TESTING USER PERCEPTIONS OF RETROFITTED COVID-19 VENTILATION SYSTEMS IN NATURALLY VENTILATED SPACES

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Abstract

The outbreak of the COVID-19 viral pandemic in 2020 reopened the discussion about indoor air quality in educational buildings. This paper presents the results of a pilot study with the aim of evaluating the user perception of four different ventilation scenarios in the context of COVID-19 prophylaxis, including a mechanical extract system, recently developed by the Max Planck Institute, that can be easily retrofitted into naturally ventilated spaces. The findings of this pilot study highlight the importance of comprehensively assessing new ventilation strategies from a multi-factorial perspective and will inform a follow-up study in a nearby school on a much larger scale. The results helped us in re-shaping the approach and refining the survey. The initial findings indicate that local draughts, appliance noise and perceptions of risk can dominate the user's acceptance of such systems.

Introduction and concept

An important strategy in reducing the infection rate indoors was to find ways to reduce the airborne transmission of the SARS-CoV-2 virus. In addition to the use of masks, the benefits of using low-cost filtration methods and retrofitted fan-based ventilator systems to continuously extract aerosols from within naturally ventilated spaces became a focus of research. One of the first dedicated COVID-19 mechanical extract ventilation (MEV) concepts was designed by the Max-Plank-Institute for Chemistry, but has subsequently been adapted by other commercial suppliers (Klimach et al., 2021; Helleis et al., 2021). The German environment agency estimate that 90% of German schools are ventilated naturally by openable windows (Poetschke, 2020) and this approach remains commonplace in many European countries. An ongoing study conducted by the Munich University of Applied Sciences (based on 52 schools) has shown that less than 8% of naturally ventilated classrooms are aired regularly (i.e. every 20 minutes or less). Instead, most classrooms are only ventilated during the break periods (Schwarzbauer, 2021) . Similar findings have been documented in a study by the Swiss federal research agency EMPA, (EMPA, 2021) where analysis showed a clear correlation between poorly ventilated classrooms and an elevated risk of infection with COVID-19. Hence, the number of educational buildings with either inadequate mechanical ventilation systems or poor (or non-existent) natural ventilation strategies highlight the need for more efficient technical measures to improve indoor air quality.

At TU Graz four naturally ventilated spaces were retro-equipped with slightly different mechanical extract ventilation (MEV) based systems. This paper considers the effects on the wellbeing of the occupants and the possible discomfort caused by such retrofitted ventilation systems (i.e. issues caused by low air-temperatures during winter, fan noise, air velocity in relation to air quality). The aim of this research is to understand user perceptions of the Max Planck Institute for Chemistry (MPIC) MEV system in comparison to natural ventilation methods. The results of this research are important in the context of understanding the thermal comfort, air quality and user interaction associated with retrofitted COVID-19, building services systems. This research also demonstrated the importance of addressing thermal and acoustic comfort alongside good air quality during winter-time, highlighting the complexities encountered when attempting to address both issues in tandem. For optimal wellbeing and user acceptability outcomes, the research shows that building user surveys play a vital role in supporting building performance simulation methods when evaluating the full socio-technical impacts of such systems.

Methods

Post occupancy evaluation (POE) studies are a widely established means to gather detailed responses regarding user perceptions and experiences with buildings and building technologies (Li et al., 2018; Way and Bordass, 2007) . In this pilot-study a mixedmethods research design was deployed to gather subjective occupant feedback and compare it to objective physical parameters. A seven-point Likert scale was used as an ordinal ranking system to position the occupants' responses to individual questions regarding the indoor environmental quality (IEQ) in the space around a neutral reference point. The following sections describe the post occupancy study design; including the case study room, ventilation scenarios assessed, selection of occupants, occupant seating positioning, the post occupancy survey questionnaire and the physical parameters monitored.

Case study room and monitored data

The ventilation system examined in this study was developed by the MPIC (Klimach et al, 2021; Helleis et al., 2021) to minimize the risk of airborne transmission of the SARS-CoV-2 virus and to improve indoor air quality even after the pandemic (Figure 1). The system consists of an axial fan positioned in a window box housing an openable window. The stale indoor air (containing aerosolised contaminants) is removed from the room using extract hoods and ductwork connected to the fan. The extract hoods are positioned above the occupants desks to directly capture and remove respiratory aerosols as they rise on the warm air plume generated by the seated occupant (Bhagat et al., 2020). Ductwork consists of a main central duct (300mm diameter) from which smaller (90mm diameter) ducts branch off to the extract hoods (Figure 2).

The long-term objective of this study is to test the usability and end-user perceptions of various retrofit COVID-19 ventilation strategies within the school setting. However, prior to this, a pilot set up was designed in order to test the POE system using university students as the survey subjects. To test the thermal and acoustic comfort perceptions of the different ventilation strategies, we have chosen to use the seminar room in the institute for concrete construction (TU Graz), which has been equipped with an MPIC-MEV system and also has natural ventilation possibilities using openable windows (Figure 1). Four different ventilation scenarios were specified to evaluate the user's perceptions of the MPIC-MEV system in comparison to commonly used natural ventilation strategies.

- Scenario 1: Windows closed, system turned off (no ventilation)
- Scenario 2: Windows tilted, system turned off
- Scenario 3: One window tilted, MPIC-MEV system turned on
- Scenario 4: Windows open, system turned off

Figure 2 shows the room layout and the position of the principle components (fan, ducts, hoods, and openable windows) used in the MPIC-MEV system.

Participants and survey

A number of undergraduate and post graduate students in the TU Graz, School of Civil Engineering were asked to participate in trialling the initial POE survey in February 2022. In total 9 students participated in the study and the numbering on the tables in Figure 2 refers to the seating chart.

Figure 1: Max Planck Institute (MPIC)- Mechanical Extract Ventilation (MEV) system installed in a TU Graz seminar room

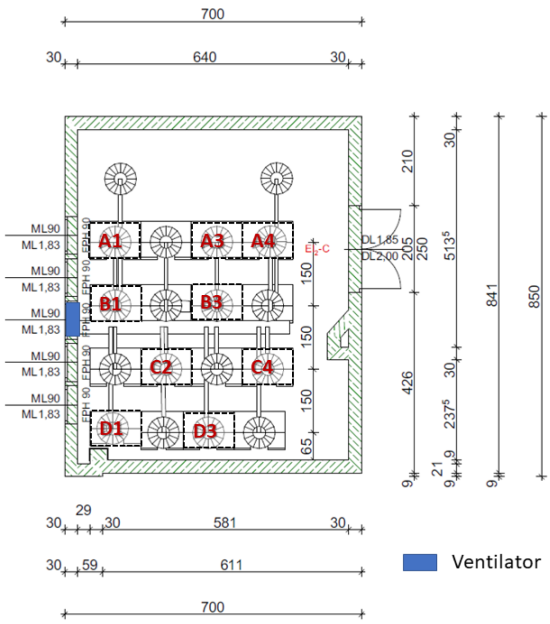

Figure 2: Room geometry, system layout and survey seating chart

The purpose of the survey is to investigate the thermal and acoustic comfort and perceptions of safety of room occupants when exposed to different ventilation strategies on a typical winter day. A comparison is made between different types of natural ventilation using continually closed (i.e. no ventilation), partially open (i.e. tilted windows) and intermittently fully open (i.e. purge ventilation) strategies. These natural ventilation strategies were then compared with the MPIC-MEV system, which extracts the stale air mechanically and uses a tilted window to continuously supply the fresh make-up air

(Figure 1). Prior to the survey the students were informed that all information provided by them in the online survey would be treated confidentially and in compliance with statutory data protection provisions in accordance with the European Data Protection Regulation (GDPR). To create a realistic classroom context for the research the pilot study was carried out ‘in-class’ immediately after a seminar involving student presentations using pre-prepared questionnaires. This is a common method of gathering feedback from students and takes around 5-10 minutes per scenario using anonymous feedback forms which were locationally coded to the individual’s position within the room (Figure 2). In the first part of the POE the questions were structured to identify specific issues with the ventilation modes, particularly in relation to IEQ. We added a 7-point ordinal ranking (Likert scale) with questions structured to address each aspect of the IEQ assessment: here we asked the students to rank their response to the different IEQ areas (i.e. perceptions of thermal comfort, draughts, lighting quality, acoustics, perceived infection risk, and their overall comfort).

Survey Questions:

1. How do you experience the room temperature with the current ventilation mode?
2. How would you prefer the temperature to be?
3. How do you experience the room air movement (i.e. draughts) with the current ventilation mode?
4. How would you prefer the air movement to be?
5. How do you experience the lighting in the room?
6. How do you find the room acoustics (background noise level in the room)?
7. In relation to COVID-19, how safe (in terms of infection risk) do you with the current ventilation mode?
8. How would you describe your overall comfort?

Scenario 3 included an additional question, i.e.

9. Overall, considering all the factors listed above – would you prefer to spend the day in the classroom with the ventilation system turned off or do you prefer it when the ventilation system is turned on?

In the second part of the feedback form, to capture additional qualitative information, we posed the following questions to the students using an unstructured (i.e. free-response) format:

1. Is there anything you would like to add that has not been discussed above in relation to your thermal comfort?
2. Is there anything you would like to add that has not been discussed above in relation to your acoustic comfort (or background noise)?
3. Is there anything you would like to add that has not been discussed above in relation to your perceptions of safety during the COVID-19 pandemic?

Finally, we asked the students to report on their clothing level and calculate their clo value based on a table of standard clo values provided to them.

Results

CO_2 and Temperature

The CO_2 and indoor temperature were measured using a pre-calibrated AirControl5000 monitoring device. The data recordings took place at 1-minute time intervals. The results during the pilot study across the four different scenarios, as well as the questionnaire response intervals following each scenario, are shown in Figures 3 and 4.

Room temperature

Scenario 1 (room temperature 20°C): Most people reported feeling thermally neutral (2,3,7,8), three felt slightly cold (4,5,6), one felt slightly warm (1) and one cool (9). In terms of how they would like to feel instead the majority (5 in total) responded slightly warmer (2,4,5,6,9). The candidate who felt slightly warm would have preferred to feel slightly cool (1). Persons 3,7, and 8 would prefer to continue feeling neutral. Scenario 2 (room temperature from 19 down to 15°C): The majority felt cool (2,4,5,6,9), three felt slightly cool (1,3,7). One felt cold (8). Equally, the majority (5 in total) would have preferred to feel warmer, four would have preferred to feel slightly warmer. Scenario 3 (room temperature from 15 down to 14°C): Five felt cool and four felt cold. Eight would have wanted to feel warmer, one would have wanted to feel slightly warmer. Scenario 4 (room temperature from 14 down to 11°C): All but one (who felt cool) reported feeling cold. 5 would have preferred warmer whilst four would have preferred much warmer. Moreover, 5 of the participants adjusted their clothing to increase their clo value during this scenario (Table 1).

Draughts

Scenario1: The majority reported almost no draught sensation in the room (5 out of 9). One reported a slight draught (8) and three felt neutral (3,4,7). Apart from one (2) who would have preferred a little more draught, all others reported that they would not want any changes. Scenario 2: The majority reported they felt neutral (2,3,6,9), two felt a weak draught (1,5), and two a somewhat strong draught (7,8), and one a strong draught (4). Scenario 3: Here the majority (6 out of 9) reported a somewhat strong draught. One person felt neutral (1), one reported a strong (4) and one a very strong draught (8). Four would have preferred somewhat less draught (2,3,5,7), four less draught (4,6,8,9) and one did not want the situation to change (1). Scenario 4: Three felt the draught very strongly (4,6,7), three strongly (2,5,9), two were neutral (1,3), and one reported a low draught (8). In terms of what they would like the draught level to be, two reported much less (4,6), another two said less (5,9), further two wished for somewhat less (2,8), two did not want the situation to change (1,3) and one wished for a much stronger draught (7).

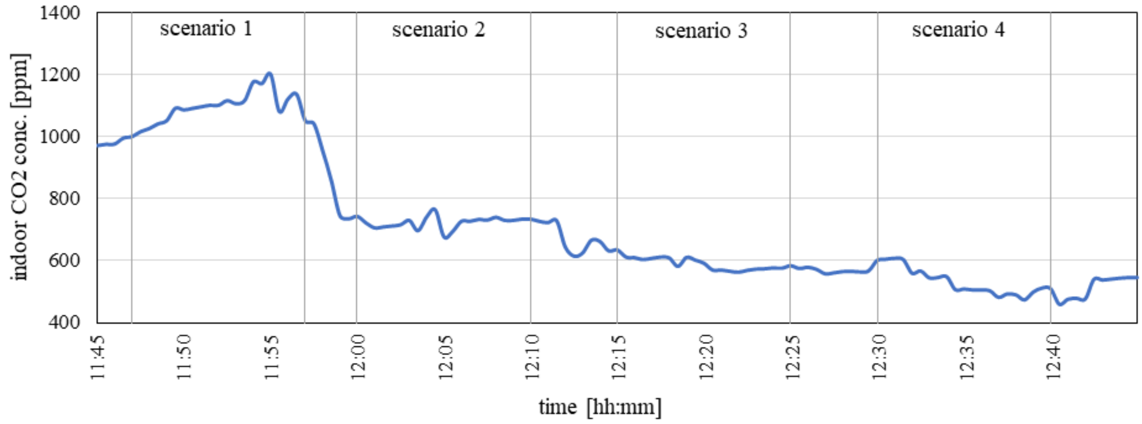

Figure 3: Monitored indoor CO2 concentration in the room during the four different scenarios

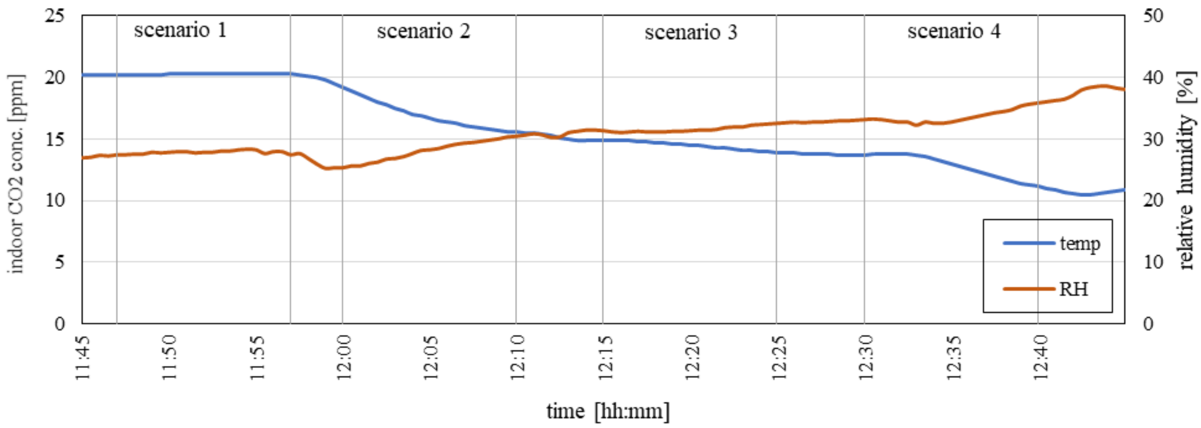

Figure 4: Monitored temperature and relative humidity in the room during the four different scenarios

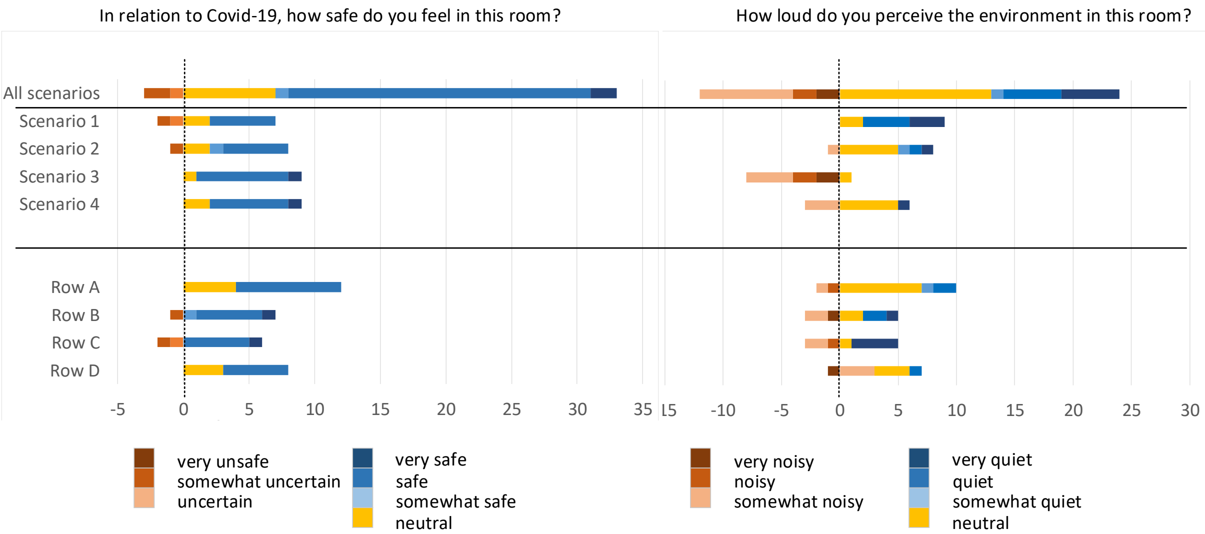

Figure 5: Monitored temperature and relative humidity in the room during the four different scenarios

Lighting

Four people reported the lighting situation as bright (4,7,8,9). Two felt neutral (1,2), one thought it was somewhat dark (3) and one felt it was very bright (6). The lighting perception remained constant in all scenarios apart from one person (4) who changed in scenario 2 from bright to somewhat bright.

Table 1: Clothing value

				clothing value scenarios			
Person	Seat	Age	Sex	1	2	3	4
1	A1	23	W	0.76	0.76	0.76	**1.24**
2	A3	25	M	0.66	0.66	0.66	0.66
3	A4	24	M	0.40	0.40	0.40	**0.68**
4	B1	27	M	0.66	0.66	0.66	**1.77**
5	B3	29	M	0.60	0.60	0.60	0.60
6	C2	25	M	0.70	0.70	0.70	**1.18**
7	C4	28	M	0.90	0.90	0.90	0.90
8	D1	30	M	0.36	0.36	0.36	0.36
9	D3	21	M	0.66	0.66	0.66	**0.90**

Background noise

Scenario 1: The majority (4/9) felt it was quiet (2,3,4,8), three reported it to be very quiet (5,6,7), and two remained neutral (1,8). Scenario 2: Five felt neutral (1,3,4,6,9), one very quiet (7), one quiet (5), one somewhat quiet (2), and one somewhat noisy. Scenario 3: Four felt it was somewhat noisy (1,5,7,9), two felt it was noisy (3,6), two very noisy (4,8) and one felt neutral (2). Scenario 4: Five felt neutral (1,2,3,5), three somewhat noisy (4,6,8) and one thought it was very quiet (7)

Perceived infection risk

Sceanrio1: The majority (5 in total) felt safe with scenario 1 two (3,9) felt neutral, one somewhat uncertain, and one uncertain. Scenario 2: As scenario 1, but one person who felt somewhat uncertain in scenario 1 now felt somewhat safe (5). Scenario 3: 7 out of 9 feel safe, one (7) feels very safe, and one (3) feels neutral. Scenario 4: 6 feel safe, one feels very safe (5), two feel neutral (3,9).

General wellbeing

Scenario 1: Four felt neutral (2,5,7,9), three somewhat cold (3,4,6), one somewhat warm (1) and one warm (8). Scenario 2: The majority felt somewhat cold (7/9), one felt cold (1) and one neutral (8). Scenario 3: The majority (7/9) felt cold, and two somewhat cold (2,7). Scenario 4: Five felt very cold (4,5,6,7,9) and four cold (1,2,3,8).

Summary

This is a preliminary pilot study designed to evaluate the suitability of the POE questionnaire, the scenarios chosen, and the variables measured in relation to the results obtained.

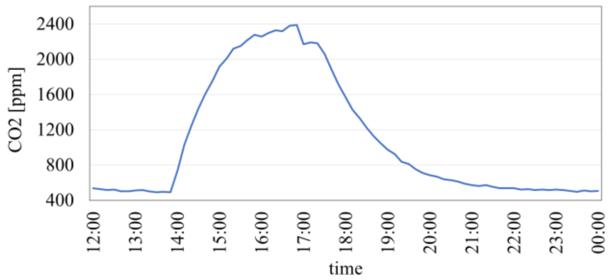

Figure 6: CO_2 values in seminar room exceeding 2300 ppm during a 2-hour exam

This is an important stage in the refinement of the study before commencing a larger scale study in local schools. Feedback from the participants indicated that there is some overlap between the questions asked with potential for the scenarios and questionnaire to further shortened. An important finding is that the order and spacing of the scenarios means that the preceding scenario is likely to be impacting on subsequent scenarios (e.g. by excessively cooling the room). To overcome this and retain independence between the scenarios the order of the scenarios may have to be reversed or randomised to avoid biasing the results.

Room temperature: The more the scenarios progressed the colder the participants reported feeling, which is in line with the temperature readings and the clo value modifications of some participants. Interestingly, despite most people feeling slightly cool or neutral to begin with and even with temperatures dropping significantly in scenarios 2 and 3, no one responded that they would like to feel “much warmer” (as opposed to the final scenario).

Draught: In scenario 1 (with no ventilation) 8/9 were content and did not want any changes. As soon as the windows were opened, the answers started to diverge strongly in both directions. As anticipated people felt a greater sensation of draught with the extract fan on, despite no additional windows being opened. With the windows fully open the perception of draught went in both directions, some felt it less, and some much more in comparison to the MPIC system being on. This might be due to local air currents in the room.

Lighting levels: Lighting levels did not change during the scenarios. The MPIC system remained in place even when it was turned off. This is shown by the relatively constant results apart from one person who changed their opinion during the tilted windows scenario slightly.

Sound: When all windows were closed the majority reported it to be quiet or even very quiet. This changed with opening the windows and people’s perception towards noise went up (in line with the ventilation rate). With the MPIC system running, two participants felt it was very noisy.

Perception of infection risk: The majority felt safe the whole time even when there was no ventilation in place whatsoever. Having the MPIC system running did not change the perception of safety in comparison to the fully opened windows, however three of nine felt safer with the MPIC system on compared to just having tilted windows. In Scenario 1, whilst the CO_2 levels were relatively high, only two felt somewhat uncertain and uncertain respectively, the majority felt safe throughout all scenarios. One person always feels neutral. Whilst one person reported feeling very safe with scenarios 3 and 4.

Key findings

- No relation was found in terms of seating position with respect to safety perceptions and noise. Rows B and C (middle rows) perceived the noise to be the loudest and felt the most uncertain with respect to COVID-19 infection risk
- Some participants did not fully understand the question about the clo-value and failed to include every item of clothing. The revised study requires a better explanation to ensure participants correctly identify every applicable piece of clothing.
- The thermal comfort and general well-being scores got lower with every scenario as the room temperature became progressively colder.
- Little to no difference was found regarding perceptions of infection risk. Respondents stated that the use of 2m social distancing and universal FFP3 masking provided sufficient safety.
- Most people reported reduced concentration in Scenario 3 and 4 relative to Scenarios 1 and 2.
- 8/9 people preferred the ventilation system turned off.

Final remarks

Further information about the ventilation efficacy and performance can be found in Pollozhani et al., (2022). Thermal and acoustic comfort appear to be the dominant issues influencing the acceptability of ventilation scenarios. Since the MPIC-MEV system was installed, a two-hour long exam was conducted in the room. Despite clearly displayed operational instructions, the room CO_2 concentration (Figure 6) indicated that no ventilation was used, with CO_2 values exceeding 2300 ppm. In a parallel study the infection risk including the energy consumption of different ventilation strategies was assessed and compared using simulation (Pollozhani et al, 2022). The response to this pilot POE study has shown that based on a small sample (n=9) university students, ventilation is unlikely to be used voluntarily in wintertime. This paper shows that building user surveys have a key role to play in supporting building performance simulation methods when evaluating the full socio-technical impacts of new systems.

Further work to enhance the POE methods used

- Sound pressure level (SPL) readings should be taken in the room for each scenario.
- The order of the scenarios and spacing between them should be structured to avoid undue influence from one scenario to the next.
- Applying these methods to a larger sample is planned to increase confidence in the results.

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