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MULTI-DOMAIN SENSATION OF CHILDREN AT PRIMARY SCHOOL: A CASE STUDY

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ABSTRACT

Students' well-being is influenced by the Indoor Environmental Quality (IEQ) of classrooms. Poor IEQ, particularly inadequate acoustic conditions, can negatively affect students' learning performance and comfort. This study aims to identify indoor environmental conditions that promote students' multi-domain comfort in classrooms. Field campaigns were conducted in various primary schools in Northeast Italy, where physical parameters related to the four main comfort domains—namely sound pressure level, CO_2 concentration, air temperature, and horizontal illuminance—were measured during the administration of a right-here right-now questionnaire to gather their sensation regarding the acoustic, thermal, visual, and indoor air quality environments. Prior to the study, all participants underwent a comprehensive hearing screening to eliminate any potential biases related to auditory impairments. Subjective responses under different indoor conditions were analyzed to explore possible correlations between indoor parameters and students' multi-domain sensation.

Keywords: *Multi-domain sensation, cross-domain sensation, children, classroom.*

1. INTRODUCTION

Children at school are subjected to a multi-domain experience, caused by thermal, acoustic, air quality and light stimuli. All these components can affect students' wellbeing and consequently their academic performance. While research on the effects of indoor thermal conditions on students' thermal sensations dates back to the 1960s [19], only in recent years investigations have examined thermal comfort, perception, and academic performance in various countries [1]. In one study [2], which involved 2,850 children in Australian schools, it was highlighted that students preferred cooler temperatures than what is predicted by current thermal comfort models. Regarding noise and the acoustic environment, the impact of external and internal noise on students' performance is widely investigated since the 1970s [3-7]. Findings from these studies indicate that both external and internal noise significantly affect school children's academic performance. Regarding lighting, research has addressed issues such as inadequate daylight and its consequences on performance and health [8,9], excessive daylight leading to glare and overheating problems [10]. Moreover, many studies on the impact of indoor environment and children's comfort and performance have primarily focused on air quality [1]. Despite accumulating knowledge, so far, only a few studies have taken a holistic approach to analyzing classroom environments and student well-being [1].

This paper describes the first results of the field investigation performed in 4 schools comprising of a questionnaire among 133 children, aged between 8 and 10 years old, and a measurement campaign in 8 classrooms, collecting air temperature (T), carbon dioxide (CO_2), sound pressure level (SPL) and horizontal illuminance levels (E). The aim of the study is to investigate possible in-domain correlations between children's sensation of the different environmental aspects and the physical indoor parameters measured during the campaigns. Moreover, possible cross-domain effects are investigated. This is particularly useful to understand how to improve the indoor environmental quality of classrooms taking into account that children's needs are often different from adults' needs [1].

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2. METHOD

This study presents the results of 8 field campaigns carried out in four different primary schools in Italy, during the heating season 2024-2025. During the field campaigns the indoor environment has been evaluated by means of right-now objective evaluation, i.e. measurements of the main physical parameters related to the thermal environment, Indoor Air Quality (IAQ), visual and acoustic environment, and right-now subjective evaluation, i.e. transverse surveys administered to the students inside their classrooms. Objective and subjective evaluation have been performed simultaneously during regular classes.

2.1 Objective measurements

Environmental parameters were recorded at 1-minute intervals, while 5-minutes step was used for the CO_2, during a series of listening and cognitive tests, starting from the beginning of the testing session until the students had completed the questionnaires. Thermohygrometric parameters were recorded by means of the Microclimatic Station DeltaOhm HD32.1 located in the center of the classrooms, away from heat sources (e.g., radiators and projectors), and also away from sun patches at a height of 1.1 m as recommended by the Standard EN ISO 7726 [11]. CO_2 concentration was measured with Onset HOBO loggers MX1102A positioned on a perimeter wall. The horizontal illuminance level was measured with Onset HOBO loggers MX1104 located on students' desks in nine positions in order to map spatial distribution of illuminance in the classrooms. The A-weighted Leq sound level (LA,eq) was measured with class 1 Nti XL2 Sound level meter. The sensor was located in the center of the classroom near the Microclimatic Station. Specifications of the sensors are reported in Table 1.

2.2 Subjective survey

The subjective survey consisted of a questionnaire, filled after children had participated in performance tests, simultaneously with the measurements of the physical parameters. The four comfort aspects, i.e. thermal, visual, acoustic and indoor air quality (IAQ), have been included in the questionnaire. In particular, children had to report their right-here-right-now thermal and visual sensation on a 7-point bi-polar scale and their acoustic and air quality sensation on a 4-point one-polar scale (Table 2). An extract of the questionnaire is reported in Figure 1. Children were instructed and trained during a dedicated session, about the meaning of the questions and a number of 8 panels, i.e. groups of students interviewed in the same moment in the same classroom, have been interviewed, collecting 133 questionnaires, analyzed in this work. The votes about sensation, by students in each panel have been aggregated in bins and then analyzed. The aggregation method and the analysis of the dataset are presented in the following section.

Table 1. Instruments and physical parameters

Instrument	Parameter(s)	Accuracy
DeltaOhm HD32.1	Globe Temperature Ambient Temperature Relative Humidity Air Velocity	Temperature: Pt100 Accuracy ±0.01°C in the range ±199.99°C, ± 0.1°C outside this range RH: Accuracy ±0.1%RH Velocity: ±0.2m/s (0…0.99 m/s), ±0.4 m/s (1.00…9.99 m/s)
HOBO MX1102A	CO_2	Accuracy ±50 ppm ±5% of reading at 25°C, less than 90% RH non-condensing and 1,013 mbar
HOBO MX1104	Illuminance (lx)	Accuracy ±10% typical for direct sunlight
Nti XL2	$L_{A,eq}$ (dB)	Free-field ½ " Microphone: Nominal Open-circuit Sensitivity: -27.5± 2 dBV/Pa (42 mV/Pa); Microphone Preamplifier: Nominal Preamplier Attenuation: < 0.17 dB

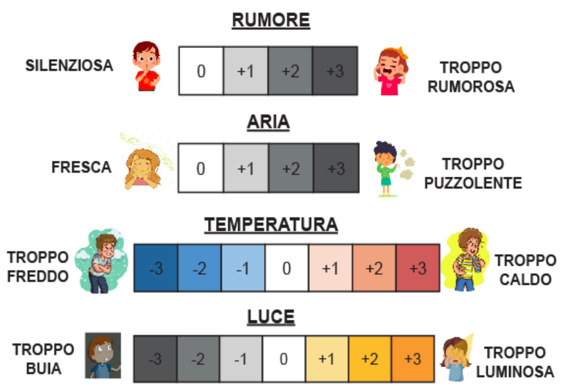

Figure 1. Example of questionnaire administered to children.

Table 2. Questionnaire statement and extremity labels

Statement	Right now I feel/ the classroom light is/the air is/the classroom noise is
Evaluation scale	+3 hot/too bright/too stuffy/too noisy
	+2
	+1
	0 neither warm/bright nor cool/dark/ fresh/quiet
	-1
	-2
	-3 cold/too dark

2.3 Data processing and statistical analysis

The environmental conditions of each panel have been binned according to the mean value of the main physical parameters related to each of the four environmental aspects separately, i.e. the indoor air temperature, the CO_2 concentration, horizontal illuminance and the equivalent A-weighted sound pressure level, LAeq, according to a methodology presented in previous work [11].

In details, for the indoor air temperature the intervals of 0,6 °C have been considered [12]; for the CO_2 average concentrations have been binned according to the categories defined by EN 16798-1 [13], i.e. 500 ppm, 800 ppm, 1100 ppm and 1400 ppm; illuminance levels have been binned according to the recommended steps of illuminance defined by EN ISO 12464-1 [14], i.e. 20, 30, 50, 100, 150, 200, 300, 500, 750, 1000, 1500, 2000 lx; finally a step of 2 dB has been used for the sound pressure level [15]. Panels have been aggregated into groups according to the bin values and the average sensation votes of each group have been calculated to be used in the further analysis.

After that, a correlation analysis was carried out to test the correlation of the average physical parameters with the subjective mean responses. The Pearson correlation coefficient, ρ, was used to verify the strengthness of the correlation. The higher the Pearson coefficient the stronger is the correlation. In detail, values near ±1 indicate a perfect correlation with an increase (or decrease) in one variable corresponds to an increase (or decrease) in the other; values between ±0.50 and ±1 are considered in this study a strong correlation; values between ±0.30 and ±0.49 are considered a moderate correlation; other values are considered a weak correlation; while values near zero imply that no relationship is found.

Then, when correlation was assessed a linear regression analysis was performed to represent the relation between the indoor conditions and the mean sensation votes. A significativity level of maximum 5 % was considered to assess the goodness of the model.

Moreover, a cross-domain investigation has been implemented correlating children mean sensation votes of each panel with the mean physical descriptors of the other domains (i.e. thermal sensation vs CO_2 concentration, illuminance and sound level; indoor air quality sensation vs indoor temperature, illuminance and sound level; visual sensation vs indoor temperature, CO_2 concentration and sound level; acoustic sensation vs indoor temperature, CO_2 concentration and illuminance) by means of a multiple linear regression analysis.

3. RESULTS

3.1 Thermal environment

Through the data aggregation in temperature bins, a final number of 5 groups for thermal conditions have been composed, whose numerosity is fairly distributed between 17 and 30 children per group. Table 3 reports the mean values of the air temperature, the mean thermal sensation votes for each group and the results of the statistical analysis (i.e. the coefficient of correlation, ρ, the regression p-value and the coefficient of determination, R^2). The correlation coefficient, which is higher than 0.5 shows the existence of a high correlation between air temperature and thermal sensation.

The regression analysis points out that the mean indoor air temperature is significantly correlated (*p-value* < 0.05) with the thermal sensation votes (TSV), with a slope equal to 0.0863 and a coefficient of determination (R^2) equal to 0.43. According to the regression found, the thermal neutrality would be reached at about 19 °C.

Table 3. Thermal environment: environmental conditions, mean thermal sensation votes of each group and statistical analysis

Group	n.	T_{air} [°C]	TSV	*ρ*	R^2	*p-value*
S1	20	20.1	-0.2	0.63	0.43	0.000*
S2	27	21.1	0.4			
S3	17	22.6	0.5			
S4	30	23.0	0.2			
S5	20	23.9	0.7			
S6	19	26.4	0.5			

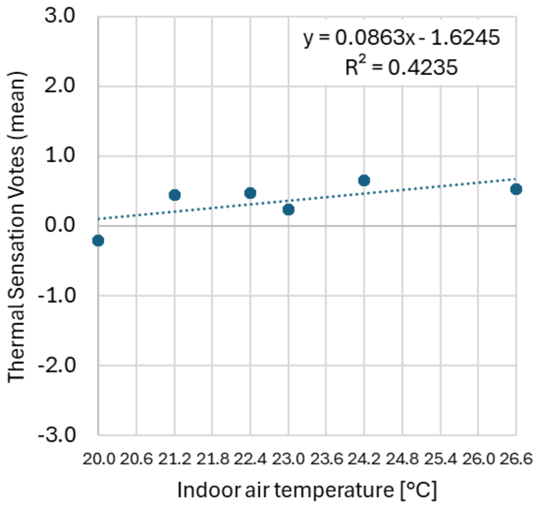

Figure 2. Mean thermal sensation vote vs mean air temperature.

3.2 Indoor Air Quality

Through the data aggregation in CO_2 bins, a final number of 5 groups for air quality conditions have been composed, whose numerosity ranges between 17 and 40 children per group. Table 4 reports the mean values of the CO_2 concentration, the mean indoor air quality sensation votes for each group and the results of the statistical analysis carried out after the data binning (i.e. the Pearson correlation coefficient, ρ, the regression p-value and the coefficient of determination, R^2).
It can be seen that, even if the carbon dioxide concentration is highly correlated with the IAQ sensation votes (IAQSV) expressed by children, the slope of the regression and the R^2 are very low, 0.0002 and 0.23, respectively, thus showing a low sensitivity of children in assessing the air quality in classroom.

Table 4. Indoor Air Quality: environmental conditions, mean IAQ sensation votes of each group and statistical analysis

Group	n.	CO_2 [ppm]	IAQSV	*ρ*	R^2	*p-value*
S1	33	849	0.6	0.55	0.23	0.000*
S2	17	1151	0.8			
S3	40	1331	0.5			
S4	12	1805	0.8			
S5	30	1929	0.8			

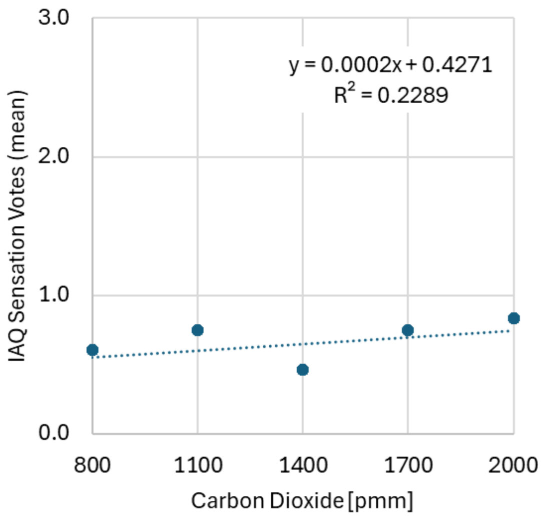

Figure 3. Mean IAQ sensation vote vs mean CO_2 concentration.

3.3 Visual environment

Through the data aggregation in illuminance bins, a final number of 4 groups for visual conditions have been composed, whose numerosity ranges between 20 and 49 children per group. Table 5 reports the mean values of the horizontal illuminance level, the mean visual sensation votes for each group and the statistical analysis results.
The regression analysis shows that the horizonal illuminance significantly affects the visual sensation vote (VSV) with R^2 = 0.53. Nevertheless, the slope of the regression is very low 0.0031, thus highlighting a low sensitivity of children in rating the brightness or the darkness of the classroom.

Table 5. Visual environment: environmental conditions, mean visual sensation votes of each group and statistical analysis

Group	n.	E [lx]	VSV	*ρ*	R^2	*p-value*
S1	20	137	0.4	0.68	0.53	0.000*
S2	32	231	0.8			
S3	32	328	0.0			
S4	49	488	1.5			

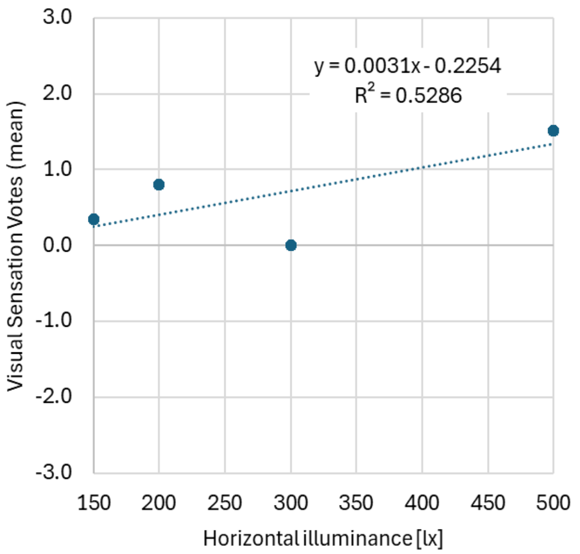

Figure 4. Mean visual sensation vote per panel vs mean horizontal illuminance.

3.4 Acoustic environment

Through the data aggregation in sound pressure bins, a final number of 5 groups for acoustic conditions have been composed, whose numerosity ranges between 15 and 54 children per group. Table 6 reports the mean values of the sound pressure level, the mean acoustic sensation votes for each group, together with the p-value and the coefficient of determination of the regression. According to the analysis, the sound pressure level is highly correlated with the mean acoustic sensation vote and significantly impact on it. Moreover, the regression analysis shows a very high coefficient of determination $R^2 = 0.94$, and a slope of about 6 %. The zero vote corresponding to a quiet sensation would be reached with an equivalent sound level of about 50 dB(A).

Table 6. Acoustic environment: environmental conditions, mean acoustic sensation votes of each group and statistical analysis

Group	n.	LAeq [dbA]	ASV	*ρ*	R^2	*p-value*
S1	15	63.4	0.5	0.97	0.94	0.000*
S2	17	64.5	0.8			
S3	35	71.0	1.1			
S4	54	72.8	1.2			
S5	12	76.2	1.3			

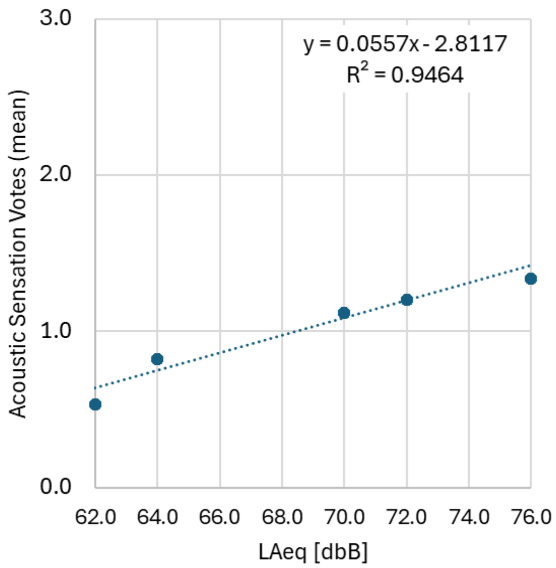

Figure 5. Mean acoustic sensation vote per panel vs mean sound pressure level.

3.5 Cross-domain effects

Table 7 reports the results of the multiple linear regression analysis between the thermal, IAQ, visual and acoustic sensation vote averaged for each panel and the mean physical parameters of the four domains. The multiple regressions were built considering the addition of one secondary environmental parameter at a time. A p-value lower than 0.05 results in a significant effect, a p-value between 0.05 and 0.1 is considered as slightly significant and a p-value higher than 0.1 means non-significant (reported in red).

Concerning the thermal domain, the multiple linear regression analysis shows that the horizontal illuminance and sound pressure level affect thermal sensation, but the R^2 are small (lower than 0.5). Conversely the variation of CO_2 has no impact on TSV.

As regards the IAQ, horizontal illuminance and sound pressure level impact on IAQ sensation votes, but the R^2 of the regression built on the sound pressure level is very low (0.13). Moreover, the regression built with combination of CO_2 and indoor temperature lead to slightly significant prediction (p-value < 0.1) of IAQ sensation vote.

Considering the visual domain, CO_2 concentration and indoor temperature seem to significantly influence visual sensation when considered together with illuminance, but

R^2 is very low in the case of the latter (0.13), while the sound pressure level results to affect visual sensation.
Finally, regarding the acoustic domain, it can be seen that indoor air temperature and horizontal illuminance significantly influence the mean acoustic sensation vote, with quite high R^2 (i.e., 0.78 and 0.87, respectively), while CO_2 concentration does not influence the acoustic sensation.

Table 7. Cross-domain statistical analysis indoor conditions and acoustic sensation votes.

Dependent variables	Independent variables	*p-value*	R^2 adj.
Thermal sensation	T, CO_2	0.000**; 0.205	0.32
	T, E	0.000**; 0.001**	0.36
	T, SPL	0.000**; 0.012**	0.34
IAQ sensation	CO_2, T	0.066*; 0.072*	0.11
	CO_2, E	0.000**; 0.000**	0.32
	CO_2, SPL	0.010**; 0.008**	0.13
Visual sensation	E, T	0.006**; 0.000**	0.13
	E, CO_2	0.003**; 0.000**	0.39
	E, SPL	0.156; 0.000**	0.49
Acoustic sensation	SPL, T	0.000**; 0.000**	0.78
	SPL, CO_2	0.000**; 0.289	0.75
	SPL, E	0.000**; 0.000**	0.87

**significant effect ($p < 0.05$); *slightly effect ($p < 0.1$)

4. CONCLUSION

The within-domain analysis shows that the indoor conditions, such as indoor air temperature, CO_2 concentration, horizontal illuminance and sound pressure level significantly influence the corresponding subjective sensation expressed by children, , i.e. thermal, Indoor Air Quality, visual and acoustic sensation respectively. In detail, the slope of the regressions implemented for the thermal and the acoustic environments results steeper than the ones found for the other domains, thus proving a higher sensitivity of the related votes on the variation of the physical parameters, in accordance with a previous work carried out in high school [11]. This means that children are more sensitive to the thermal and acoustic, than the visual or the olfactory stimuli. In fact, the regressions in the visual and indoor air quality domains, have small slopes indicating that children are not sensitive to the horizontal illuminance and CO_2 concentration in the classroom.
As regards the cross-domain effects, multiple linear regression analysis implemented in this study shows that: indoor air temperature has a significant effect on visual and acoustic and a slight effect on the IAQ sensation; CO_2 concentration influences visual sensation, but is irrelevant for thermal and acoustic sensation; horizontal illuminance and SPL has a significant effect on the sensation expressed for all the other domains.
Further analysis can be carried out to improve the elaborate models, looking at some personal and contextual factors that might influence the children comfort.

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