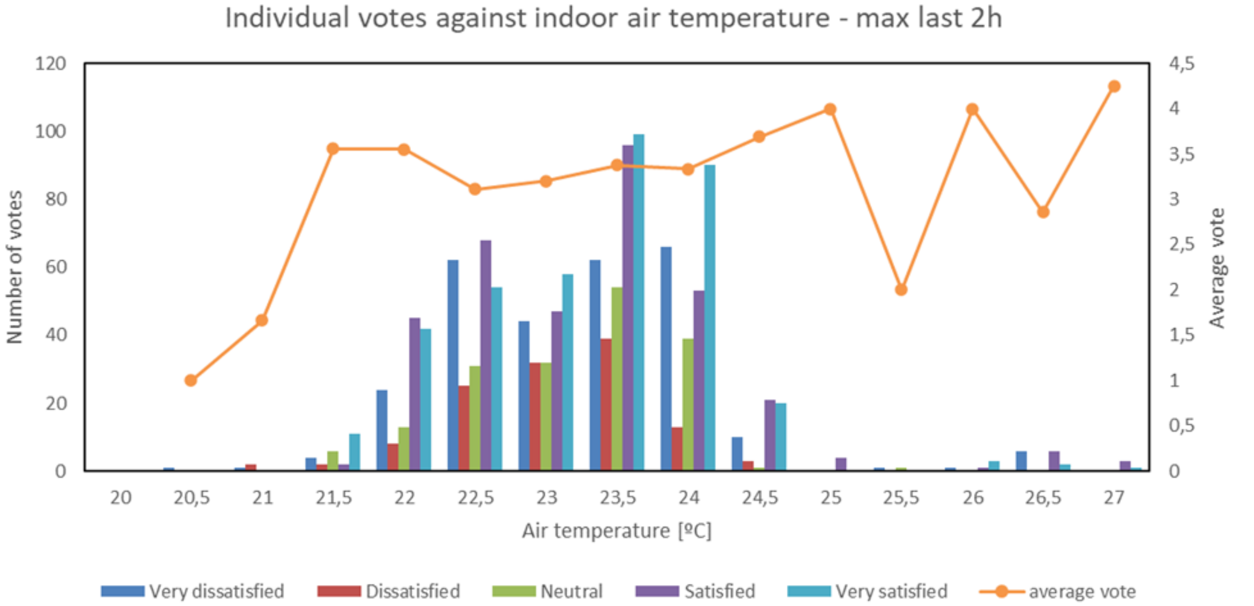
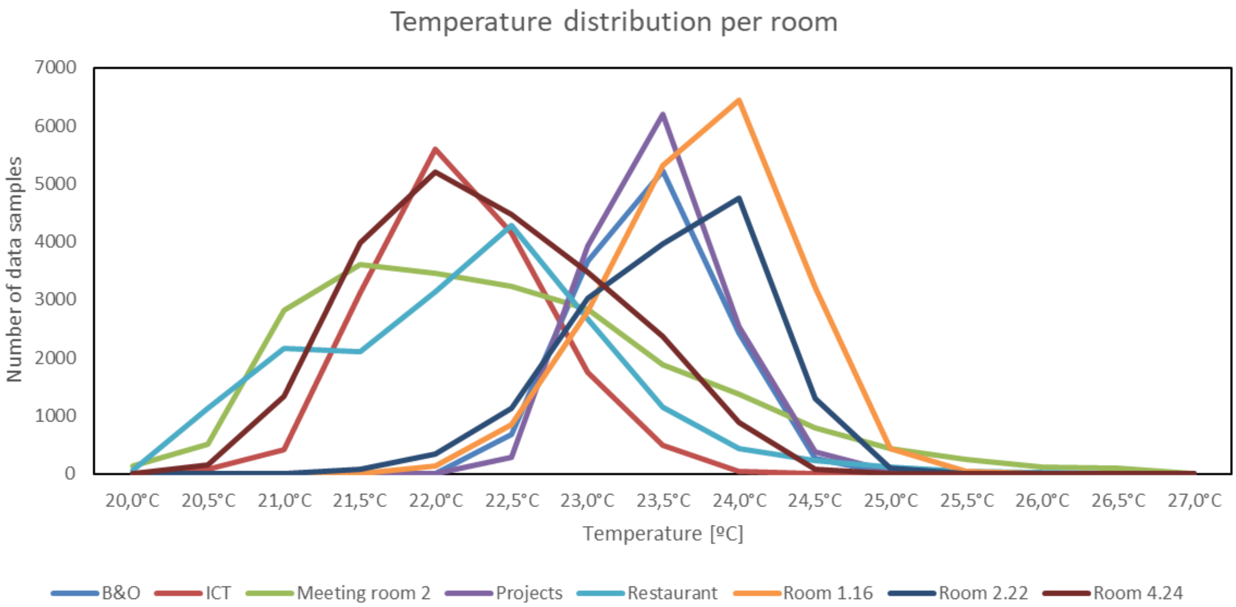


Figure 17: Vote button results concerning temperature as a function of the measured temperature. Upper graph: temperature value measured at the moment of the vote. Lower graph: votes plotted against the maximum T value during the previous two hours.



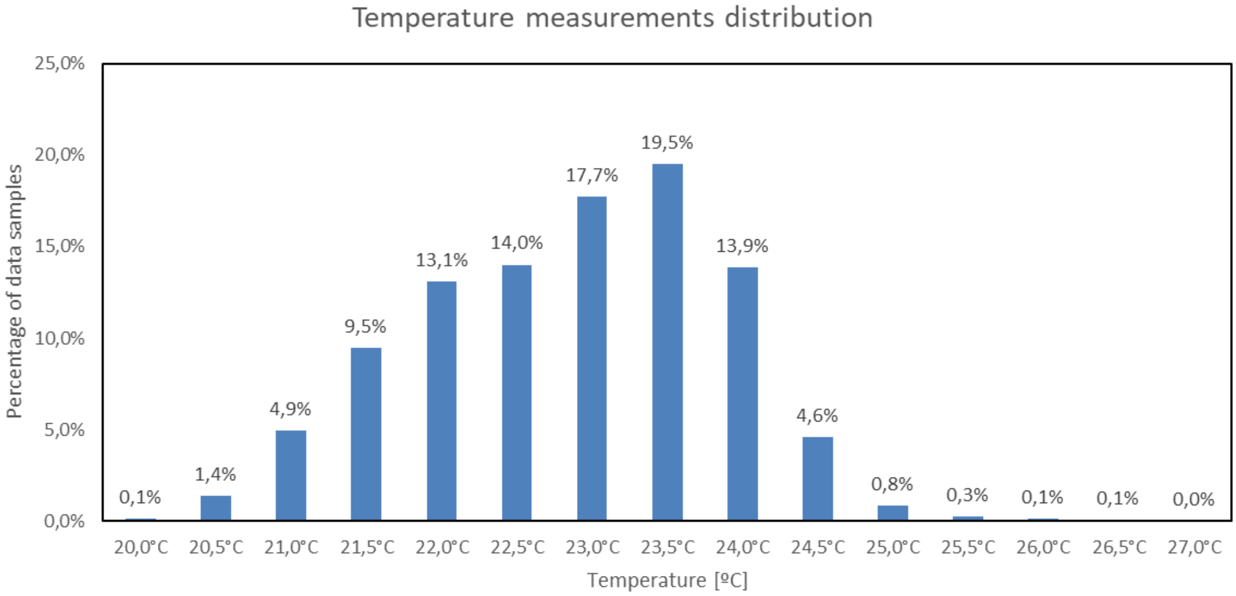


Figure 18: Upper graph: temperature distribution per room in monitoring period during office openings. Lower graph: temperature distribution over all rooms in monitoring period during office openings..

QR-codes

Figure 19 shows no clear trend between the QR-code results and the measured air quality. One would expect that with higher CO2 concentrations, the perception might deteriorate. However, this is not the case. Going from 500 to 1000 ppm, the number of times 'Satisfied' has been chosen remains the same. It should be noted, however, that the number of votes is too low to draw solid conclusions.

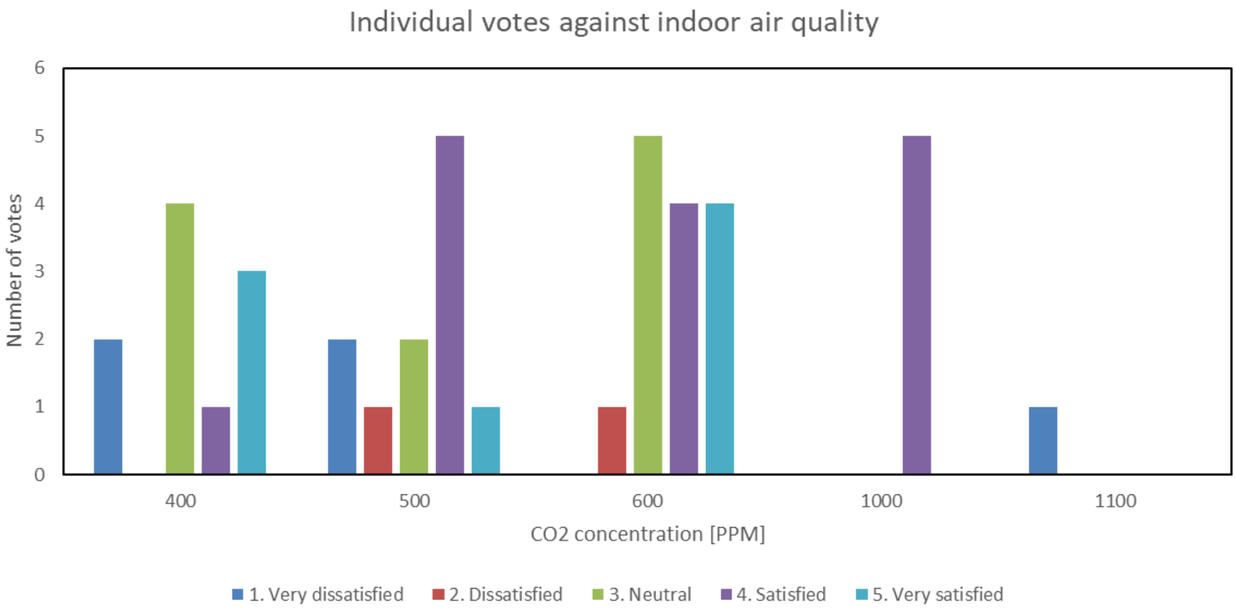


Figure 19: QR-code results concerning perceived air quality as a function of measured air quality.

According to ISO 7730[3] with summer clothing (0,5 Clo) level at 24,5°C a Predicted Mean Vote (PMV) of zero would be expected for sedentary office activity (1,2 met). Below this temperature cold complaints can be expected. At 21°C one would expect according to ISO 7730 that 30% of the persons are dissatisfied with the temperature. In Figure 20 at 24°C 60% of the QR votes are 'dissatisfied'. Going from 24 to 21°C the number of 'very dissatisfied' complaints becomes gradually higher. However, as the number of votes is low it is difficult to determine clear trends.

No QR codes were scanned at higher temperatures than 24 °C. This is in line with the limited time that the temperature was above this level.

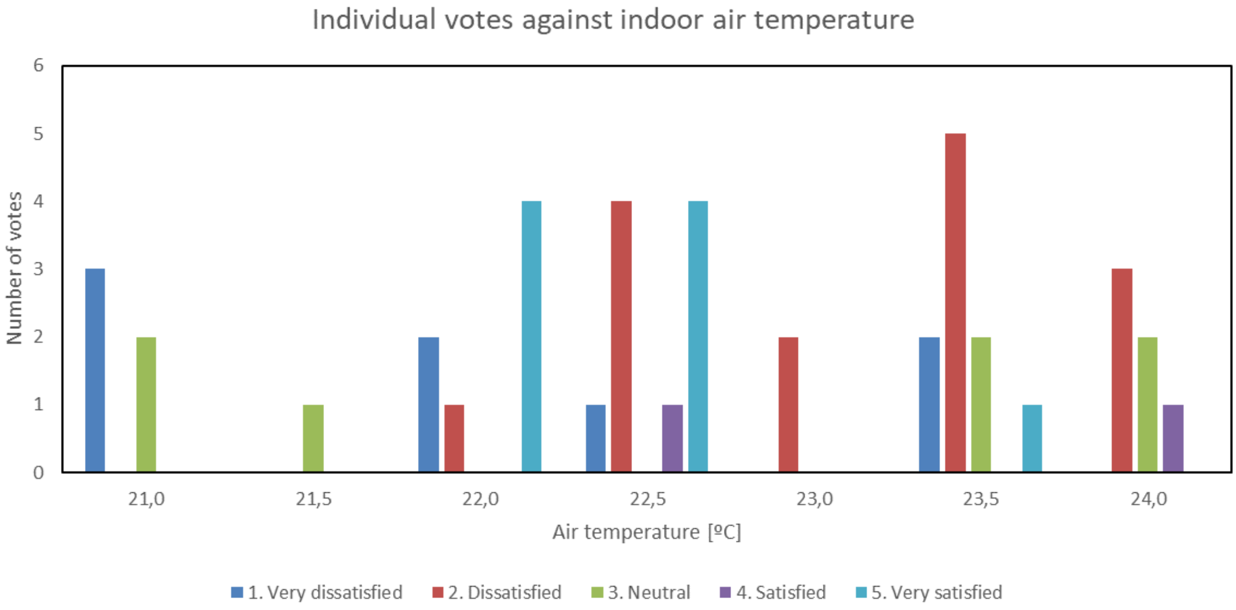


Figure 20: QR-code results concerning temperature as a function of the measured temperature.

5 DISCUSSION

5.1 How do the vote boxes/QR code data relate to the yearly Healthy building index survey?

The average values obtained with the three methods correspond quite well during the summer period. Small but significant differences (T-test, $p < 0.05$) are found between the light and control scores obtained with the vote boxes and the questionnaire. The average response of the vote boxes and from the QR codes can be used to provide a year-round general prediction of the indoor climate. This might make it possible to get a year-round impression which might have benefits compared to 1 questionnaire per year. This hypothesis has to be confirmed further in other (office) buildings.

5.2 How can we trigger and motivate users to deliver self-reported subjective comfort data?

The vote boxes generate a much higher number of feedback (3500 votes) than the QR codes (51 votes). At the beginning of the monitoring period, the highest number of votes was observed for the vote boxes and the QR codes. After several weeks, the response is a factor of four lower than in the beginning.

Which question is shown above the vote boxes does not seem to have a large influence on the number of votes. This raises the question of whether the votes are specific for the questioned comfort aspect or the perceived comfort in general.

With the QR codes, no votes were given at temperatures above 24 °C. With the vote boxes, no votes were given above 27 °C. This is in accordance with the very limited time fraction that the temperature was above this level. Therefore, whether discomfort concerning thermal and indoor air quality does trigger building users to deliver self-reported comfort data with vote boxes and QR-codes needs to be investigated further in other (office) buildings with a larger temperature and CO_2 range than in the Spie building.

5.3 What is the effect of the position of the vote box?

The vote boxes next to the entrance door of office wings have attracted more votes than vote boxes placed inside rooms. This might be explained by the large number of people passing by.

However, it wasn't easy to relate the votes with the objective sensor data. Even when we looked at the highest concentration/temperature during the last two hours before the vote, we did not see a clear relation. This might be because each office wing consisted of several closed office rooms in combination with a landscape office. Therefore. the vote box gave an average of an office wing or even an average score of a floor. A higher correlation with the objective sensor data might be obtained by placing the vote buttons directly in the workspace. Another reason may be that only during a limited fraction of the time, deviations of ”optimal” physical conditions occurred.

5.4 Are the physical sensor data in line with the subjective feedback of vote box and QR code?

Both the votes of vote boxes and QR codes have no clear relation with the measured physical indoor climate at a specific moment.

One would expect that the perception would deteriorate at low and high room temperatures. However, this has not been observed. The QR-codes have reported even the highest thermal dissatisfaction at 23,5 °C. According to ISO 7730, the lowest number of complaints would be expected under summer conditions at this temperature. It might be possible that with the Adapted Temperature Limit value (ATG) method, a better agreement can be found.

The same applies to air quality. One would expect that at higher CO_2 concentrations, the perception would deteriorate. However, going from CO_2 concentrations of 400 to 800 ppm, the share of ‘Satisfied’ or ‘Very satisfied’ votes even increases.

The first explanation for the weak relation might be that in the office building, the fraction of time that the temperature or air quality expressed as CO_2 is outside the comfort conditions is rather limited.

The second explanation might be that the perceived indoor climate is influenced by more variables than were measured. For example, solar radiation or draught can also have an impact. And the votes can also be influenced by personal factors unrelated to the physical indoor conditions. For example, if people don't have enough sleep, are stressed, or are annoyed by a colleague, that may also be a trigger to push the red button.

A third explanation might be the placement of the vote box. The vote boxes placed at the entrance of the office wings gave the average votes of persons sitting in several closed office rooms in combination with other persons sitting in the landscape office. The physical climate may differ between these persons.

The fourth explanation might be the assumption that people do not read the comfort question above the vote box and thus might vote for another comfort aspect. For example, the question above the vote box is "How satisfied are you with the temperature?' and the vote is casted based on dissatisfaction with noise.

An interesting observation is that with the vote boxes for all four comfort aspects and control, the extremes of the scale are preferred: 'Very dissatisfied' and 'Very satisfied. With the QR codes for air quality and noise, the 'neutral' value is more prominently chosen. While for the temperature and light with the QR-code also, the extremes are more favourable. However, the number of votes here is considerably lower; therefore, it is more difficult to conclude from the available data. The preference for extremes with the vote boxes might be explained by the fact that there was only one question. Thus dissatisfaction/satisfaction may be more expressed regardless of the aspect it is about, while with the QR code, there is more nuance because there are several questions.

Our exploratory study in an office didn't find a clear relation between perceived comfort and sensor data. Brink[4] has found a statistically significant relationship between the air quality (CO_2 concentration) measured in 59 classrooms and the at the same time perceived air quality by 366 students, see figure 21. No significant effect was determined in a follow-up study in 34 classrooms and under 276 students. Possible because not enough cases with good IAQ were observed[5]. In a second follow-up study[6] under 163 students in two classrooms with a full air recirculation system again demonstrated a significant relation between CO2 and perceived air quality.

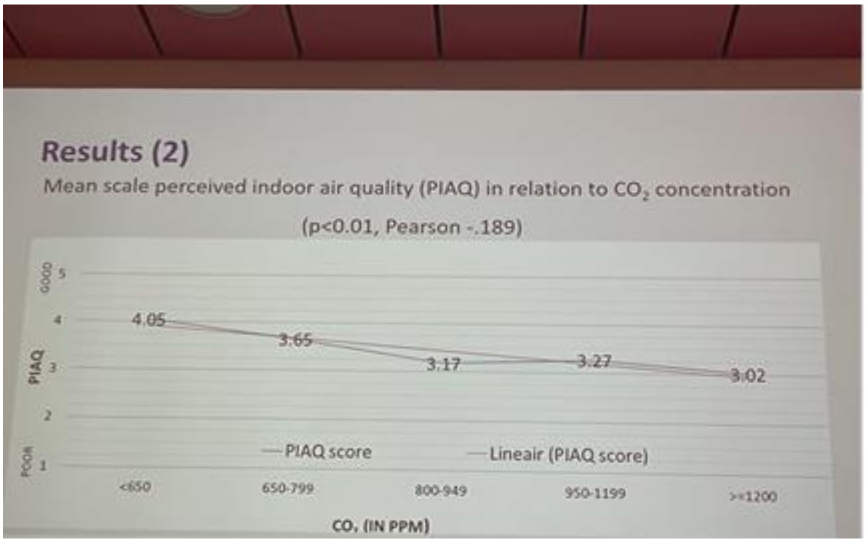


Figure 21: Relation between CO_2 concentration and the perceived indoor air quality (PIAQ)[4].

An important difference between the studies by Brink and the present study is that in the study by Brink the perceived air quality was obtained by reaching out a questionnaire to all participants and ask them to fill it in directly. Furthermore, In the present office study there are indications that the people passing the vote buttons might not have read the question very well. And third the CO_2 levels in the office were also not that high as in the school situation.

In the present study the comfort feedback of the office workers was self-triggered. The highest motivation to vote was in the beginning of the study. People might be hoping that based on their vote actions should be taken to improve the comfort. As these interventions were not incorporated in the study, the comfort situation did not change, and this might people cause to stop vote. People might also be curious about how the vote worked. This might especially be the case for the QR-code. As this method involved a website which was only visible after scanning the QR-code. Another reason might be that the indoor climate was rather constant and of a sufficient enough quality. Further only temperature and air quality have been objectively measured. For noise and light no physical measurements were collected. This makes it difficult to establish relations between the perceived comfort and the objectively measured comfort.

6 RECOMMENDATIONS

Based on the measured temperatures and CO_2 concentrations, the comfort level in the test office can be considered reasonable to good. Despite this, the vote boxes delivered a high level of reporting. This suggests that using vote buttons is an attractive way to deliver self-triggered comfort feedback. We, therefore, recommend investigating the following three improvements.

1. Repeat the research in other office buildings

To further confirm that the vote boxes give a good impression of the perceived comfort, it is necessary to make additional comparisons with the Healthy Buildings Index in other office buildings. The average and the votes' distribution should be compared with the questionnaire results. In this research, it may be interesting to have short interviews about why people have used the vote box. Or by checking the vote boxes results by reaching out a questionnaire to all participants and asking them to fill it in directly, similar to Brink[4]. And whether their vote was related to the attached comfort question or it was feedback on another aspect. Also of interest may be to use aside ISO 7730, the ATG method, to compare with the self-reported feedback.

2. Place the vote buttons directly at the workspace

In the current set-up, most vote boxes have been placed near the entrance of office wings. This might have generated a lot of feedback. However, it wasn't easy to relate the votes with the objective sensor data. This might be because each office wing consisted of several closed office rooms in combination with a landscape office. Therefore. the vote box gave an average of an office wing or even an average score of a floor. A higher correlation with the objective sensor data might be obtained by placing the vote buttons directly at the workspace. It also might be interesting to focus more on (office) buildings with more extreme climate conditions.

3. Use vote buttons connected with a touchscreen

In the current set-up above the vote buttons, an A-four with the comfort question was attached. Whether people responded to this question or gave feedback on another comfort aspect was questionable. The idea is to investigate this further by connecting the vote button to a screen with which follow-up questions can be shown. Which comfort aspect: noise, light, temperature, or air quality. And if e.g. temperature is pressed, whether the temperature is too low or too high. Further, in case the vote box is placed at a central location, it may be interesting to add possibilities to mark the location to which room the vote is applicable. In this way, a more detailed insight can be obtained comparable with the Healthy Building Questionnaire. Several prototypes of the layout need to be tested to obtain an optimum setup that is attractive to give feedback by the user and to retrieve as much as possible information about the self-perceived indoor climate.

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6. Brink, H. W., Loomans, M. G. L. C., Mobach, M. P. & Kort, H. S. M. A systematic approach to quantify the influence of indoor environmental parameters on students ' perceptions , responses , term academic performance. Indoor Air 32, 1–19 (2022).

APPENDIX 1: TEXT ABOVE VOTE BOXES

Time scheme for changing the questions over the vote boxes

moodbox	period 1: 9 - 20 Mai	period 2: 23 Mai - 10 June	period 3: 13 - 24 June	period 4: 27 June 8 July	period 5: 11 - 22 July
1	temperature	control	noise and acoustics	light	air quality
2	temperature	light	noise and acoustics	light	air quality
3	air quality	temperature	control	noise and acoustics	light
4	air quality	temperature	control	noise and acoustics	light
5	light	air quality	temperature	control	noise and acoustics
6	light	air quality	temperature	control	noise and acoustics
7	noise and acoustics	light	air quality	temperature	control
8	*In repair*	*In repair*	air quality	temperature	control

moodbox	period 6: 25 July - 5 aug	period 7: 8 - 19 aug	period 8: 22 aug - 2 sep	period 9: 5 - 16 sep
1	temperature	control	noise and acoustics	light
2	temperature	control	noise and acoustics	light
3	air quality	temperature	control	noise and acoustics
4	air quality	temperature	control	noise and acoustics
5	light	air quality	temperature	control
6	light	air quality	temperature	control
7	noise and acoustics	light	air quality	temperature
8	noise and acoustics	light	air quality	temperature

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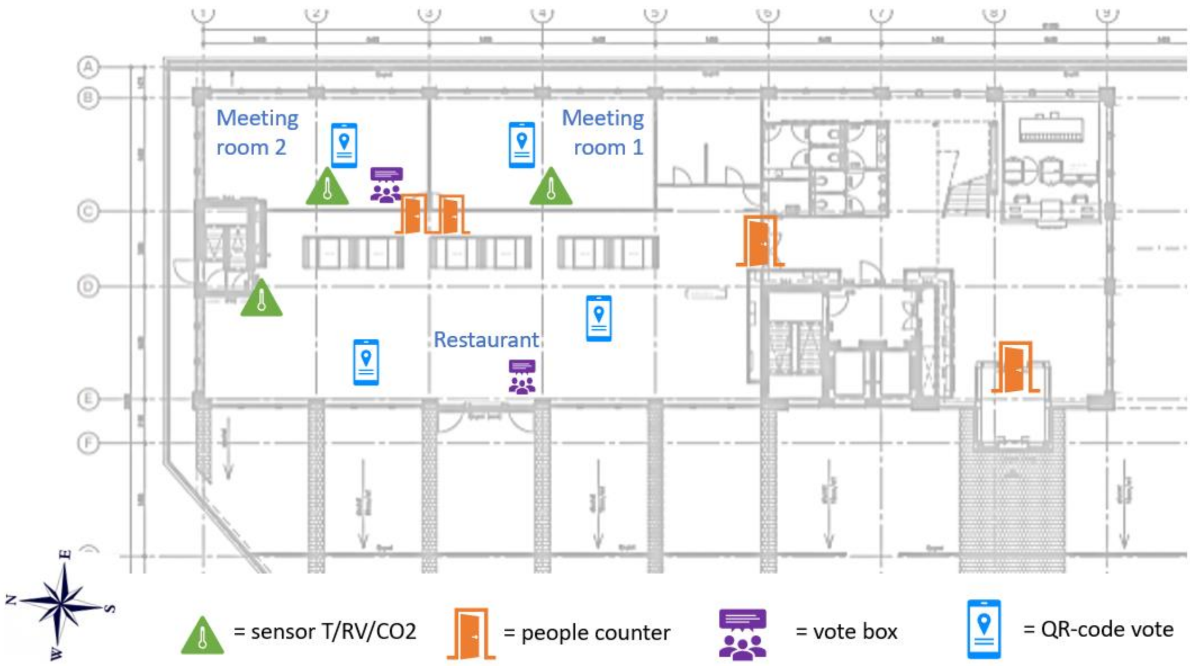
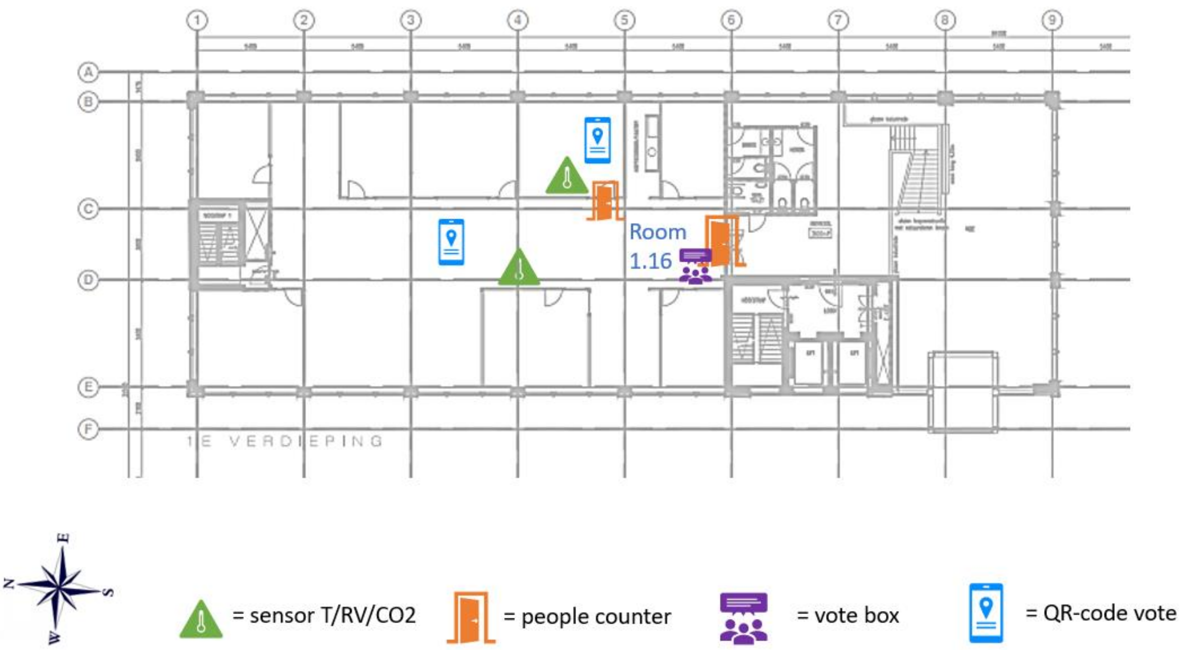
Email: servicedeskpulse@spie-ws.com

APPENDIX 2: FLOOR MAPS

BG



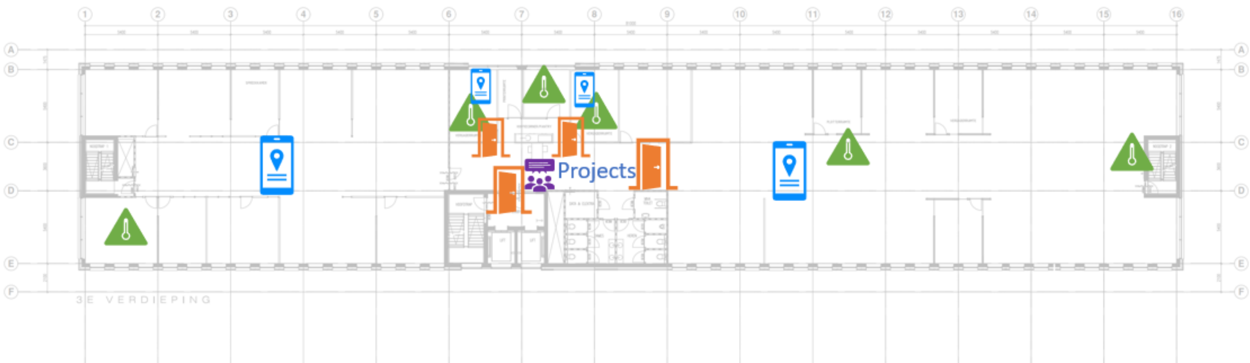
1ste



2de

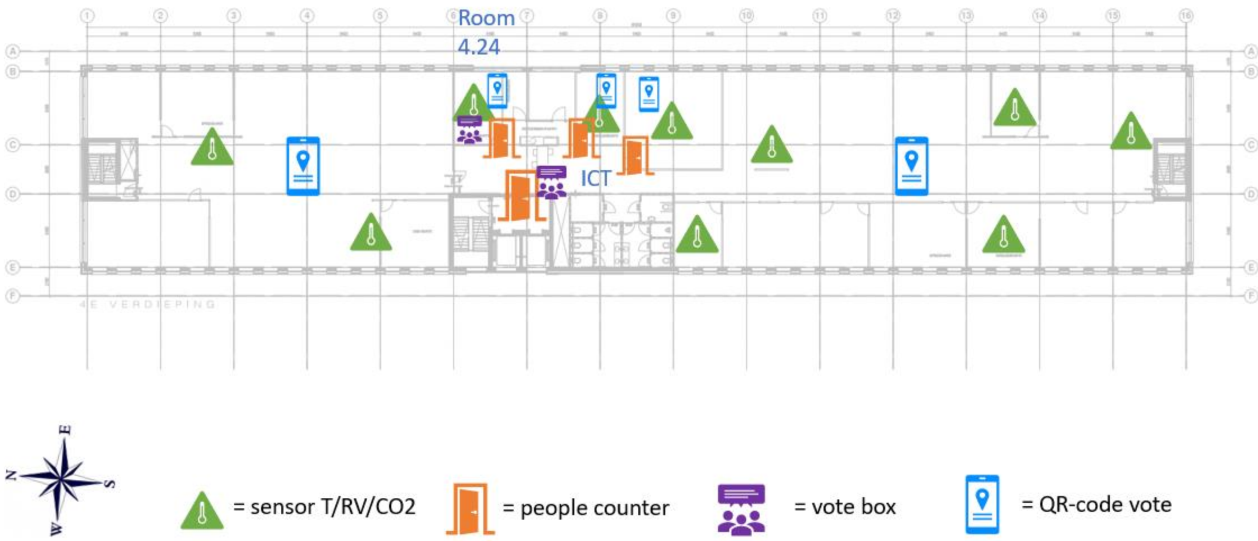
= sensor T/RV/CO2 = people counter = vote box = QR-code vote

3de



= sensor T/RV/CO2 = people counter = vote box = QR-code vote

4de


Room
4.24
ICT
4E VERDIEPING
N
E
S
W
= sensor T/RV/CO2
= people counter
= vote box
= QR-code vote

APPENDIX 3: QUESTIONNAIRE 7- AND 5-POINT SCALE