

From Measurements to Perceptions: Sensors and Structural Equation Modelling to Evaluate Indoor Comfort in University Buildings

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Summary:

How is the Indoor Environmental Quality (IEQ) affecting the university students' satisfaction, comfort, and perceived learning performance? Technical conditions were monitored, while students' perceptions were collected through questionnaires spanning over the four seasons. Structural Equation Modelling (SEM), implemented through a Generalized Structured Component Analysis (GSCA), was used for the first time in university buildings to explore direct and indirect relationships among comfort domains, overall IEQ satisfaction, and perceived performance.

Keywords: Indoor Environmental Quality, multi-domain evaluation, structural equation modelling, comfort in university classrooms, human perception

Introduction

Extensive studies highlight how adequate school climate, particularly its environmental dimension, promotes student development. In this context, the interplay between physical environmental parameters and building layout represents a primary driver of IEQ [1]. Most existing studies addressed the question highlighted in the summary by considering IEQ domains individually, overlooking their combined effects. Conversely, this study adopts a practical multi-domain and multi-level approach to investigate indoor comfort by integrating such challenging long-term in-field measurements over all the four domains of IEQ and students' subjective evaluations, additionally applying for the first time SEM in university classrooms.

Materials and methods

In-field measurements and surveys were carried out in two lecture classrooms, labelled A and B, of Ferrara University (Italy), selected for the study as they share the same volume but differ

in all aspects that might impact indoor environmental quality and comfort. Measurements included thermal (temperature and (relative humidity)), air quality (CO₂, VOCs, PM10) [2], acoustic (sound pressure level) [3], and lighting (screen and horizontal illuminance) domains of the IEQ.

A questionnaire survey was employed to collect data on students' perceptions and psychological responses to the physical characteristics of the classroom environment, focusing on the key dimensions of IEQ. It included 25 closed-ended questions based on the EN ISO 10551 standard. The questionnaire was completed during 23 lessons in 14 different days. Overall, a total of 614 students participated in the survey.

The relationship among person-related factors, students' subjective response to the individual domains of IEQ, and perceived outcomes (i.e., global satisfaction with the IEQ and perceived performance), was simultaneously investigated through SEM-based approach (see Fig. 1). A GSCA-SEM was implemented with the software GSCA PRO. Before estimating the SEM,

diagnostic checks were performed to confirm that data met modelling assumptions. Given the qualitative nature of the questionnaire items, Multiple Correspondence Analysis (MCA) was employed.

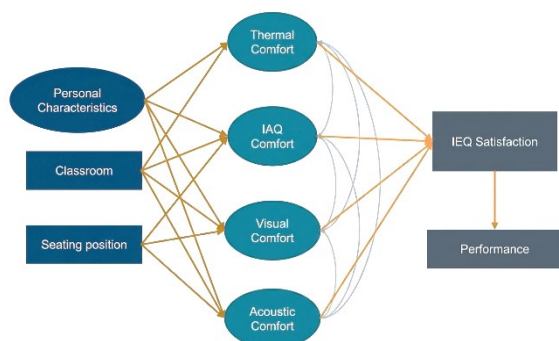


Fig. 1. Conceptual diagram with hypothesized pathways between variables. Rectangles and ellipsoids represent measured and latent variables, respectively.

Results

In order to allow comparison with the survey responses, the technical parameters measured over each two-hour session were aggregated into representative single values (see Fig. 2).

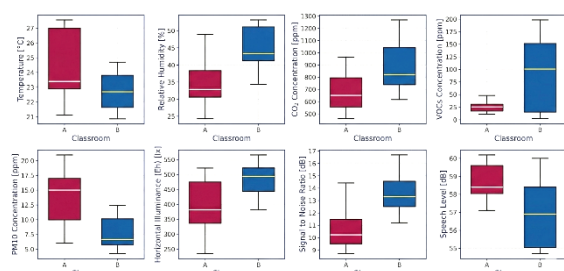


Fig. 2. Boxplots comparing environmental parameters measured during different lessons between Classroom A and B. The plots illustrate median values and interquartile ranges.

Then, the relationship between measured parameters and subjective data was estimated using linear mixed-effects models, with the measured parameter as a fixed effect and lesson as a random intercept to account for the hierarchical structure of the data. Correlations were generally low or non-significant. In the thermal domain, air temperature and relative humidity showed significant positive correlations. However, the effect size is very small and likely attributable to artefacts or to the sample size. In the indoor air quality (IAQ) domain, CO₂ and PM₁₀ were negatively correlated with IAQ. VOCs, lighting parameters (Eh) and acoustic measures (speech levels and SNR) showed non-significant correlations with subjective evaluations. This is consistent with prior IEQ research.

The MCA results suggested that the chosen personal characteristics do not constitute a unified construct but rather reflect multiple distinct

factors, then the latent variable representing personal characteristics was not considered in the final version of the SEM. This included 18 out of 28 items from the questionnaire. The model explained 39% of the variance in IEQ global satisfaction, indicating a moderate level of explanatory power. The GSCA-SEM explained 46% of the variance of thermal comfort, 54% in IAQ comfort, 31% in lighting comfort, and 30% in acoustic comfort. The high value for IAQ comfort supports the reliability of these perceptual assessments, in line with previous studies showing that air pollutants produce perceptible sensations of stuffiness, reduced freshness, or fatigue. Overall, IEQ satisfaction was positively associated with thermal, visual, and acoustic comfort. No significant relationship was observed with IAQ comfort, likely because the IAQ conditions during surveys showed limited variation and mostly fell within favourable or acceptable ranges.

Conclusions

Despite generally adequate classroom technical conditions, small or non-significant relationships were found between long-term monitoring and students' perception, suggesting the need to go beyond the separate analysis of the single domains. Indeed, SEM highlighted significant correlations among comfort domains, proving that indoor environment is perceived holistically rather than as a sum of independent factors. The results provided a practical outcome in terms of domains ranking, showing that thermal, visual, and acoustic comfort are the main predictors of overall IEQ satisfaction, while IAQ showed no direct effect. These findings underscore the value of integrated, multi-domain and human-centred assessment frameworks, providing insights to understand hierarchical human–environment interactions supporting the design and management of university classrooms.

References

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