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Environmental preferences of occupants: A multi-domain approach in the Swiss open office case study

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Abstract. Defining indoor environmental conditions that meet the needs and preferences of occupants in open space offices can be challenging since the same space might be occupied by people with different individual needs and preferences regarding what constitutes a comfortable work environment. This study presents outcomes of a set of longitudinal point-in-time comfort surveys that were designed to capture instantaneous preference votes about momentary environmental conditions twice a day covering all four major domains of IEQ. The surveys were disseminated during two weeks across three seasons (fall, winter, summer) to 31 occupants in a Swiss open space office and supplemented with environmental data simultaneously measured in-situ at the occupant's desk level. These surveys (up to 670 responses per environmental domain) offered insights into the discrepancies of expressed environmental preferences with respect to measured environmental conditions in open space offices.

1. Introduction

The indoor environmental quality (IEQ) can significantly impact occupants' comfort, health, productivity, and engagement, in both positive and negative ways [1][2]. The comfort of employees at their work space typically denotes the ability of the environment to provide pleasant and stimulating physical working conditions for them to be productive. Office employees are exposed to a variety of environmental and contextual stimuli that might be perceived differently by individuals according to, for instance, their individual environmental expectations or preferences (related to the thermal, olfactory, visual, and aural environment), their individual physiologies, and the specific microclimatic conditions at their desks [3].

Several studies compared the effects of traditional vs open plan offices on different aspects of environmental design and behavior. They found that open offices with an increased proximity of co-workers are negatively related to workers' satisfaction with their physical environment and perceived productivity [4][5][6][7]. In particular, noise has often been reported as the most significant source of dissatisfaction in such situations [8][4]. Determining indoor environmental conditions that satisfy most occupants can become even more challenging in open space offices. While such types of working environments might present increased opportunities for collaboration and social interactions between employees, the variability of the indoor environment in the space and diverging preferences of occupants with limited personalized control can present a downside if not considered carefully during design and operation. For that reason, perceptions and preferences of employees shall be accounted for and linked to simultaneous environmental monitoring of the space to gain deeper insights into relationships between users' needs and what the environment they work in provides.

In this study, we present selected results of the eCOMBINE project ("Interaction between energy use, COMfort, Behaviour and the INdoor Environment in office buildings"), which relies on a mixed experimental approach that allows us to gain insights into occupant preference votes covering all four IEQ domains (thermal, IAQ, visual, acoustic) in relation to objective data collected at the desk level (environmental measurements). The investigation is based on data collected in one of the Swiss pilot case studies over the span of two weeks each across three different seasons.

2. Methodology

2.1. Case study

The studied open space office is located on the fifth floor of a six-story commercial building in Geneva, Switzerland. The studied space consists of two connected, open spaces facing South-West (96 m^2) and South-East (85 m^2), and a smaller shared office space exposed to South (61 m^2) (Figure 1).

The space is equipped with a mixed-mode ventilation system, but the mechanical ventilation system was not operating during fall and winter seasons. All occupants have access to freely operable windows and external shades within 5 meters from their working station. The office space is equipped with radiators for heating, but occupants do not have access to thermostat controls. The office space is equipped with dimmable and automatically controlled luminaires shared by two desks.

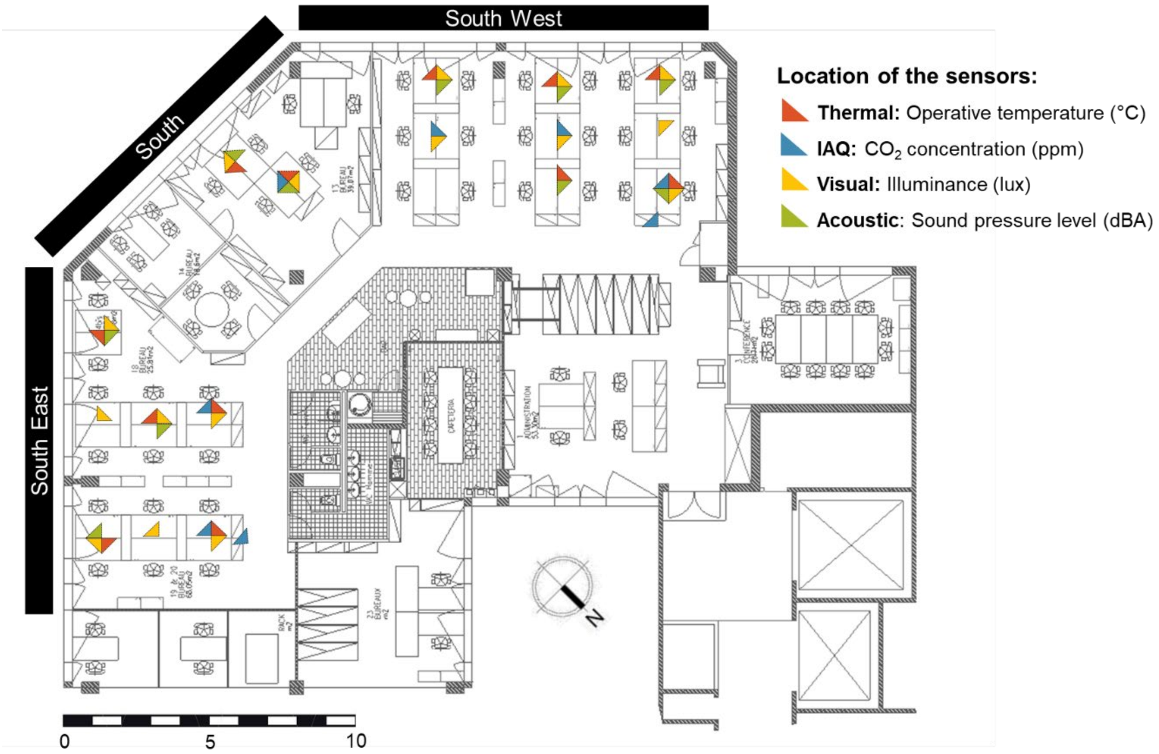

Figure 1. Floor plan of the open space office and the locations of experimental sensors

2.2. Subjective and objective data collection

Point-in-time comfort surveys were disseminated to 31 participants (65% male) twice per day (at 10 am and 3 pm, Monday-Friday) as an online survey over two weeks during fall (18.11-29.11.2019), winter

(17.02-28.02.2020), and summer (17.08-28.08.2020). Table 1 shows the selectable preference votes related to all four environmental dimensions.

Subjective feedback was supplemented with environmental data simultaneously measured in situ at the occupants' desk level. For this analysis, we included key parameters belonging to each environmental dimension: operative temperature, carbon dioxide levels, illuminance levels, and sound pressure levels (Table 1). The chosen environmental parameters are common performance indicators for the evaluation of environmental comfort [9]. The location of the sensors is shown in Figure 1. More details on the subjective and objective data collection strategies of the eCOMBINE project (e.g. details of instruments) can be found in Barthelmes et al. (2020)[10].

Table 1. Subjective and objective indicators for the four environmental dimensions (the subjective indicators were tied to the question: "You would prefer [colder / no change / warmer, e.g.]?") [10]

		THERMAL	**IAQ**	**VISUAL**	**ACOUSTIC**
SUBJECTIVE	**Preference**	**Temperature**	**Amount of fresh air**	**Lighting level**	**Noise level**
	Selectable votes	- colder - no change - warmer	- no change - fresher air	- less light - no change - more light	- less noise - no change - more noise
OBJECTIVE	**Variable (Unit)**	**Operative temperature (°C)**	**CO_2 concentration (ppm)**	**Illuminance (lux)**	**Equivalent sound level (LAeq)(dBA)**
	Type of sensor	Calculated*	Nondispersive infrared (NDIR) CO_2 logger	Photodiode sensor connected to a data logger	Integrating averaging sound level meter

** The operative temperature (T_{op}) is calculated as a function of air temperature (T_a) and mean radiant temperature (T_{mrt}) according to ISO 7726 Standard* [11]. *T_{mrt} is estimated as a function of the globe temperature (T_{gl}), measured with the grey-globe thermometer (d=40 mm), and air speed measured using omnidirectional anemometer.*

3. Findings and discussion

The environmental preference votes collected in the open space were plotted against the four environmental parameters for each season (Figure 2). The reported measurements for each preference vote refer to the measuring point of the closest sensor to each responding occupant and to the closest timestep (5 minutes) before the reported preference vote. The respondents were asked to ignore the survey in case they were not sitting at their work station. We excluded responses from two occupants of the reception since no thermal or IAQ data was collected in this area.

3.1. Preferences over the perceived temperature:

During fall, we received 283 thermal preference votes from 28 subjects, out of which 7% were "warmer" votes, 80% "no change" votes, and 13% "colder" votes. The median operative temperature measurements corresponding to "warmer", "no change", and "colder" votes were equal to 24.1°C, 24.4°C, and 24.9°C, respectively. During winter, we received 247 preference votes from 26 subjects in total, of which 4% "warmer" votes, 84% "no change" votes, and 11% "colder" votes. The median operative temperature corresponding to "warmer", "no change", and "colder" votes had more deviation with respect to fall, corresponding to 24.1°C, 24.6°C, and 25.6°C, respectively. In both seasons, a clear trend towards an increasing number of "colder" votes can be observed when operative temperature values exceed 24°C in fall and winter. The overlapping of temperature ranges related to "no change", "warmer", and "colder" votes shows a significant variability of thermal preference votes at similar operative temperature values. However, votes between the upper quartile of "warmer" votes and the lower quartile of "colder" votes fall within the range of 24.5 – 24.9 °C in winter. Hence, this range might be considered coming closest to the "neutral" state in which most of the occupants did not prefer the environment to be warmer or cooler.

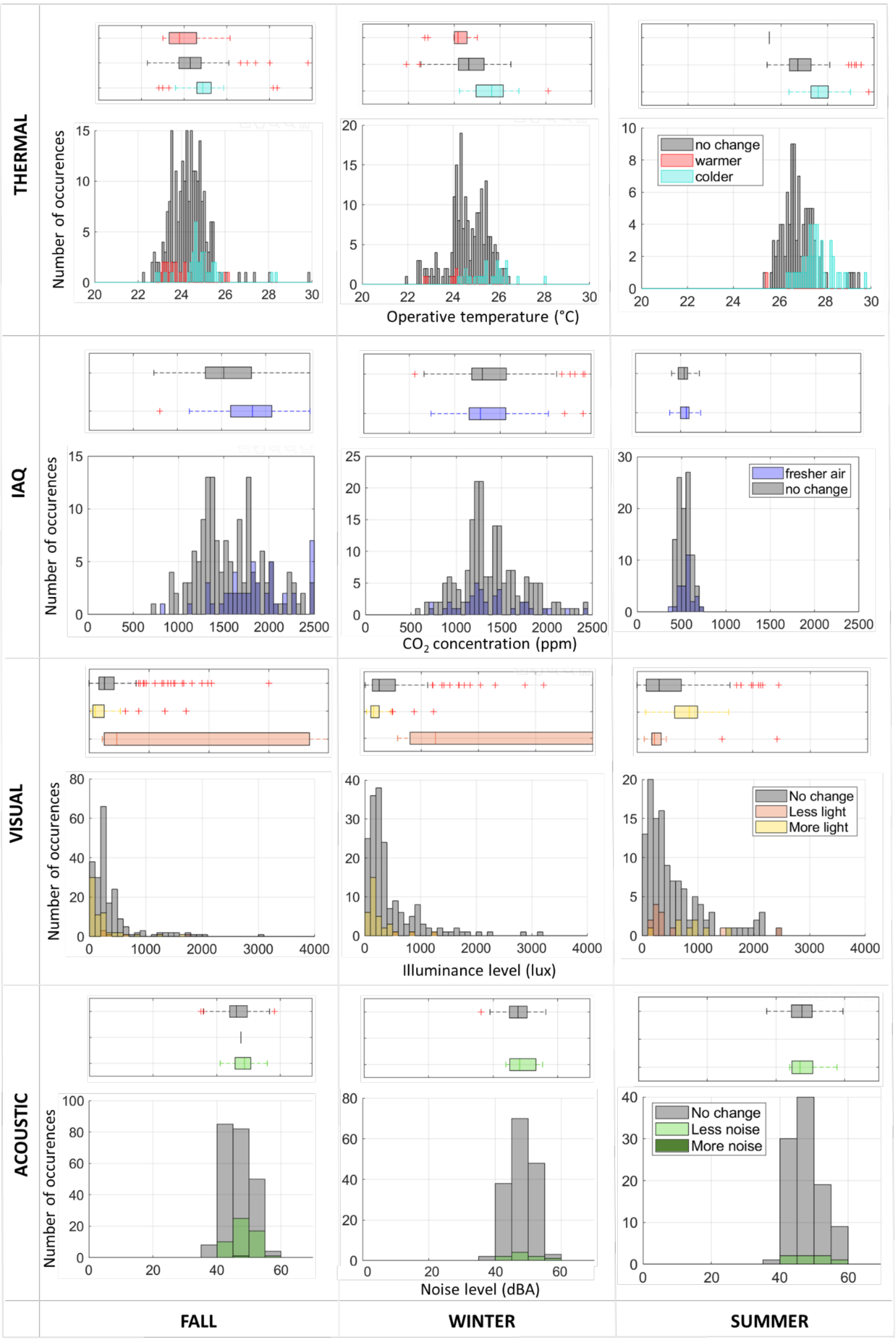

Figure 2. Preference votes and environmental measurements during fall, winter, and summer season

This "neutral" range in winter is in line with EN 16798-1:2019 Category I ($T_{op,lim,Cat\ I}$: 24.4-25.6, considering average boundary conditions in the case study for all responses during winter: air speed = 0.06 m/s, relative humidity=40%, MET=1.1, I_{clo}=0.6)[12]. During summer, we received 140 votes from 17 subjects, out of which there was only one "warmer" vote (1%), 70% "no change" votes, and 29% "colder" votes. The median operative temperature corresponding to "no change", and "colder" votes were equal to 26.7°C and 27.6°C, respectively. During summer, thermal preference votes were, therefore, more concordant between different occupants with respect to the heating seasons.

3.2. Preferences over the perceived amount of fresh air:

The preferences of the participants remained similar during fall, winter, and summer for "fresher air" (18-24%) and "no change" (76-82%). During fall, 197 votes from 20 participants were linked to CO_2 values. The median CO_2 concentration during these periods was 1300 ppm when the participants preferred "no change" and 1500 ppm for "fresher air". These values are above the recommended maximum limits of 700 ppm above outdoor air levels [13]. In winter, 224 votes from 24 participants were associated with the corresponding CO_2 measurements. The median CO_2 levels were 1250 ppm during "fresher air" and "no change". In summer, 132 of the votes corresponding to 17 participants were collected. Due to the use of mechanical ventilation, the median CO_2 levels were below the standard limits with 540 ppm for "no change" and 560 ppm for "fresher air". The results show a similar trend on the percentage of votes across the seasons where most voters preferred no change in the air quality even when the CO_2 levels were above the recommended limits. The majority of the votes for "fresher air" during fall were above 1000 ppm, however, during winter and summer, the votes for "fresher air" were below this limit. The results agree with previous studies where the perception of air quality of the participants only changed slightly during high and low air pollutant concentrations [14]. This paper presents measurements for CO_2 as an indicator of indoor air quality, however, other air pollutants with different dynamics may still affect the participants' perception of the air quality.

3.3. Preferences over the perceived illuminance level:

The light levels recorded during fall and winter were, as expected, substantially lower than during summer due to increased daylight penetration. The overall illuminance at the times of the surveys remained rather dim despite the South and West orientations during a significant amount of time (below 150 lux for 30% of the time in the Fall, 27% in Winter and 23% in Summer). The frequent usage of the blinds and the depth of the offices (3 lines of desks) can explain this tendency. Overall, occupants reported comfort with lighting conditions during 74% of the time for a very wide range of illuminance levels (between 74 lux for the 5th percentile and 1,586 lux for the 95th percentile). In the fall, 53% of the occupants reported visual comfort for illuminance levels below 100 lux compared to 77% of the occupants between 100 and 300 lux. These figures increase to 74% and 74% during winter and to 76% and 77% during summer. Overall, responses indicate comfort for 71% of the occupants below 300 lux. This percentage increases to 74% if we add to it the responses for 'slight discomfort with no change' below 300 lux. Overall, these values are in line with the literature, as for instance in Wienold (2010) [15], where 75% of the occupants were either satisfied or somewhat satisfied with lighting levels below 300 lux.

During the summer we observed that occupants wished less light for lower light levels (below 315 lux) (5 responses (from 4 occupants) out of 8 responses in total). The opposite observation could be made for bright conditions (above 650 lux) where occupant wished more light (6 responses (from 2 occupants) out of 18 responses in total). We explain these responses by personal preference, which are again in line with the literature (at levels of 750-1500 lux, 19% of the occupants voted that light levels were too low in Wienold (2010) [15]. The wish for slightly brighter conditions during summer time, when outdoor conditions are typically bright, could also be motivated by an adaptive biais.

3.4. Preferences over the perceived acoustic level:

Only one person expressed a "more noise" preference vote during fall (48.4 dBA). The majority of responses were "no change" (79%), corresponding to an average of 46.9 dBA, while "less noise" preference votes (21%) corresponded to an average sound pressure level of 47.6 dBA. During winter

15% of the preference votes were "less noise" and 85% were "no change". The average sound pressure levels were 49 dBA and 47.6 dBA, respectively. During summer, only 5% of the preference votes were "less noise" ($LA_{eq,av}$ = 48.6 dBA) showing that occupant were more satisfied with their acoustic environment during this season. Since there are no significant discrepancies between average measured sound pressure levels for the different preference votes, we conclude that some of the occupants perceive the noise more disturbing than others, but – based on this specific data - it was not possible to identify specific thresholds or trends of sound pressure levels linked to specific acoustic preferences.

4. Conclusion

In this study, occupants' preference votes were collected twice per day for two weeks during three different seasons in a Swiss open space office covering all four major domains of IEQ. The preference votes were compared to key IEQ parameters related to the thermal, visual, IAQ, and acoustic environment. The outcomes showed significant discrepancies between preference votes at similar thermal environmental conditions, especially during the heating season. Due to the use of mechanical ventilation, CO_2 concentrations fluctuated considerably during the seasons between high concentrations in fall and winter and below the standard limits during summer. However, the percentage of no change votes related to air freshness remained similar across the seasons (approximately 80%), suggesting that occupants did not perceive (or were forgiving with) CO_2 concentrations levels above recommended limits. The results pertaining to visual comfort showed a wide range of experienced illuminance values, which is typically expected for South and West facing offices over time. Occupant responses indicate comfort for low illuminance levels (in lux levels below 300 lux, 74% of the votes indicate "comfort" or "slight discomfort with no change"). Although occupants expressed different preferences over the acoustic environment, the latter was not clearly reflected by any specific trends in the acoustic data. Further investigations will include the spatial and temporal variability of the expressed preference votes in relation to environmental measurements, as well as correlation analysis between domains of IEQ.

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