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The Impact of Personal and Contextual Factors on Multi-domain Subjective Comfort Responses in Classrooms

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ABSTRACT

Subjective assessment of the indoor environmental quality (IEQ) and multi-domain comfort depends on environmental parameters as well as on contextual and individual characteristics. The latter is even more important in educational buildings, where students share the same space, affecting their comfort and response in multiple domains. This work presents the impact of personal (i.e., gender, clothing level, body mass index, age, use of glasses) and contextual (i.e., sitting position inside the classroom and orientation/outdoor view) factors on the students' sensation votes (thermal/air quality/visual/acoustic) collected in 50 classrooms (825 questionnaires) during regular lectures. First, we identified which environmental variables were significantly correlated to sensation votes in each of the four domains and studied the role of personal/contextual factors on cross-domain interactions through multi-linear regression. Then, the impact of categorized levels of personal/contextual factors on sensation votes was studied through covariance analysis and post-hoc tests. This analysis determined which of these factors would enable different responses when exposed to the same environmental conditions. The results showed that gender and age affect multi-domain sensation votes, while body mass index and clothing level affect thermal sensation. Males have a larger sensitivity to environmental conditions in the thermal and IAQ domains. Clothing adaptation varies depending on gender, sitting position and body mass index. Younger students express higher thermal sensation votes and are more sensitive to noisy environments. In addition, sitting distance from windows affects thermal, IAQ, and visual sensation.

INTRODUCTION

Indoor environments expose occupants to a combination of stimuli, which are classified according to mainstream literature as thermal, visual, acoustic, and air quality conditions (Wu el al. 2020). By extending the definition of thermal

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comfort (CEN 2005) to a multi domain approach, it can be defined as “that state of mind that expresses satisfaction with the environment”. Not only comfort is the condition that enables occupants to perform their tasks in the most convenient conditions - it has been long established that inappropriate conditions affect learning performance and concentration (Zhang et al. 2019; Barrett et al. 2015) – but it is also a driver for users’ interaction with the building envelope and the building systems, affecting thus the energy performance of buildings.

With specific reference to classrooms, multi domain comfort studies approach either individual comfort domains, a combination of a few of them, or the four comfort domains at once. The thermal perception of students is correlated with indoor air temperature, relative humidity, operative temperature, air velocity (Fanger 1970; Teli et al. 2012; Mors et al. 2011; de Dear et al. 2015; de Dear and Kim 2018). Air quality is in most cases assessed through the measurement of CO_2 concentration (Korsavi et al. 2020; Shendell et al. 2004; Toftum and Clausen 2023), while lighting conditions mostly relate to illuminance level and colour temperature (Ricciardi and Buratti 2018; Castilla et al. 2018). Acoustic perception inside the classrooms relates to sound pressure level (Ricciardi and Buratti 2018; Klatte et al. 2010). Room acoustic criteria, such as reverberation time and clarity, are not considered as physical variables as they are “constant” features of a classroom, depending on materials acoustic characteristics and room geometry, in the same manner as reflectance and other optical properties of surfaces affect the luminance distribution in the visual domain. Few cross domains interactions were identified in the literature: when students are exposed to high indoor air temperature and operative temperature, the rating of air freshness is lower compared to lower temperature conditions (Korsavi et al. 2020, Zhang et al. 2023). Illuminance level was found to affect students’ thermal sensation (Pittana et al. 2023), while exposure to higher sound pressure level was found to have a negative effect on thermal response (Yang and Moon 2018; Huang et al. 2012).

In shared spaces, interpersonal variability of subjects emerges that relate to physiological, psychological and behavioural features. Moreover, the spatial variability of the environmental conditions might scatter subjective evaluations, with a possible mediation related to expectations. The knowledge of the effect of such personal and contextual factors is of paramount importance as (i) they allow to gain insight into sensitivities of different groups of subjects, (ii) which in turn allow to tailor control strategies on specific segments of occupants, and (iii) improve the reproducibility across studies.

Literature reviews identified personal and contextual factors that should be recorded when running comfort studies (Frontczak and Wargocki 2011; Schweiker et al. 2020). With specific reference to classrooms, personal factors include age (Li et al. 2022; Torriani et al. 2023; Kang et al. 2017; Thapa 2019), gender (Li et al. 2020; Kang et al. 2017; Jowkar et al. 2020; Yang et al. 2013; Nico et al. 2015; Zhang and de Dear 2019; Thapa 2019), Body Mass Index (Li et al. 2020; Rupp et al. 2018; Rupp and Ghisi 2017; Thapa 2019), well as individual features such as clothing level (Jowkar et al. 2020; Rupp and Ghisi 2017; Nico et al. 2015; Choi et al. 2010) as well as psychological and socio-cultural aspects which fall out of the scope of the present study. Contextual factors include classroom layout (Makaremi et al. 2024), proximity to windows (Li et al. 2022; Yang et al. 2013; Bortolini and Forcada 2021), view to the outside (Makaremi et al. 2024), type of building system (Bortolini and Forcada, 2021; Zhang and de Dear 2019) and occupant density (Chatzidiakou et a. 2015; Liu et al. 2019). The outcomes of the studies reported above are diverse and often contrasting, as discussed in Morandi et al. (2025). Most of the studies tackle one or a few domains at a time, furthermore, the use of different scales, psychological continua, and the adoption of different data collection and processing strategies make it difficult to generalize findings.

The aim of this study is to investigate the effects of a selection of personal and contextual factors in the framework of a multi domain field study in naturally ventilated classrooms.

METHOD

The study is based on the analysis of objective and subjective data collected in a high school located in a rural context in the province of Rome, Italy. The school is a naturally ventilated building inaugurated in 1992 and further expdanded in 2002. Typical classrooms have a surface area of 50 m^2, a height of 3 m, and three two-sash windows, which are oriented either S/SE (facing the school’s parking lot) or towards N/NW (countryside).

Data Collection

Field surveys on multi-domain comfort were conducted during 50 regular classes in the morning. The environmental conditions shown in Table 1, pertaining to the four comfort domains, were monitored with a time step of 1 minute and averaged on the observation time of interest.

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Table 1. Environmental Monitoring

Domain	Physical Quantities Measured	Measurement System
Thermal	Air temperature, Relative Humidity, Air Velocity, Mean Radiant Temperature	DeltaOhm HD32.1 climate station located in the middle of the classroom
IAQ	CO_2 concentration, TVOC	Graywolf Wolfpack with IQ-610 probe positioned on the teacher's desk
Visual	Horizontal illuminance	Konika Minolta T-10A luxmeter, data recorded at each desk
Acoustic	A-weighted equivalent sound pressure level	B&K 2270 sound level meter located in the middle of the classroom

After at least 30 minutes of lecture, questionnaires were administered to students. Students were informed about the purpose of the study as these activities were part of a wider project of alternance training.A first part of the questionnaire collected information specific to the individuals (age, weight, gender identity, first language, clothing level, activity carried out during the previous hour, self-reported visual/hearing/olfactive impairments, position inside the classroom, self-evaluation of health and alertness). Moreover, the subjective response related to sensation in the four domains was collected inquyring about the following attributes and scales:

- Thermal sensation | from -3 (cold) to +3 (hot)
- IAQ sensation | from 0 (fresh) to +3 (very stuffy)
- Visual sensation | from -3 (very dark) to +3 (very bright)
- Acoustic sensation | from 0 (quiet) to +3 (very noisy)

The psychological continuum chosen for the present analysis is "sensation", regarded as the attribute which is most closely related to the perception (Chinazzo et al. 2019). A total of 825 questionnaires were collected and analysed in the present study.

Additional information regarding the condition of the classroom (state of door, windows, shades, lights, number of occupants, sky coverage and more) was reported by the researchers who distributed the questionnaires. Among all data collected, a subset of factors was selected for use in the present study. The choice privileged factors that had a sufficient degree of variability in terms of distribution of values and that had a significant number of observations with each of the environmental conditions tested. In detail, the personal factors investigated included gender identity (GEN), age, BMI, clothing level (CLO), use of glasses (GLA). Contextual factors included window-relative sitting position (POS win) and blackboard-relative sitting position (POS black). Whenever the factor was a categorical variable (e.g., gender), it was used as is to determine groups. When factors were continuous variables (e.g., BMI), further clustering was required to be able to assign a label to each group and perform covariance analysis. BMI was discretized in three categories: underweight ($\leq$ 18.5 kg/m^2), normal weight (18.5 to 24.9 kg/m^2) and overweight ($>$ 25 kg/m^2). Clothing level was discretized in two groups, namely lighter ($\leq$ 0.75 clo) and heavier ($>$ 0.75 clo). Age was clustered in three groups: younger ($\leq$ 15 years), mid (16-17 years) and older ($\geq$ 18 years). Finally, sitting position inside the classroom was categorized based on the proximity of each desk either to the window or to the blackboard. Window-relative position was discretized into three levels: desks located within 1.5 m from the window (near), desks located within 1.5 m from the opposite wall (far), and desks in the central region of the classroom (center). Likewise, blackboard-relative position was classified into desks within 3.0 m from the blackboard (near), desks located within 1.5 m from the opposite wall (far), and the positions in between (center).

Data Processing

The monitored environmental conditions were used as independent variables to fit multi linear regression models in which thermal, IAQ, acoustic, and visual sensation votes – analyzed independently – were dependent variables. Starting from a regression with 8 independent variables (see Table 1), variables that were not significant were progressively excluded from the analysis until only significant independent variables were identified (Figure 1a). Then, environmental conditions were binned (Figure 1b) and votes expressed by subjects within each bin were clustered. Within each bin, sensation votes were further grouped based on the personal/contextual factor grouping criteria (Figure 1c). Votes falling within each bin and grouped by factors were then averaged and regression between environmental conditions and subjective votes were tested for significance (Figure 1d). Finally, covariance analysis followed by post-hoc tests was performed to check whether the

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regressions identified for each group were statistically different, either in slope or in intercept. A significance level of 5% was assumed for all the analyses presented in this work.

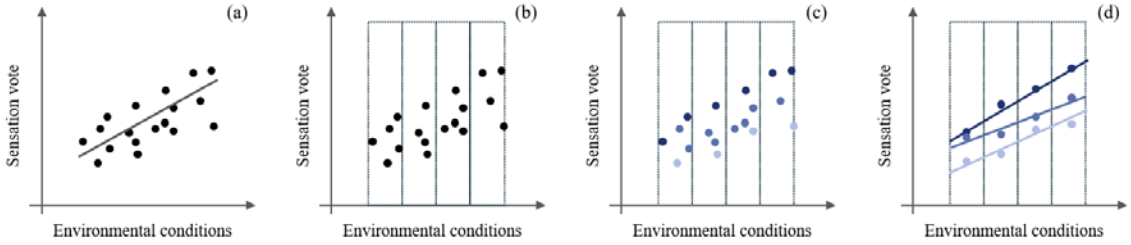

Figure 1 Methodology overview. (a) Multi-linear regression analysis, (b) binning of environmental conditions, (c) clustering of votes based on factors, (d) regression analysis between groups.

RESULTS

The methodology illustrated above led to two main results: one related to the outcome of the multilinear regression analysis and one related to the impact of personal and contextual factors on the expression of sensation votes. In the following, the two results are presented in separated subsections.

Multi-linear regression analysis

The multilinear regression analysis allowed to detect the strongest predictors related to the expression of thermal, IAQ, acoustic and visual sensation, providing information about the sensitivity of groups of subjects (classrooms) to variation of stimuli, and identifying potential cross modal effects. For all domains, linear models were used to fit sensation votes to environmental conditions. On the one hand, such simple models displayed a satisfactory explained variance. On the other hand, using the same regression models for all variables allowed straightforward comparison of the results. Details about the individual domains follow.

Thermal sensation. The multilinear regression analysis performed on thermal sensation as dependent variable identified air temperature as the only significant independent variable. Indoor air temperature ranged from 19.5 to 24.4 °C and was binned using 0.6 °C intervals. Regression analysis showed that a unit variation of temperature causes a variation of 0.26 of mean sensation vote.

IAQ sensation. The multilinear regression for IAQ sensation identified two significant independent variables: air temperature and CO_2 concentration. The two variables were tested for collinearity; the variance inflation factor equaled 1.4, indicating the absence of such a condition. Using a multilinear regression model with two independent variables would mean to bin an interaction between two physical variables, approach that would not be meaningful for the scope of the present work. Therefore, the regression of IAQ sensation vote on air temperature and CO_2 concentration were analyzed separately. In here, only correlations relative to CO_2 concentration are reported for the sake of brevity. The CO_2 concentration measured in the monitored classrooms ranges from 411 to 1464 ppm and was binned in 200 ppm intervals. Regression analysis showed that a variation of 1000 ppm would lead to a variation of 0.38 of mean sensation vote.

Acoustic sensation. The progressive exclusion of non-significant variables identified the sound pressure level as the only independent variable correlated with acoustic sensation votes. The A-weighted equivalent sound pressure level in the monitored classroom ranged from 57.1 to 75.9 dBA and a 2 dB binning interval was chosen for the present analysis. An increase in 10 dB of sound pressure level returns a variation of 0.70 of mean sensation votes.

Visual sensation. Visual sensation was significantly predicted by horizontal illuminance measured on each desk and averaged within each classroom. Measured illuminance ranged from 75 to 1283 lx and binning intervals were chosen in accordance with EN ISO 12464-1 (CEN 2011). The progressive increase in bin width impacted on the regressions and their quality, calling for a careful evaluation of the results. In the analysis presented here, a variation of 1000 lx in horizontal

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illuminance causes an increase of 1.4 of mean sensation votes.

Factors impact analysis

The analysis on the factors and their levels allowed to assess which factors impact on sensation votes when subjects are exposed to the same environmental conditions. The results of the multiple comparison analysis for all four domains are presented in a summarized form in Table 2. Regression pairs might differ in slope, indicating a different sensitivity of the groups to the environmental conditions, or have similar slope but significantly different intercepts, indicating an offset in the expression of votes. To provide further insight into these features, Table 2 reports a star (*) for correlations that have significantly different slopes (p-value < 0.05) and a double star (**) for correlations that do not differ in slope but differ in intercept. Correlations that do not differ in either of the two are marked as "NS" while the once that were not tested are filled in grey. For the visual domain, the blackboard-relative position returned non-significant correlations between illuminance and sensation votes for the "near" group: it was not possible to further analyze differences between groups, and these conditions were marked with a minus sign (-). For the sake of brevity, in this paper results are discussed in detail as the thermal domain is concerned, while a full discussion of the results on the four domains can be found in Morandi et al. (2025).

Table 2. Results of the Regression Analysis for Personal and Contextual Factors

Factor	Group A	Group B	Thermal	IAQ	Acoustic	Visual
GEN	M	F	*	*	*	**
AGE	Younger	Mid	*	*	*	*
	Younger	Older	*	**	*	*
	Mid	Older	*	*	*	*
BMI	Under	Normal	*			
	Under	Over	**			
	Normal	Over	*			
CLO	Lighter	Heavier	*			
GLA	Without	With				NS
POS win	Near	Center	*	*	NS	**
	Near	Far	*	*	NS	*
	Center	Far	*	*	NS	**
POS black	Near	Center			*	-
	Near	Far			NS	-
	Center	Far			*	*

Thermal sensation. All factors investigated for thermal sensation display significant differences between the groups. An overview of the regression analysis is presented in Figure 2 for the five factors analyzed. The size of the bubbles is proportional to the number of observations within each category, and regressions are weighted by the sample size. Among the most interesting results, subjects with lower BMI score lower sensation votes compared to subjects with higher BMI. Clothing level impacts sensation votes as subjects with lower clothing level score higher sensation votes than subjects with lower clothing level, possibly indicating that clothing level as an adaptation measure is not sufficient to counteract for uncomfortable thermal conditions. Males express higher sensation votes compared to female subjects, while younger students rate lower sensation votes compared to older ones. Finally, subjects sitting close to windows returned lower sensitivity (i.e., smaller slope) to air temperature variations compared to subjects sitting far away from the windows.

IAQ sensation. The personal and contextual factors investigated for IAQ sensation display significant difference between the groups, either in slope or in intercept. Males reported higher sensation votes compared to females and a slightly higher sensitivity (larger slope), while also in this domain younger students reported lower sensation votes compared to older ones. Significant differences were found also for sitting position inside the classroom, where subjects sitting close to windows had a larger sensitivity to variation of CO_2 concentration compared to other subjects.

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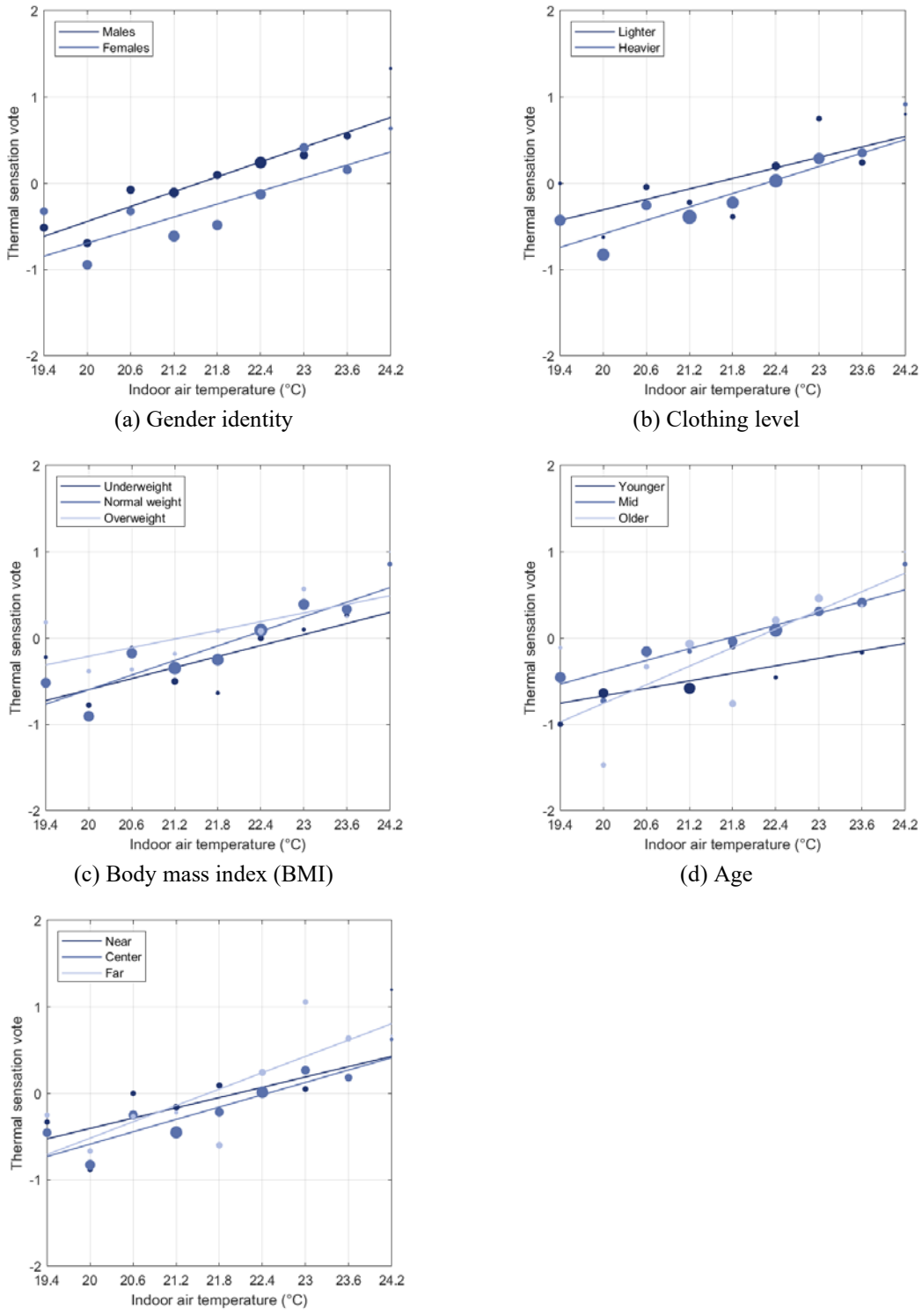

Figure 2 Personal and contextual factors affecting thermal sensation: effects of gender identity (a), clothing level (b), BMI (c), age (d) and window-relative sitting position (e).

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Acoustic sensation. Sensitivity of males and females strongly differ, as females express lower sensation votes compared to males below approximately 67 dBA, while above that threshold, males express lower sensation votes. This result might suffer from interpolation biases, as at lower sound pression levels the sensation votes tend to flatten. Younger subjects exhibit higher sensitivity to noise compared to older ones, while differences in sensation votes between groups discriminated by sitting position are not significant.

Visual sensation. Males express slightly lower sensation votes compared to females, whereas subjects wearing glasses or contact lenses do not differ from subjects who do not, relative to the expression of sensation votes. Subjects sitting close to windows express lower sensation votes, while proximity to the blackboard could not be evaluated as the correlation for the group sitting near the blackboard was not significant.

DISCUSSION

The multi-linear regression analysis showed that, for each domain, the main environmental variable is a significant predictor of sensation. Thermal sensation is predicted by temperature, acoustic sensation by sound pressure level, and visual sensation by horizontal illuminance. The only exception is represented by indoor air quality, as IAQ sensation is significantly correlated with air temperature and CO_2 concentration, identifying thus a cross-modal effect.

The personal factors analysed determine significant differences concerning the expression of sensation votes in all the domains analysed. As gender is concerned, the findings discussed in the results related to thermal sensation agree with previous works carried out in classrooms (Nico et al. 2015; Mishra et al. 2017), with lower sensation votes expressed by females. Similar considerations hold for the visual domain (Yang et al. 2013). The findings of this study differ from the ones in (Yang et al. 2013) as acoustics and indoor air quality are concerned; no impact of gender identity was found on IAQ satisfaction, while trends for acoustic comfort are inverted. It should be stressed that the perceptual attribute investigated in this study is sensation, while in other studies comfort and satisfaction are analysed. This might bring significant differences to the results. Body mass index and clothing level affect the expression of sensation votes, as agreed in the literature (Li et al. 2022; Rupp et al. 2018; Rupp and Ghisi 2017). While in the present analysis all factors were considered as independent, the clothing level might be affected in turn by the gender, the BMI and the age of the students. This point should be further investigated. Finally, age groups report different sensation results in the four domains analysed, in agreement with (Torriani et al. 2023) as the thermal domain is concerned, and with (Li et al. 2022) as acoustics is concerned. It should be stressed that grouping by age, for the narrow sample analysed, might not allow to generalize findings.

The contextual factors analysed here relate to the sitting position of students inside the classroom. Previous literature showed that sitting position may influence subjective thermal and acoustic comfort responses (Li et al. 2022) as well as IAQ and visual comfort (Kang et al., 2017). The sitting position in this study was analysed as a factor affecting subjective sensation, since position might expose subjects to different local environmental conditions, as well as other factors which are not considered directly in the analysis (e.g., proximity to direct solar radiation or psychological biases related to expectations, e.g. when sitting close to the window or far away from the teacher).

CONCLUSION

Evaluating the impact of personal and contextual factors on sensation votes is crucial during field campaigns, to ensure reproducibility of multi-domain comfort studies. In this study, an experimental campaign was carried out to collect environmental conditions and subjective votes regarding sensation expressed in the four domains of comfort. A multilinear regression analysis allowed to identify significant variables for each sensation attribute (air temperature for thermal sensation, horizontal illuminance for visual sensation and sound pressure level for acoustic sensation), while a cross-domain effect was found for IAQ sensation, for which both air temperature and CO_2 cocnentration are significant predictors. As personal factors are concerned, groups based on age and gender identity led to significantly different results across all domains, while BMI and clothing level were found to impact on sensation votes in the thermal domain. The effect of the use of glasses was not significant for the visual domain in the present study. As contextual factors are concerned, window-relative sitting position determined significant difference in the expression of sensation votes for the thermal, IAQ and acoustic domain, while blackboard-relative position was non-significant for the domains tested. Further work will consider the interaction between factors in a wider framework and evaluate the effect that personal and contextual factors have on the expression of preference votes.

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