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# Understanding the Effects of Environmental Factors on Human Perception by Means of Surveys and in Field Measurements

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## ABSTRACT

*The discomfort prediction inside buildings by means of correlations able to estimate people subjective response from indoor conditions has been widely investigated with the purpose of supporting design, commissioning and operation of buildings. Technical standards have been developed based on these findings, suggesting or prescribing acceptability ranges for the different environmental quantities involved mainly in single comfort aspects. However, buildings' occupants are not exposed to one environmental factor at a time, but to acoustical, thermal, visual, and air quality stimuli simultaneously so that the overall effect of the indoor environment on human perception and performance depends on their combined effect. Some researchers have investigated these aspects by means of laboratory studies, while few ones have conducted with field studies. Even if lab environments allow the full control of the environmental parameters, the research in real buildings has the advantage of capturing the response of people in an everyday context, while they are involved in their real activity. Among all different building types, in the educational ones the indoor factors can critically affect students' concentration and ability to learn, so that they are worth investigating. The main aim of this paper is to present results from field subjective surveys and measurements carried out in university and high school classrooms to find the crossed effects and interaction effects of different environmental factors on human perception and comfort.*

## INTRODUCTION

Students spend in classrooms a considerable amount of their daytime. Their mental effort and performance are arguably influenced by the quality of the environment where they carry out their activities, from which the importane of accuratey predicting the consequences of design and control strategies in terms of Indoor Environmental Quality (IEQ) and occupants' satisfaction. IEQ is the result of multiple environmental variables, which have an effect on occupants' sensation, preference, comfort and satisfaction. In the last decades, the Indoor Environment of school classrooms have been studied through objective evaluation by means of physical measurements separately related to the main IEQ domains, namely air quality, and thermal, acoustic and visual environment. In recent years, several studies combined in-field measurements (objective evaluation) with occupants' surveys (subjective evaluation) for inspecting occupants' perception of the built environment, highlighting that building occupants are a valuable source of information about indoor environmental quality (IEQ). Most of these studies take into consideration comfort aspects singularly and, they focus mainly on thermal comfort (Kim, 2018) but some recent

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researches tried to embrace a more holistic approach including more than one comfort area, at least one, besides thermal comfort, such as IAQ (Korsavi et al., 2020), acoustic comfort (De Giuli et al., 2012) and visual comfort (Dorizas et al., 2015). Furthermore, some studies put some effort in finding possible correlations between objective monitoring, occupants subjective response, and relationships among different comfort aspects (Ricciardi, 2018). Even when more than one comfort aspect is inspected, there is not homogeneity among the questions and definitions related to different aspects so that sensation, preference, comfort and satisfaction are difficult to compare between different domains. This paper aims to investigate the correlation between the measured environmental characteristics and the subjective response obtained by means of a questionnaire, designed for the purpose of capturing people sensation, preference comfort and satisfaction concerning all the four environmental aspects that contribute to people indoor wellbeing in educational buildings. In details, the mean sensation, preference, comfort and satisfaction votes have been compared with the peculiar characteristics of each environmental aspect. To achieve this goal the authors have designed a questionnaire to capture the subjective perception, preference, comfort and satisfaction in all the four environmental aspects in a coherent manner; then they have collected responses and measurements under different exposure conditions in educational buildings and finally implemented a statistical analysis of responses. The final result of this research is the identification of students' preferred environmental conditions (i.e. neutral condition) and the identification of possible influences of environmental conditions on the sensation of a different domain (i.e. thermal sensation vs $CO_2$ concentration, desk illuminance, sound pressure level).

## METHODOLOGY

### Field campaigns

This study presents the results of three field campaigns carried out in two different educational buildings in Italy, during the heating season. 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 carried out simultaneously during regular classes. A total number of 31 different panels, i.e. groups of students in the same classroom at the same time, have been interviewed.

### Objective Evaluation

Environmental parameters related to IEQ were recorded at 1-minute intervals, during regular classes, starting from the beginning of the lecture 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., projectors), and also away from sun patches at a height of 1.1 m as recommended by the Standard EN ISO 7726 (CEN 2001). TVOC, $CO_2$, CO, T, RH were measured with the IAQ Meter Graywolf Wolfpack (IQ-610). The sensor was located on the teacher's desk. The horizontal illuminance level was measured at all the students' desk inside the classrooms with the illuminance meter Konika Minolta T-10A. The A-weighted Leq sound level ($L_{A,eq}$) was measured with B&K 2270 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.

**Table 1. Objective evaluation: instruments and physical parameters**

| S.No | Instrument | Parameter(s) | Accuracy |
|---|---|---|---|
| 1 | DeltaOhm HD32.1 | Globe Temperature<br>Ambient Temperature<br>Relative Humidity Air<br>Velocity | Temperature: Pt100 Accuracy ±0.01°C in the range ±199.99°C,<br>± 0.1°C outside this range<br>RH: Accuracy ±0.1%RH<br>Velocity: ±0.2m/s (0…0.99 m/s), ±0.4 m/s (1.00…9.99 m/s) |
| 2 | Graywolf Wolfpack (IQ-610) | TVOC, $CO_2$, CO, T, RH | CO: Accuracy ±2ppm <50ppm, 3%rdg >50 ppm<br>$CO_2$: Accuracy ±3%rdg ±50 ppm<br>VOC: Resolution 1ppb, L.O.D. <5ppb<br>RH: Accuracy ±2%RH <80%RH (±3%RH>80%RH)<br>Temperature: Accuracy ± 0.3°C |
| 3 | Konika Minolta T-10A | Illuminance (lx) | Linearity: ± 2% ± 1 digit of displayed value |
| 4 | B&K 2270 | $L_{A,eq}$ (dB) | Free-field ½ " Microphone: Nominal Open-circuit Sensitivity: 50mV/Pa 1.5bB; Capacitance: 14pF at 250 Hz<br>Microphone Preamplifier: Nominal Preamplier Attenuation: 0.25 dB |

## Subjective Evaluation

The subjective survey consisted of a questionnaire, filled during regular classes, simultaneously with the measurements of the physical parameters. The four comfort aspects, i.e. thermal, visual, acoustic and indoor air quality (IAQ), along with the global comfort and satisfaction have been included in the questionnaire. A number of 31 panels, i.e. groups of students interviewed in the same moment in the same classroom, have been interviewed, collecting 440 questionnaires which have been analysed in this work. The votes about sensation, preference and comfort expressed by students in each panel have been aggregated in clusters and then analysed. The aggregation method and the analysis of the dataset is presented further on.

## Panels aggregation and analysis

Since the number of responses collected from each panel is not sufficiently representative, the panels have been grouped according to a methodology described in this section, which takes into account for similar environmental conditions and for similar subjective responses. Then the mean values of the indoor air temperature, $CO_2$ content and $L_{A,eq}$ were calculated and assigned to the related panel. Regarding the visual environment, the illuminance level has been calculated as the mean value of the horizontal illuminance level measured at all the desks inside the classroom. The method applied for the panels aggregation can be devided into three main steps (Figure 1).
First, the panels have been binned considering specific ranges of the measured physical parameters (*Data binning*). In this way, subjects of panels exposed to similar indoor conditions in terms of indoor air temperature, $CO_2$ content, illuminance level and sound pressure level were aggragated into preliminary groups. The preliminary groups were then checked by analysing the distribution of sensation votes of each group by means of statistical tests: panels with the same distribution of sensation votes within a specific bin were aggregated (*Preliminary Data aggregation*). Secondly, the same statistical tests were used for verifying the groups (*Definition of the groups*). Finally, the correlation between measured parameters and the subjective responses of the final groups has been inspected (*Analysis of the groups*), as described below.

**Data Binning.** 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 $CO_2$ content, the illuminance level and the A-weighted sound pressure level, LAeq. In details, for the indoor air temperature the intervals of 0,6 °C have been considered (CEN 2001); for the $CO_2$ average levels have been binned according to the categories defined by EN 16798-3 (CEN 2017), i.e. 500 ppm, 800 ppm, 1100 ppm and 1400 ppm; regarding the visual environment the data have been binned according to the recommended steps of illuminance definend by EN ISO 12464-1 (CEN 2011), i.e. 20, 30, 50, 100, 200, 300, 500, 1000 lx and reported in EN 12464 (CEN 2011); finally for the Acoustic data the step of 3 dB has been used.

**Preliminary Data Aggregation (Statistical Analyis I).** In order to verify the possibility to aggregate the panels into groups, the distribution of the sensation votes expressed by subjects about one comfort aspect at a time, have been analyzed by means of non-parametric statistical test, namely the pairwise Mann Whitney U-test. All the panels inside a specific bin have been compaired pairwise. The results of the statistical analysis have been interpretated as follow: (a) if the distributions of sensation votes of two panel within the same bin are the same, it is possible to combine the panels and thus form a preliminary group; (b) if not, it is not possible to combine the panels, so the panel is not considered in the analysis.

**Definition of the groups (Statistical Analyis II).** In order to confirm the preliminary groups a second pairwise Mann Whitney U-test has been carried out considering the newborn groups. The results of the statistical analysis have been interpretated as follow: (a) if the distributions of sensation votes of two groups referring to subsequent bins are the same, it is possible to aggregate forming a broader; (b) conversely if they had different distributions they were considered as separate groups.

**Analysis of the groups.** In order to analyze the correlation between measured environmental characteristics and the subjective response, the mean value of the physical parameters referring to a specific environment domain was compared with the mean sensation, preference and comfort votes referring to the same domain (regression models). Moreover, for the thermal environment the mean sensation votes for different domains expressed by each group, i.e. IAQ, Visual and Acoustic environment, were calculated and compared with temperarature ranges in order to highlight if they are affected by indoor air temperature variation.

## Data Quality Assurance

**Objective Measurements.** Regarding the objective evaluation, all the right-now measurements have been carried out during regular classes between 8 a.m. and 3 p.m., starting at the beginning of the lecture and lasting until the end of the filling of the questionnaires. For this work measurements carried out before (at least 30-35 minute before giving them the questionnaire) and during the filling of the questionnaire have been considered. Thermal measurements underwent a quality check by verifying their stationarity according to the Standard EN ISO 7726 (CEN, 2001).

**Subjective evaluation.** According to the survey method, the questionnaires were administered ensuring that the students had spent in the classroom enough time to reach an adequate balance with the thermal environment, being exposed for a suitable period of time to the environmental conditions. Before the administration, the questionnaire is explained in all its parts to the students by the researchers, answering all the students' clarification requests. Moreover, it was ensured that students had all the time they needed for filling the questionnaires, neither the teacher nor the researcher hurrying them to answer. To avoid bias due to tiredness, the order of sections of the questionnaire related to the four environmental aspects has been randomized for each student. Collected responses underwent a quality verification by identifying and removing irrational or inconsistent answers. Responses by people with some learning, language, or acoustic impairment were removed. Questionnaires with up to one missing answer about one of the perception aspects, i.e. sensation, preference and comfort, or satisfaction were used anyhow for the analysis of the other questions not to reduce too much the number of surveys per classroom.

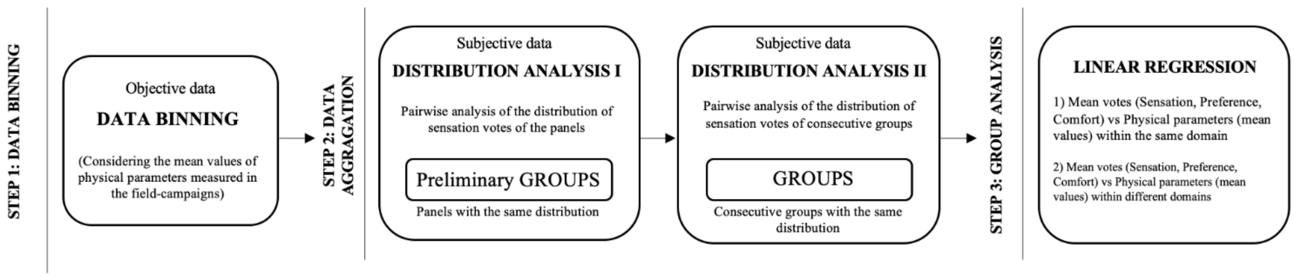


**Figure 1** The main steps of the method for analysing the dataset collected for the four environmental (Step 1: Data Binning; Step2: Data Aggregation; Step 3: Group Analysis.

## RESULTS

The data aggregation method led to the constitution of 4 groups for the thermal environment (26 panels), 3 groups for IAQ (26 panels), 5 groups for both the visual (24 panels) and the acoustic environment (22 panels).

**Thermal Environment.** Table 2 reports the environmental conditions (i.e. the indoor air temperature, the absolute humidity) and the subjective mean votes (mean observed votes) along with the number of subjects of each group. In Figure 2 the mean observed votes (blue dots) obtained using the questions about sensation ($TSV_{mean}$), preference ($TPV_{mean}$) and comfort ($TCV_{mean}$) is correlated with the mean value of the indoor air temperature. In the same plots all the subjective votes have been also reported with a blue cross just to see the dispersion of the votes. The dependence of the sensation and preference mean votes on the air temperature is represented in the graphs by the linear regression line and its slope. Despite the limited range of indoor temperature the mean thermal sensation vote increases linearly with the temperature. Both the mean sensation vote and the preference vote resulted significantly correlated with the indoor air temperature, with the same correlation coefficient $R^2 = 0.99$. According to the analysis, the neutral conditions, namely the environmental conditions under which the sensation vote is equal to 0, occur when the indoor temperature is about 23 °C.
As it can be seen the $TCV_{mean}$ of the four groups have a quadratic correlation with the temperature, but the least discomfort level is reached around 23°C.

**Table 2. Thermal Environment: environmental conditions and subjective mean votes of the groups**

| Group | Subjects num. | Tair [°C] | x [g/kg] | $TSV_{mean}$ | $TPV_{mean}$ | $TCV_{mean}$ |
|---|---|---|---|---|---|---|
| T1 | 178 | 21 | 8,69 | -0,47 | 0,47 | 0,74 |
| T2 | 46 | 23 | 6,30 | 0,22 | -0,02 | 0,26 |
| T3 | 82 | 24 | 6,67 | 0,51 | -0,28 | 0,50 |
| T4 | 59 | 25 | 6,56 | 0,80 | -0,39 | 0,48 |

In Figure 3 the mean observed sensation votes for the IAQ, the visual and the acoustic environment expressed by the thermal groups are plotted against the mean air temperature (Figures 3a, 3b, 3c). Those graphs allow to inspect if the temperature may affect students' perception in other domains. In Figures 3d, 3e, 3f, the box-plots of the environmental parameters related to the corresponding sensation domain are reported in order to give a qualitative support to the analysis. In particular, the distributions show that the trends are not clearly correlated to the main factor, supporting the hypothesis that temperature may have a role on the sensations in the other environments. As concern IAQ, in particular, it may be that cooler air is perceived as fresher. The graph in figure 3b shows the variation of the $VSV_{mean}$ on the temperature increasing: it is possible to see a decreasing trend of the vote with the temperature that is only partially justified by the illuminance distribution reported in figure 3e. Finally, the graph 3c reports the trend of the $ASV_{mean}$ for the thermal groups: in this case the slope of the regression line is almost null, so the effect of temperature on the acoustic sensation is negligible.

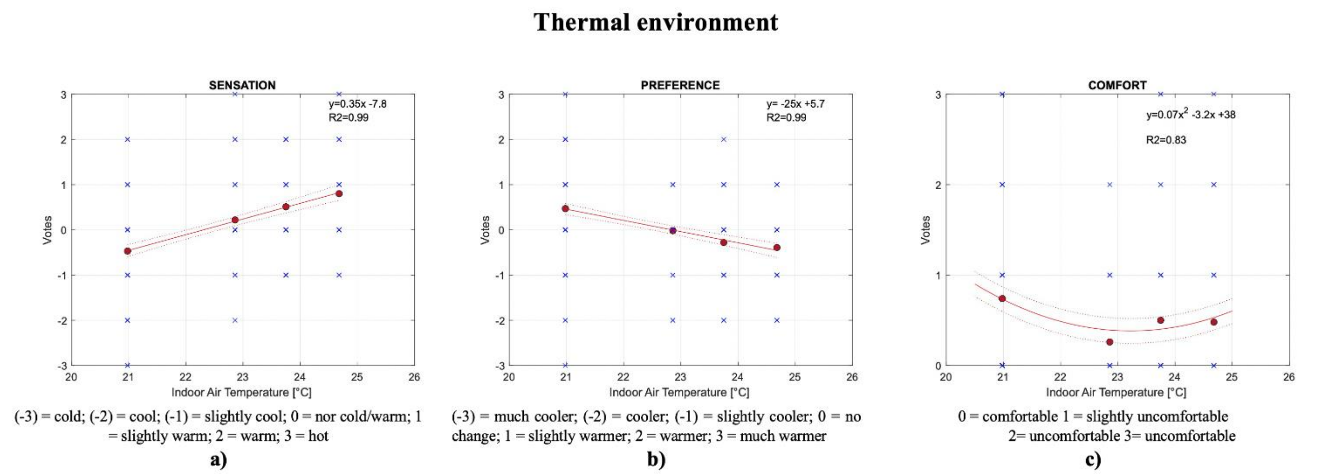


**Figure 2** Correlation between the mean thermal sensation (a), preference (b) and comfort (c) votes with the indoor air temperature.

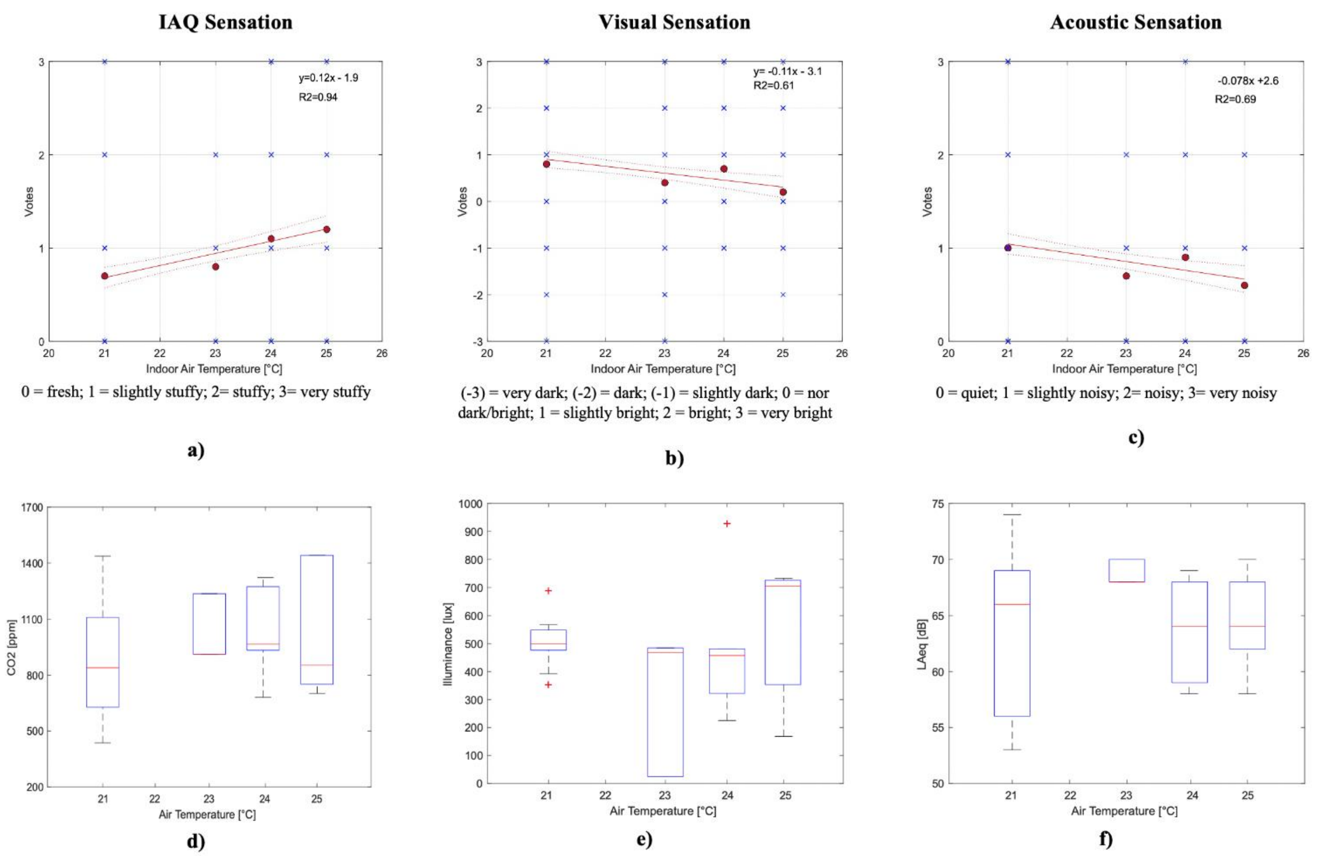


**Figure 3** Correlation between the mean IAQ; Visual and Acoustic sensation votes with the indoor air temperature (a, b, c). The votes are expressed by people divided into the thermal groups. Blue crosses represent single votes, red dots are the mean votes of the groups exposed to the similar condition. Distribution of the main physical parameters related to the IAQ, Visual and Acoustic environment within the thermal groups.

**Indoor Air Quality.** Table 3 reports the $CO_2$ concentration, the subjective mean votes along with the number of subjects of each group related to the Indoor Air Quality. The mean observed votes obtained using the three IAQ perceptual questions about sensation ($IAQSV_{mean}$), preference ($IAQPV_{mean}$)and comfort ($IAQCV_{mean}$) have been correlated with the mean value of the $CO_2$ concentration of each group (Figures 4a, b and c). The x axis reports the mean value of $CO_2$ concentration while the y axis reports the average votes expressed by sensation (from 0 = fresh air to 3 = very stuffy), preference (from 0 = no change to 3 = much fresher) and comfort scales (from 0 = comfortable to 3 = very uncomfortable). Even though the regression coefficients are very high, respectively $R^2$ = 0.916, $R^2$ = 1 and $R^2$= 0.96, the sensitivity is quite low. In fact, looking at the slopes of the regression curves, it can be highlighted that $CO_2$ concentration seems not to be a good indicator for the subjective sensation about air quality. In details, with the increasing of the $CO_2$ content the mean votes get close to 1 which means the sensation of slightly stuffy air, the preference of slightly fresher air and "slightly uncomfortable" in case of comfort vote. When the $CO_2$ is equal to 500 ppm the IAQ sensation vote is equal to 0,6. It would mean that the neutral conditions, with the sensation vote tending to 0, correspond to $CO_2$ much lower than 500 ppm.

**Table 3. Indoor Air Quality: environmental conditions and subjective mean votes of the groups**

| Group | Subjects | $CO_2$ [ppm] | $IAQSV_{mean}$ | $IAQPV_{mean}$ | $IAQCV_{mean}$ |
|---|---|---|---|---|---|
| IAQ1 | 57 | 500 | 0,6 | 0,8 | 0,4 |
| IAQ2 | 233 | 800 | 0,7 | 0,8 | 0,4 |
| IAQ3 | 82 | 1400 | 0,9 | 1,2 | 0,8 |

**Visual Environment.** Table 4 reports the illuminance level, the subjective mean votes and the number of subjects of each group related to the visual environment. The mean observed vote obtained through the questions about sensation ($VSV_{mean}$), preference ($VPV_{mean}$) and comfort ($VCV_{mean}$) have been correlated with the mean value of the illuminance level of each group (Figures 4d, 4e, 4f). The x axis reports the mean value of illuminance while the y axis reports the votes expressed by sensation (from -3 = very dark to 3 = very bright), preference (from – 3 = much brighter to 3 = much darker, 0 = no change)) and comfort scales (from 0 = comfortable to 3 = very uncomfortable). Contrary to the thermal and IAq aspects, in this case the visual sensation, preference and comfort votes do not have a linear dependency on the main environmental parameter, i.e. illuminance. With the increasing of the illuminance level from 20 lx to 300 lx the mean sensation vote increases as well, but, after that threshold the sensation seem to be less correlated to the increasing of the illuminance, because the sensation does not change much between 300 lx and 800 lx. Above 800 lx the sensation tends to increase again. The preference is much more explanatory: in average people do not want to change when they are exposed from 300 lx till 1000 lx. Looking at figure 4f it can be seen that the comfort vote is less correlated to the illuminance than the other votes, even though it can be seen a quadratic denpendency that would be better highlighted if extreme conditions could have been tested. In summary, according to the analysis, the neutral conditions, namely the environmental conditions under which the sensation vote is equal to 0, occur when the illuminance is 300 lx, according to the sensation vote. Preference indeed is stably around 0 change from 300 to 1000 lx and comfort confirm this tendency with mean votes between0.3 and 0.6 in the same illuminance range.

**Table 4. Visual Environment: environmental conditions and subjective mean votes of the groups**

| Group | Subjects | Illuminance [lx] | $VSV_{mean}$ | $VPV_{mean}$ | $VCV_{mean}$ |
|---|---|---|---|---|---|
| V1 | 12 | 20 | -1,7 | 1,7 | 0,8 |
| V2 | 51 | 349 | 0,0 | 0,23 | 0,28 |
| V3 | 209 | 498 | 1,0 | 0,1 | 0,4 |
| V4 | 39 | 713 | 0,5 | 0,4 | 0,3 |
| V5 | 17 | 928 | 1,4 | -0,1 | 0,6 |

**Acoustic Environment.** Table 5 reports the A-weighted equivalent sound pressure level, $LA_{eq}$, the subjective mean votes and the number of subjects of each group related to the acoustic environment. The mean observed vote obtained using the three acoustic perceptual questions about sensation ($ASV_{mean}$), preference ($APV_{mean}$) and comfort ($ACV_{mean}$) has been compared with the mean value of the LAeq of each group. Figures 4g, 4h, 4i show the correlation. The x axis reports the mean value of LAeq while the y axis reports the votes expressed by sensation (from 0 = quiet to 3 = very noisy), preference (from 0 = no change to 3 = very quieter) and comfort scales (from 0 = comfortable to 3 = very uncomfortable). Like in the visual environment, also in this case the relation between the mean acoustic votes and the LAeq is not linear. From 55 dB to 70 dB the mean sensation vote varies only a bit between 0.7 and 0.9; the preference varies also less than the sensation and the comfort less than the preference. So it is possible to conclude that in that range the LAeq does not influence the subjective response that is maintained next to the comfort. On the contrary levels above 70 dB seem to heavily impact on the subjective votes.

**Table 5. Acoustic environmental conditions and subjective mean votes of the groups**

| Group | Subjects | LAeq dB | $ASV_{mean}$ | $APV_{mean}$ | $ACV_{mean}$ |
|---|---|---|---|---|---|
| A1 | 73 | 55 | 0,7 | 0,4 | 0,4 |
| A2 | 47 | 59 | 1,0 | 0,7 | 0,5 |
| A3 | 68 | 64 | 0,5 | 0,4 | 0,1 |
| A4 | 68 | 69 | 0,9 | 0,5 | 0,3 |
| A5 | 19 | 74 | 2,3 | 1,6 | 1,1 |

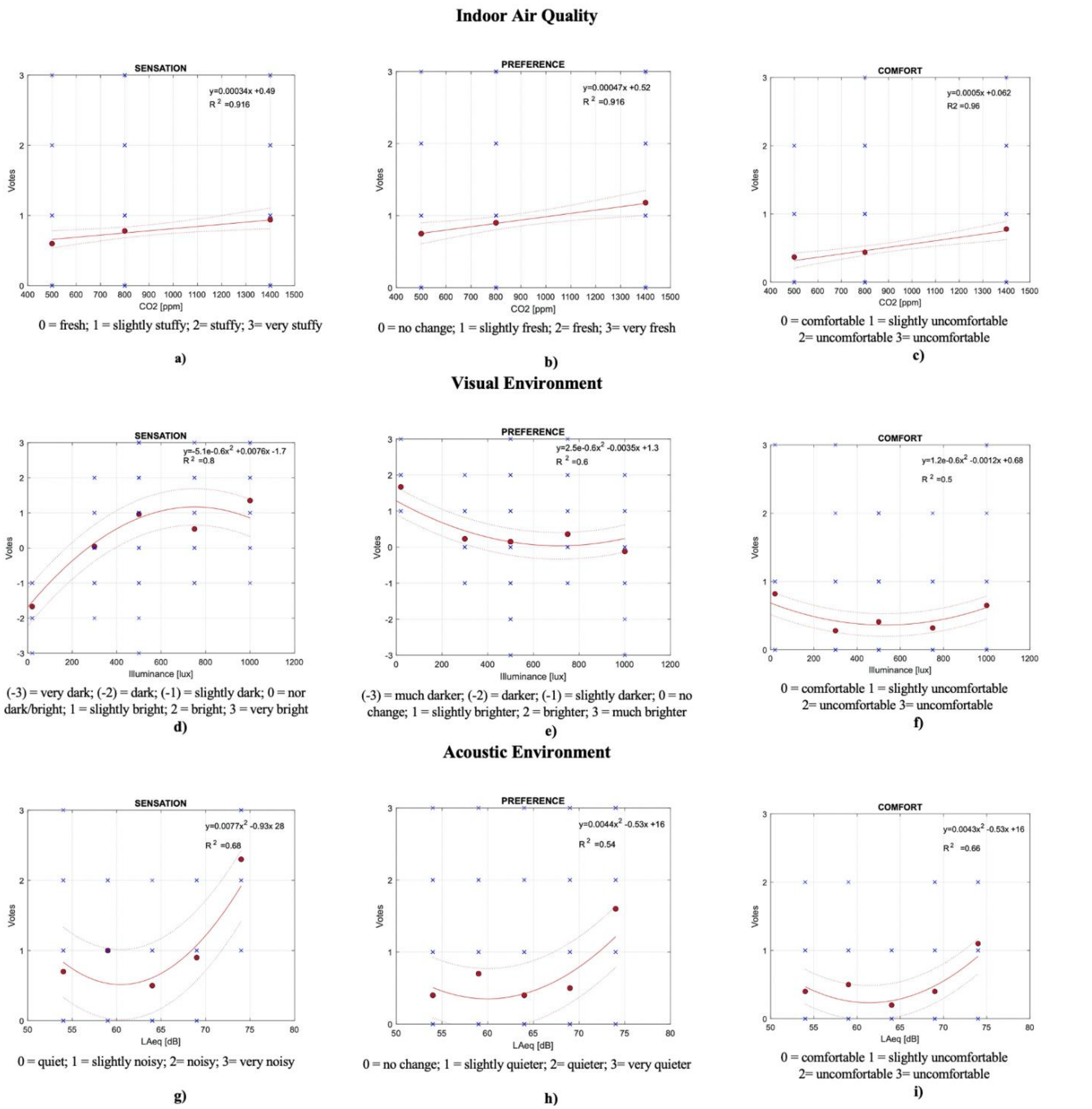


**Figure 4** Correlation between the mean sensation vote, mean preference vote, mean comfort vote expressed for respectively the Indoor Air Quality, the Visual and the Acoustic Environment the mean value of the physical parameters related to each domain. Blue crosses represent single votes, red dots are the mean votes of the groups exposed to the similar condition.

## CONCLUSIONS

This paper presents results from three field campaigns carried out inside two different educational buildings in Italy, during the heating season aiming at investigating the correlation between physical parameters and subjective responses and identifying students' preferred environmental conditions (i.e. neutral conditions). The type of dependency between the subjective response and the main environmental parameter associated to the subjective sensation is different from one comfort domain to another. In particular in the thermal environment there is a high linear correlation between sensation and preference votes and the indoor air temperature, while the comfort votes have a quadratic dependence by the air temperature with a comfort zone around 23 °C. Moreover, there seems to be a correlation between the indoor air temperature and the votes expressed by the same subjects on other comfort domains, as the IAQ sensation votes. Regarding IAQ, the subjective votes are linearly correlated with the $CO_2$ content. In the visual and acoustic environments the subjective votes have a quadratic dependence respectively on the illuminance and the sound pressure level. For the visual environment a comfort range can be found between 300 lx and 800 lx, while in the acoustic environment the preferred range is between 55 dB and 70 dB.

## FURTHER DEVELOPMENTS

A further development of this work will be to extend the correlation between the main physical parameters related to a comfort domain with the mean votes of different domains as alredy carried out for the thermal environment. The outcomes of the further analysis will be the definition of comfort ranges for the different environmental aspects, the highlighting of crossed and interaction effects of different factors on one single perception and on the overall perception.

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