Politecnico di Torino

Honors Thesis

Master's Degree Architecture for Sustainability.

"Indoor Environmental Quality & Occupants Comfort Perception In Offices: PROMET&O Questionnaire debug, Mobile application design and A Short-term In-field study in various offices"

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September 2024

Abstract

According to the most recent data, the majority of individuals spend most of their time indoors. Our well-being and productivity are significantly influenced by the indoor climate we experience. Indoor pollutants not only impact our physical health but also play a role in affecting our psychological well-being. Factors such as light, temperature, humidity, and noise contribute to this complex interplay, influencing both our physical and mental states. This underscores the significance of ensuring satisfactory Indoor Environmental Quality (IEQ) across its various domains. Standards and certifications developed over the years propose a vast number of possible parameters and indexes to be monitored.

Adopting a multidisciplinary approach, the PROMET&O (Proactive Monitoring System for Indoor Environmental Quality & Comfort) project engages experts in architecture, building physics, electronic engineering, and computer science engineering to collaboratively develop an innovative and precise multi-sensor for in-site monitoring of IEQ in offices. The PROMET&O multi-sensor is specifically aimed at improving the health, well-being, and overall productivity of occupants. This project is a collaboration between various departments at Politecnico di Torino, including DAD (Architecture Department), DENERG (Department of Energy), DIATI (Department of Environment, Land and Infrastructure Engineering), DET (Department of Electronics and Telecommunication), and DAUIN (Department of Control and Computer Engineering).

This thesis, titled "Indoor Environmental Quality & Occupants Comfort Perception In Offices: PROMET&O Questionnaire debug, Mobile application design and A Short-term In-field study in various offices" focuses on monitoring IEQ and understanding occupants' comfort perception in office environments. The study involves three main stages: debugging and revising the PROMET&O web questionnaire and dashboard design to refine the tool for gathering subjective feedback, designing and prototyping the mobile application to enhance user interaction and data collection, and conducting a short-term in-field measurement in Polito Living Lab, Polito audio Space Lab, company open space and a university residence bedroom. The in-field study, which includes deploying multi sensor devices and collecting objective data, aims to provide insights into optimizing indoor environmental conditions to enhance occupant comfort, health, and productivity.

Thesis approach is concluded by summarizing the key findings and their implications for future work. Firstly, the designed wireframe for the mobile application, which has been developed to provide a user-friendly interface and intuitive navigation. This initial prototype will serve as the foundation for future iterations, allowing for continuous refinement and enhancement.

To ensure users have convenient access via their mobile devices, we decided to redesign the online questionnaire to be fully responsive to various screen sizes. This redesign is crucial for users to seamlessly receive all information about Indoor Environmental Quality, personal information, and data calculated by the PROMET&O multi-sensor. Making the online questionnaire responsive and user-friendly across all devices is fundamental to our approach. A responsive design guarantees that users can easily interact with and complete the questionnaire on smartphones, providing a consistent and efficient user experience regardless of the device used. This enhancement not only improves accessibility but also ensures that data collection is accurate and comprehensive, capturing user feedback effectively. So I delve into the user interface (UI) and user experience (UX) design of the mobile app, adapted from the webpage design to ensure responsiveness and ease of access for USERS answering the questionnaire. The objective is to adapt the design to fit mobile phone screens seamlessly, facilitating straightforward navigation and interaction. By integrating these UI/UX and Gestalt principles, the mobile application optimizes user engagement, prioritizes clarity, and ensures efficient navigation of complex information and tasks.

Fig. 1. Prototyping the mobile application design

Secondly, the findings from various experiments have provided significant insights into the behavior of PROMET&O multi-sensors in different measurement settings. These experiments have been crucial in understanding how individual sensors perform under varying environmental conditions and how multiple sensors can be integrated to provide comprehensive monitoring solutions. For example, it was observed that the CO sensor in multi-sensor 10 consistently recorded significantly higher levels compared to other sensors, indicating a potential issue with calibration or coding that needs further investigation. Additionally, multi-sensor 3 exhibited higher CO_2 levels across different experiments, suggesting that this sensor may be more sensitive or a potential issue with calibration or coding occurred. These observations guide the next phase of debugging and development, allowing for targeted improvements to both single sensors and assembled multi-sensor configurations.

Moreover, it was noted that the sound pressure level sensor consistently showed peaks every hour, which could be an indication of a sound generated by the multi sensor itself. This finding suggests that there may be mechanical or electronic noise within the sensor assembly, which could affect the accuracy of sound measurements. Identifying and addressing these issues is crucial for ensuring the reliability of the sensor data.

Overall, these findings underscore the importance of thorough testing and experimentation in the development of sensor technology. By identifying specific behaviors and anomalies, we can better tailor our solutions to meet the unique challenges presented by different settings.

When conducting in-field measurements of Indoor Environmental Quality in offices, it's essential to consider several factors to ensure accurate analysis and interpretation of the data.

- **Sensor Placement**: Place multi-sensors strategically throughout the office space to capture variations in IEQ across different areas. Consider factors such as proximity to pollution sources, ventilation outlets, and occupant density when positioning multi-sensors.
- **Data Collection**: Continuously monitor IEQ parameters over an extended period to capture variations throughout the day. Ensure that multi-sensors are calibrated regularly to maintain accuracy.
- **Occupant Surveys**: Supplement objective IEQ data with subjective feedback from office workers through online questionnaires. Gather information about occupants' comfort perceptions, and satisfaction with the indoor environment.
- **Data Analysis**: Analyze the collected data using statistical methods to identify trends, correlations, and potential issues with IEQ. Compare objective measurements with subjective responses to gain insights into the relationship between environmental conditions and occupant comfort.
- **Intervention Strategies**: Based on the analysis results, develop intervention strategies to address any identified deficiencies or areas for improvement in IEQ. This may involve adjusting HVAC settings, improving ventilation, implementing air purifiers, or modifying building materials and furnishings.
- **Continuous Monitoring**: Establish a system for continuous monitoring and periodic reassessment of IEQ to track improvements over time and ensure ongoing occupant satisfaction and well-being.

By following these steps, it is possible to effectively measure IEQ in offices and implement targeted strategies to create a healthier and more comfortable indoor environment for office workers.

In-field measurement of Indoor Environmental Quality in Politecnico di Torino Living Lab and A.S.L (Audio Space Lab), Company open space and University residence bedroom (In-Room) using PROMET&O multi-sensors involves objective data collection to comprehensively assess the indoor environment's impact on occupants. Objective data collection involves using PROMET&O multi-sensors to measure various environmental parameters. This includes sensor deployment, data logging, data retrieval and data analysis.

1. Living Lab in-field experiment: The data collected from the multi-sensors in the Living Lab study provides an in-depth analysis of environmental conditions using multi-sensors, revealing notable deviations in temperature, humidity, and air quality measurements compared to reference devices. It is notable that the window is fixed and without a curtain.

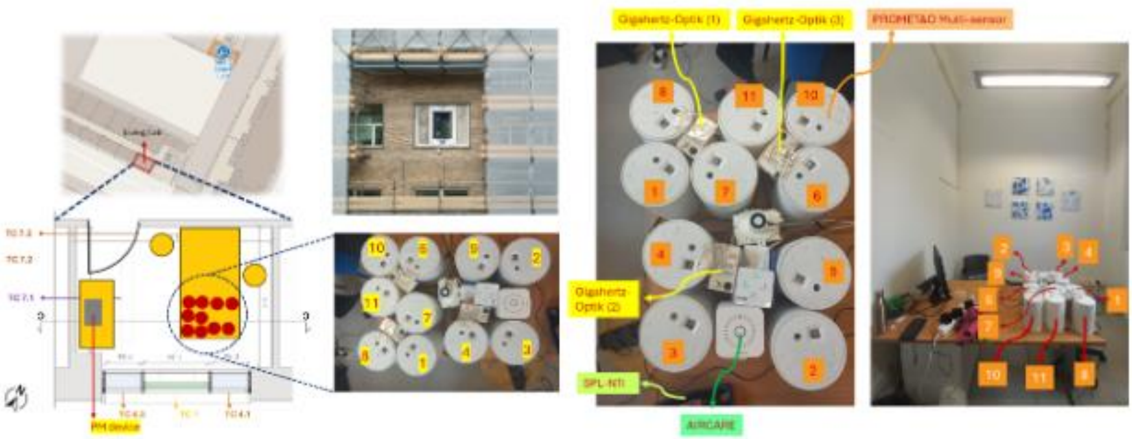

Fig. 2. Living lab environment and multi-sensors positioning

Conclusion for Living Lab experiment: Living Lab's environmental monitoring using multi-sensors revealed consistent deviations in temperature, CO_2, and particulate matter readings compared to reference devices. Additionally, the discrepancies in Sound Pressure Level and illuminance values across different sensors highlight the dynamic nature of the living lab environment, emphasizing the need for cross-referencing of sensor data to maintain data accuracy and reliability.

2. Audio Space Lab in-field experiment: The data collected from the multi-sensors in the Audio Space Lab reveals several key observations about the environmental conditions.

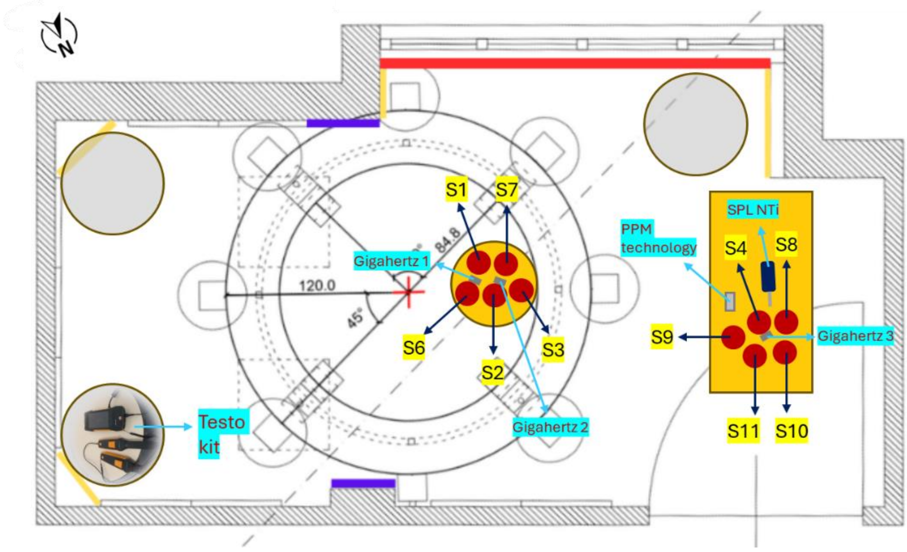

Fig. 3. Audio space lab environment and multi-sensors positioning

Conclusion for Audio Space Lab experiment: The environmental monitoring data from the Audio Space Lab highlights several discrepancies between the multi-sensors and reference devices, particularly concerning temperature, illuminance, CO levels. These inconsistencies may be due to sensor placement, calibration issues, or external environmental factors affecting the readings. Additionally, the high CO levels detected by the multi-sensors, despite the reference reading zero, suggest that there might be sensor malfunctions that need to be addressed. Overall, the findings call for a review of sensor calibration and placement strategies to ensure reliable monitoring of environmental conditions.

3. Company Open Space in-field experiment: Based on the data collected from 2 different office over five days experiments in the company experiments, several key trends and observations emerged regarding the performance of the multi-sensors across different environmental parameters.

Conclusion for Company Open space experiment: There are notable differences between the two environments in terms of room orientation, number of occupants that can cause different temperature, humidity, and air quality, with the n.2 office generally recording higher humidity, particulate matter, and sound pressure levels. The variability in sensor readings suggests the need for further investigation into sensor calibration and debugging to ensure accurate monitoring. Future developments should focus on addressing these inconsistencies and optimizing sensor configurations for more reliable and precise environmental monitoring.

4. In-Room experiment Summary: The room experiment aimed to evaluate the environmental conditions using two multi-sensors over several days, with a focus on temperature, humidity, air quality, and the impact of variables such as natural light, artificial light, and a candle test. The findings reveal consistent trends in sensor readings and significant changes under specific conditions, highlighting the dynamics of indoor air quality and environmental parameters.

Conclusion for In-Room experiment: The room experiment demonstrates the variability and sensitivity of indoor environmental conditions to different factors such as window position, light exposure, and activities like burning a candle. The discrepancies between sensor readings, particularly for CO_2, PM, and CO, underline the importance of using multiple sensors for a comprehensive assessment of air quality. The results emphasize the need for proper ventilation and monitoring to maintain healthy indoor air conditions, especially in scenarios where environmental thresholds are exceeded.

Conclusion for In-Room Candle test: During the candle test, several parameters showed significant changes in both multi-sensors, primarily in particulate matter levels, CO_2, and formaldehyde.
Overall, the candle test demonstrated a notable increase in particulate matter, highlighting the impact of burning a candle on indoor air quality. CO_2 levels also rise, although carbon monoxide and TVOC levels did not show any significant changes during this test.

Project executive summary and final actions for multi-sensors and environments improvements:

Investigating and optimizing sensor calibration and configurations will enhance the accuracy of environmental monitoring and ensure better management of air quality and comfort conditions. Using multiple sensors ensures a comprehensive assessment of IEQ, and adjustments to ventilation and monitoring systems will help maintain healthy indoor air conditions.
Actions can be taken for multi-sensors improvement from all the experiments results:

- **Temperature:** calibrate temperature sensors to address both overestimation (sensors 1, 6, 10) and underestimation (sensors 2, 4, and 6).
- **Relative Humidity:** calibrate relative humidity sensors in all multi-sensors to ensure they reflect accurate values, as they consistently record lower readings than reference devices.
- **Illuminance:** calibrate sensors 1, 10, and 4 to correct overestimation issues, and recalibrate sensor 11 for accuracy.
- **Sound Pressure Level**: calibrate multi-sensors 2, 10, and 11 to bring readings in line with the reference levels.
- **$PM_{2.5}$:** calibrate sensor 10 for overestimation and sensor 8 for underestimation of $PM_{2.5}$ levels.
- **CO_2:** calibrate multi-sensor 3 to reduce overestimation, and sensors 6, 7, and 10 to correct underestimation of CO_2 levels.
- **CO:** calibrate all CO sensors, as they are frequently malfunctioning. Pay special attention to sensor 10 for overestimation issues.
- **Formaldehyde:** calibrate sensors 1, 3, 6, and 10 to correct underestimation, and ensure sensor 4 is properly calibrated to avoid overestimation.
- **TVOC:** check all TVOC sensors against a reference device, as they consistently record low values.