# Preliminary analysis on effects of classroom and ventilation conditions during university lectures

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**Abstract.** Our study investigates indoor air quality during lectures by examining how temperature, $CO^2$, particulate matter, and volatile organic compounds affect the perceived quality of the learning environment. Building on a campus-based measurement project that used real-time environmental sensors to record air data in seminar rooms and highlight the importance of fresh air for concentration and mental performance, the paper analyzes lecture conditions as a dynamic indoor microclimate.
The results show that well-insulated rooms can reach elevated $CO^2$ levels quickly during teaching sessions, making fatigue and reduced concentration measurable environmental effects rather than purely subjective impressions.
The findings underscore the need for continuous monitoring and timely ventilation strategies to maintain healthier, more effective lecture spaces. They also suggest to further develop this sensing project to include technologies like EEG-Headsets to compare the perceived data with real measurements.

**Keywords:** Data Visualization, Air Quality, Ambient Sensing, Interactive Systems

## 1 Introduction

Indoor air quality plays an important role in learning environments since lectures combine prolonged occupancy, limited movement, and often changing ventilation conditions. In such spaces, elevated $CO^2$ concentration is commonly used as an indicator of insufficient air exchange, while particulate matter, volatile organic compounds (VOCs), and nitrogen oxides can provide a broader picture of the indoor environment.

This paper investigates how air quality changes during different lectures and how those changes vary across courses and lecturers. The goal is to identify patterns in ventilation behavior and to understand how classroom conditions differ over time as well as across teaching settings and habits.

# 2 Related Work

## 2.1 Hardware Sensors

After working on several projects on the topic of air quality during lectures at university and personal projects, we have gathered some experience as well as preferences in terms of sensor and MCU choices. In past projects, like HomeGrid [1], we were using the Bosch BME680 sensor [2] for air quality, which primarily gives temperature, relative humidity, VOC, indoor air quality (IAQ) and atmospheric pressure. While being relatively affordable and small in form, we found, for the result to be as precise as we'd like them to be, the sensor requires intensive calibration periods and procedures. We were also working with the Sensirion SCD-41 [3] sensor, which gives temperature, relative humidity and $CO^2$ (400~5000ppm) via I2C, while also having a small footprint.

The Sensirion SCD-41 sensor would have been a good choice, however we are not required to choose the smallest form factor for this project, so we went with the Sensirion SEN66 [4] sensor, as it also featured the I2C connection and expands the measured data by NOx, VOC and most important particle values for 1.0, 2.5, 4.0 and 10.0.

## 2.2 (Indoor) Air Quality

Research on indoor air quality in educational environments has increased substantially in recent years, reflecting growing awareness of the relationship between classroom conditions, health, and learning outcomes. A recent scoping review on educational buildings summarizes evidence that poor indoor air quality and thermal conditions can affect wellbeing, performance, and absenteeism. It highlights schools, nurseries, and universities as important settings for further study. This broader literature shows the relevance of monitoring indoor environmental conditions in occupied teaching spaces, especially where people spend long periods of time in rather dense and semi-enclosed settings [5]. The term CleanAir has established over the last years and demands special awareness regarding air quality in schools.

Meanwhile several empirical studies have focused specifically on classrooms and lecture rooms. For example, university classroom ventilation studies, especially during the COVID-19 pandemic, have shown that $CO^2$ is a useful proxy for ventilation adequacy, since values tend to rise during occupied periods when air exchange is insufficient [6]. A separate lecture-hall study found clear differences in indoor air quality between rooms of different sizes, with $CO^2$ and particulate matter varying across spaces and indicating that classrooms may require special attention. These findings are directly relevant to the present work, as our measurements likewise compare indoor air quality across different lectures and teaching [7].

Beyond $CO^2$, recent studies increasingly adopt multi-pollutant approaches that include particulate matter, VOCs, and other indicators of indoor environmental quality. A 2024 study in educational institutions in Dubai compared VOCs and bacterial contaminants across different room types, showing that pollutant concentrations can differ meaningfully depending on the function of the space and the activity taking place. [8] Similarly, the LEARN project proposes sensor-based monitoring of schools using real-time measurements of VOCs and ultrafine particles, underlining the value of continuous sensing and multi-parameter analysis in educational buildings [9]. These studies support the inclusion of temperature, particulate matter, VOC, and NOx data in our analysis, since a single parameter alone cannot fully describe classroom air quality.

In addition, intervention-oriented research suggests that feedback and monitoring can influence ventilation behavior in teaching environments. Recent work on IoT-driven feedback systems in classrooms demonstrates that visible air-quality information can encourage more effective window-opening and ventilation practices during lessons. This is important for interpreting our results, because differences between lecturers and courses may reflect not only room characteristics but also behavioral factors such as how often and when ventilation is used during class [10].

# 3 Experiment Setup

## 3.1 Classroom Details

We have chosen three rooms, which are all located on the same campus and inside the same building. We can therefore rule out any external factors that would influence the outdoor air, as all rooms use the same air for ventilation. While the building itself is rather “old”, all windows have been replaced and upgraded to triple-glazed windows for thermal insulation one year prior to our measurements. All rooms feature one big TV and several wooden desks with plastic chairs.

**Room R1**

This room is one of two on the ground floor on campus and mainly used for lectures. With 168m² and 504m³ it provides space for up two 55 participants. It is the only room with a carpet floor. It has 14 windows spread across three walls.

**Room R2**

This is the second ground floor room and is used for lectures as well as a photography studio and large coworking-space. It is the only room on campus having active ventilation from an air conditioning system, that got installed during COVID. With 140m² and 602m³ it is the room with the largest volume due to a high ceiling. Since this room is used as a studio and open space there is no fixed participant number. This room has no windows that can be opened.

**Room R3**

Finally, R3 is sitting on the second floor and is the most frequented room on campus for lectures. With 115m² and 345m³ and identical ceiling height it is the second smallest “lecture-room” after R1. It has no active ventilation system and is located directly above

R1. This room features enough space for at least 25 participants. It has 11 windows spread across three walls.

### 3.2 Compared Courses

To capture the broadest insight into the various lecturing scenarios, as well as into teaching and ventilation habits, we first declared a naming system, so the classes, teachers and rooms remain anonymized. The different teachers were assigned unsorted labels from T1 to T10. The three semesters at campus, which are taking classes simultaneously, got labeled C1 to C3. They differ mainly in size: C1 = 20 students, C2 = 19 students, C3 = 22 students.

All teachers and students have been informed about the collection of anonymized data about air quality during courses and have agreed to these measurements being made.

Each held and recorded lecture usually aims for a duration of 2×90 minutes with a 15-minute break in between, so 195 minutes in total. Due to the often hands-on-style of the courses, the breaks and ends might shift forwards or backwards a few minutes to better match the lecture rhythm. Each course starts either at 9:45 (abbreviated with AM), or at 14:00 (abbr. with PM). There is one course in R3 that is limited to 1×90 minutes.

Finally it is to note, that the courses held at the campus mostly have a similar workshop-character, where students and teachers exchange and discuss their thoughts together instead of having 180 minutes of monologue.

### 3.3 Data Collection

#### Hardware Setup

The sensing platform is built around an Adafruit ESP32-S3 microcontroller [11], which is connected via I2C to a Sensirion SEN66 air-quality sensor module [4]. To improve operational robustness, the device also includes a small 250 mAh battery pack as a short-term backup in case external power supply is interrupted. Each device had been calibrated using the given procedure by Sensirion before usage.

During operation, the device connects to Wi-Fi and transmits the measured values to a Google Spreadsheet via the HTTP protocol in 60 seconds intervals. Then a Google Apps Script is used to sort, structure, and format the incoming records automatically, which simplifies later analysis and comparison across lectures and rooms.

Each room was assigned its own data table. The logged fields included Timestamp, BLE Signal Strength, temperature in °C, relative humidity in %, VOC index between 1 and 500, $CO^2$ in ppm, NOx index between 1 and 500, PM1.0, PM2.5, PM4.0, and PM10.0 (each PM value in µm). This structure made it possible to compare indoor air quality across different seminars, lecturers, and room conditions while keeping the dataset consistent across measurement locations.

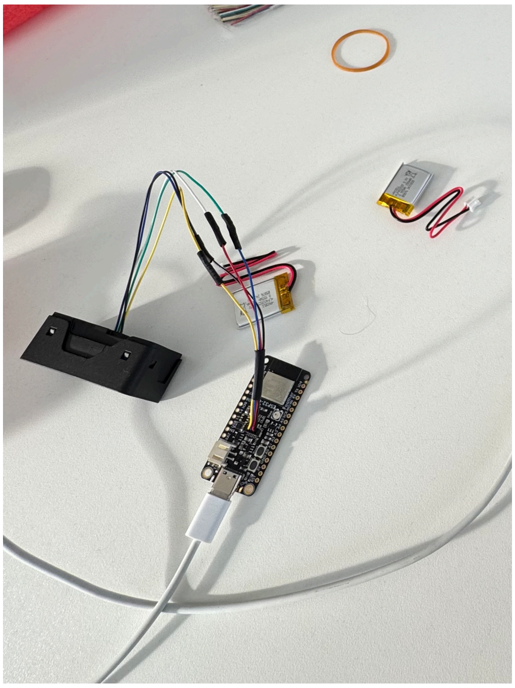

**Fig. 1.** Hardware setup with the sensor, battery and MCU

## 4 Results And Interpretations

Fig. 2 shows four different lectures in the same room on different dates (see legend for DD.MM.). This first general graph already displays the significant effects class size, teacher and ventilation style have on the air quality in the respective rooms. Notable on the first glance is the 15-minute break after around 90 minutes in which most teachers and classes are ventilating the room by opening windows. What's also notable during this ventilation-break is the different behavior of the students: The green graph shows a greater drop in $CO^2$ when compared to blue and red. In combination with the steep rise of the graph instantly after the dropping period at around 100 minutes, this is an indicator that class C1 is likely leaving the room during their break, entering simultaneously when the lecture continues and closing most, if not all, open windows. Also to note is that the red graph of T7 and the yellow graph of T10 corelate, since T10 is giving lectures after T7. This can be seen even better in Fig. 3, where T10/C3 may have slightly opened a few windows but are struggling to lower the ppm (particles per million) through the course of their lecture. Especially since there is no ventilation break.

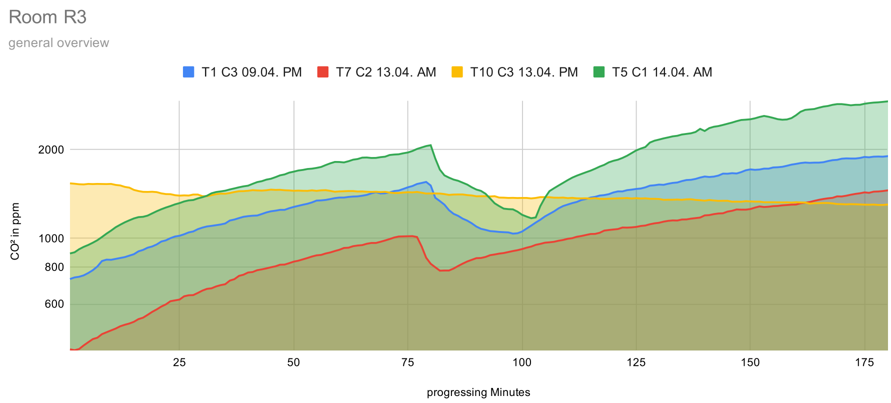


**Fig. 2.** General comparison of four different lectures

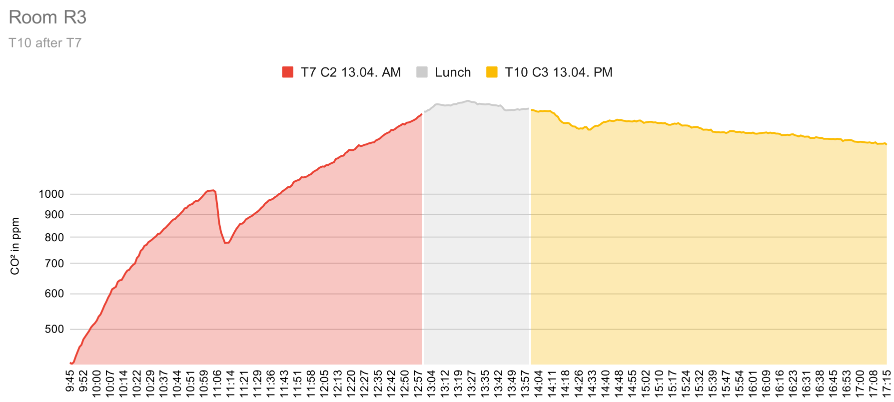


**Fig. 3.** Correlation of AM and PM lectures with bad ventilation between and during lectures.

This effect keeps appearing in the recorded data. What is consistent across most of these scenarios (e.g. in Fig. 4) is the lack of ventilation during lunch break, where the air quality should ideally be "regenerating". In response the CO² levels after Lunch reach way higher levels than they normally would have, if the air would have been "reset" during Lunch.

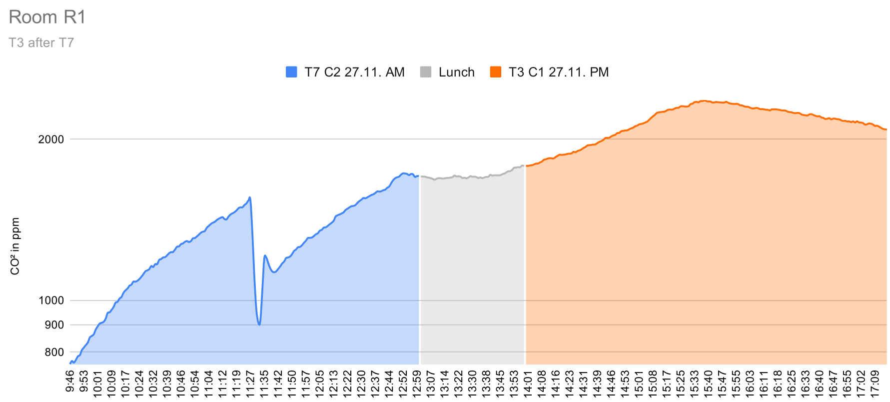


**Fig. 4.** Correlation of AM and PM lectures with no ventilation between and during lectures.

Due to its large volume with (ideally) clean air before lectures start, air quality in R2 seems to be declining slower than in the other rooms. This is further influenced by the active air conditioning system. This effect is clearly visible in Fig. 5. Notable here is also that the two orange lines represent the same lecturer, with the same class but in two different rooms, R1 and R2. What's also to note, is the significant effect of the ventilation during the 15-minute break. Values of both non-ventilated rooms (R1 and R3) are rising similarly during the first 90 minutes, however T1 and/or C3 are ventilating during their break, which keeps the ppm at lower levels during the rest of the lecture.

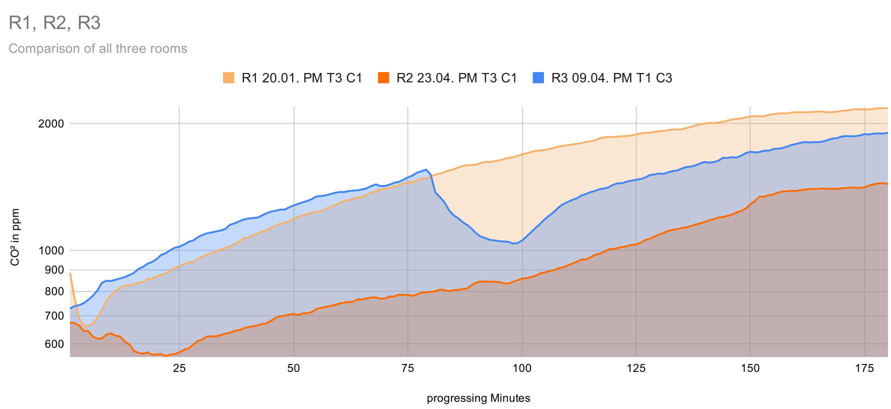


**Fig. 5.** Comparison of quality decrement in all three rooms

### 4.1 Predating Application

The initial minimal data-collection-pipeline and the hardware-setup was done in preparation for the course "Interaction- & Information Design — Design Project 1" during winter semester of 2025/2026, which was held and organized by the authors.

The aim was not only to present air quality in abstract terms, but also to make the measured data intuitively tangible. These creative approaches show new ways of data communication: Instead of rows of numbers, the focus is on sensory, emotional, and immediate experiences.

The students in the end used the recorded or live-data of the rooms for their work: building desk-companions, data-driven graphics, analogue representations and other projects. The course was honored with one of the bronze nails at the 2026 ADC Talent Award in the "Experiment / Creative Technology" category [12].

## 5 Conclusion and Future Work

This study shows that lecture-based indoor air quality can differ noticeably depending on the course, lecturer, student count and very much on ventilation behavior. $CO^2$ level appears especially useful for identifying insufficient air exchange, while particulate matter, VOC, and NOx help contextualize broader indoor environmental conditions. The measurements suggest that classroom air quality should be interpreted as a dynamic process rather than a fixed property of a room.

We also found the single ventilation break to be insufficient for keeping $CO^2$ values at levels, where participants feel energized, comfortable and retain their cognitive performance.

Future work will extend the analysis with precise EEG data to investigate how indoor air quality relates to cognitive performance and lecture-related attention of students as well as of lecturers. That step will allow the project to move from environmental monitoring towards a combined environmental-and-neurophysiological analysis. We will also add qualitative research interviews to better understand the behaviors and situations in the rooms. In addition, the current sensor setup could be expanded to improve synchronization between air-quality signals and lecture events, which would make interpretation even more precise.

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