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Indoor Environmental Quality Monitoring and Students' Feedback Collection in University Classrooms at Politecnico di Torino

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"Se non puoi misurare qualcosa, non puoi capirlo.
Se non puoi capirlo, non puoi controllarlo.
Se non puoi controllarlo, non puoi migliorarlo."

"If you can't measure something, you can't understand it.
If you can't understand it, you can't control it.
If you can't control it, you can't improve it."
- H. James Harrington

"To Carlo, Loris, and Giulia,
And to Prof. Fabio Favoino and Prof.ssa Arianna Astolfi,
who brought 'ispirazione' into my life...

To Virginia, who generously shared her knowledge without hesitation,
and made me feel fortunate to complete this degree with her guidance,
being both a mentor and a friend."

Acknowledgment

The thesis study was carried out with as supervisor Prof. Arianna Astolfi, and as co-supervisors Dr. Giuseppina Emma Puglisi and Dr. Virginia Isabella Fissore from Politecnico di Torino. Its aim is to improve Indoor Environmental Quality (IEQ) and students' comfort perception through the monitoring of IEQ parameters and the collection of occupants' feedback in four classrooms at the university campus.

This thesis is a multidisciplinary study carried out with collaborators from the Department of Energy, Department of Control and Computer Engineering, Department of Mathematical Sciences and Campus Management, Logistics and Sustainability Department at Politecnico di Torino. I would like to thank collaborators for their contribution and support throughout this thesis study.

Abstract

La qualità dell'ambiente interno (IEQ) influenza la salute, il comfort, il benessere e le prestazioni di apprendimento degli studenti, pertanto è fondamentale valutarla e migliorarla negli edifici scolastici. Questo studio di tesi include una revisione della letteratura, fatta per comprendere meglio i fattori che influenzano la percezione dell'IEQ da parte degli studenti universitari, le metodologie di monitoraggio delle condizioni dell'IEQ e casi studio sulla valutazione dell'IEQ nelle università.

Questo studio comprende il monitoraggio in campo dell'IEQ e la raccolta tramite questionario di feedback degli studenti sul comfort percepito in 4 aule del Politecnico di Torino. Il monitoraggio dei domini termico, acustico, visivo e della qualità dell'aria è stato eseguito durante i periodi primavera/estate e autunno/inverno attraverso multisensori. Contemporaneamente, agli studenti che frequentavano le lezioni in queste aule è stato chiesto, attraverso un questionario anonimo online, il loro grado di soddisfazione e le valutazioni sui quattro domini, oltre a domande personali e contestuali. Per valutare meglio i dati monitorati e le risposte ai questionari, sono state analizzate variabili contestuali nelle aule (come apertura e chiusura delle porte e delle finestre, accensione e spegnimento delle luci, ecc). L'analisi è stata eseguita tramite Microsoft Excel e IBM SPSS Statistics.

I risultati del questionario mostrano che gli studenti sono pù soddisfatti dei domini acustico e visivo, mentre sono meno soddisfatti dell'aria interna e del dominio termico. Sebbene i risultati del monitoraggio nei domini visivo e acustico non soddisfino gli standard, le percentuali di soddisfazione degli studenti sono elevate. Al contrario, gli standard sono soddisfatti nei settori termico e dell'aria interna, ma gli studenti non sono soddisfatti. I risultati mostrano che l'aumento dei valori dei composti organici volatili totali (TVOC) e della CO_2 generalmente aumenta l'insoddisfazione.

Lo scopo di questo progetto è valutare le condizioni interne delle aule e come queste sono percepite dagli studenti. Tramite l'analisi dello stato attuale sarà possibile favorire una gestione ottimizzata degli impianti per garantire il benessere degli utenti e contemporaneamente ridurre i consumi energetici.

Abstract

Indoor environmental quality (IEQ) influences students' health, comfort, well-being and learning performance, therefore it is vital to evaluate and improve it in educational institutions. This thesis study includes a literature review, made to better understand the factors affecting university students' IEQ perception, the IEQ conditions monitoring methodologies and case studies on IEQ evaluation in universities.

This study includes in-field monitoring of IEQ and collection of students' feedback via questionnaire on perceived comfort in 4 classrooms of the Polytechnic of Turin. Monitoring of thermal, acoustic, visual and air quality domains was performed during spring/summer and fall/winter periods through multi-sensor devices. Simultaneously, students attending the lectures in these classrooms were asked about their satisfaction and evaluations of the four domains, and personal and contextual questions, through an online anonymous questionnaire. To better evaluate monitored data and questionnaire responses, contextual variables in the classrooms were analyzed (such as opening and closing doors and windows, turning lights on and off, etc.). Analysis was performed through Microsoft Excel and IBM SPSS Statistics.

The results of the questionnaire show that students are more satisfied with acoustic and visual domains, while they are less satisfied with indoor air and thermal domains. Although the monitoring results in the visual and acoustic domains do not meet the standards, the students' satisfaction percentages are high. On the contrary, the standards are met in thermal and indoor air domains, but students are not satisfied. The results show that increasing total volatile organic compounds (TVOC) and CO_2 values generally increases dissatisfaction.

The aim of this project is to evaluate the indoor conditions of classrooms and how these are perceived by students. Through the analysis of the current state, it will be possible to promote optimized management of the systems to guarantee the well-being of users and simultaneously reduce energy consumption.

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Nomenclature

Table 1: Nomenclature.

AC	Acoustic Comfort
AQ	Acoustic Quality
ASAV	Acoustic Satisfaction Vote
ASV	Acoustic Sensation Vote
ASHRAE	American Society of Heating, Refrigerating, and Air-Conditioning Engineers
BVOC	Biogenic volatile organic compound
CBE	Center for the Built Environment
CO_2	Carbon Dioxide
DF	Daylight Factor
E	Illumination
hf	High Frequency
HVAC	Heating, Ventilating and Air Conditioning
IAC	Indoor Air Comfort
IAQ	Indoor Air Quality
IEC	Indoor Environmental Comfort
IEQ	Indoor Environmental Quality
LESI	Learning Environment and Social Interaction
LP	Learning Performance
LSAV	Lighting Satisfaction Vote
LSV	Lighting Sensation Vote
lf	Low Frequency
m.v.	Mean Value
MV	Mechanical Ventilation
NV	Natural Ventilation
PPD	Predicted Percentage of Dissatisfied
PMV	Predicted Mean Vote
PM	Particulate Matter
$PM_{2.5}$	Fine inhalable particles smaller than 2.5 μm

PM_{10}	Inhalable particles smaller than 10 μm
POE	Post-Occupancy Evaluation
RH	Relative Humidity
SBS	Sick Building Syndrome
s.d.	Standard Deviation
SPL	Sound Pressure Level
SPOES	Sustainable Post-Occupancy Evaluation Surveys
TC	Thermal Comfort
TQ	Thermal Quality
TSAV	Thermal Satisfaction Vote
TSV	Thermal Sensation Vote
TVOC	Total Volatile Organic Compounds
T_a	Air Temperature
T_{in}	Indoor Temperature
T_{mr}	Mean Radiant Temperature
T_{out}	Outdoor Temperature
nZEB	Nearly Zero Energy Buildings
VC	Visual Comfort
VQ	Visual Quality
WHO	World Health Organization
WWR	Window Wall Ratio

Definition of terms

Table 2: Definition of terms.

TERM	DEFINITION
Acoustic comfort	includes the capacity to protect building occupants from noise and provide a suitable acoustic environment to fulfil the purposes that the building is designed for [1].
Building envelope	means the integrated elements of a building which separate its interior from the outdoor environment [2].
Daylight and artificial lighting	should provide enough illumination to enable building users to do their tasks safely and comfortably, without interference from glare and shadows [1].
Energy Efficiency	means the ratio of output of performance, service, goods, or energy, to input of energy [3]
Energy Performance Certificate	means a certificate recognized by a Member State or by a legal person designated by it, which indicates the energy performance of a building or building unit, calculated according to a methodology [2].
Energy Performance of a Building	means the calculated or measured amount of energy needed to meet the energy demand associated with a typical use of the building, which includes, inter alia, energy used for heating, cooling, ventilation, hot water and lighting [2].
European Standard	means a standard adopted by the European Committee for Standardization, the European Committee for Electrotechnical Standardization or the European Telecommunications Standards Institute and made available for public use [2].
Indoor Air Quality (IAQ)	refers to the air quality within buildings and structures. A space with good indoor air quality is low in contaminants and odors and has reasonable levels of CO_2 and moisture. The restriction and control of indoor air pollutant sources, in combination with adequate ventilation, are critical in ensuring good indoor air quality [1].
International standard	means a standard adopted by the International Organization for Standardization, which is made available for public use [4].
Nearly Zero-energy Building	a building that has a very high energy performance, the nearly zero or very low amount of energy required should be covered to a very significant extent by energy from renewable sources, including energy from renewable sources produced on-site or nearby [2].
Technical Building System	means technical equipment for the heating, cooling, ventilation, hot water, lighting or for a combination thereof, of a building or building unit [2].
Thermal comfort	refers to the individuals' perception of the thermal environment; they should feel neither too hot nor too cold [1].
Resilience	means the ability to face economic, social, and environmental shocks or persistent structural changes in a fair, sustainable, and inclusive way [5].

Introduction

The purpose of this thesis is to present a method to analyze the Indoor Environmental Quality (IEQ) of university classrooms, the students' comfort perception and to find out main correlations between objective and subjective data. The study begins with in-field monitoring with wall-mounted multi-sensors in 4 classrooms located in an independent building in the university campus of Politecnico di Torino. In-field monitoring was carried out in the spring/summer period of 2023 and in the fall/winter period, from October 2023 to January 2024. It deals with the following four domains and their parameters: thermal, acoustic, visual and indoor air quality domains. The methodology also includes understanding students' perceptions of indoor environmental quality, their satisfaction with four domains and the personal and contextual factors that influence them through an online anonymous questionnaire.

This thesis study begins with a literature review made using the PRISMA method and Scopus search engine. Main purpose of literature review is to understand the state of art on how case studies involving more than one domain assessment are carried out, and to have sufficient information to analyze the results in this case study. At the same time, by combining literature review and current case study information, it is possible to understand and suggest possible improvements in future studies. In the first research question of the literature review, an answer is sought to how students perceive IEQ in university classrooms and what types of questions researchers ask students to analyze their satisfaction with indoor conditions. The second question contains detailed information about how IEQ is evaluated in universities, monitoring methods, important parameters and indexes to be monitored. The third question seeks answers to what personal and contextual factors may affect students' comfort, well-being, learning performance.

In the second chapter, a detailed methodology on how the case study is conducted is presented. The current state of the classrooms and contextual factors taken into account for the case study are explained. Locations of sensors, their measurement frequencies, and parameters they measure are provided. Threshold values of the parameters, determined through standards for the IEQ evaluation, are presented. How the survey questions were evaluated and how all this data was brought together are detailed.

In the third chapter, analyzes of the case study through Microsoft Excel and IBM SPSS Statistics are presented. Subjective and objective evaluation comparisons were made for overall comfort and thermal, acoustic, visual and indoor air domains.

In the fourth chapter, a discussion about the entire thesis is presented. In the fifth chapter, there are improvement suggestions for a more in-depth analysis in possible future studies. At the same time, it is expected that this study will be presented to students and university administration to increase building use awareness among students and improve building management.

1. Indoor Environmental Quality in universities and its effect on students' health, comfort, well-being, learning performance and academic achievement: A literature review.

University campuses are complex structures where different activities take place and therefore different architectural spaces are located. This literature review is about the impact of IEQ on students' comfort perception, health, well-being, learning performance and academic achievement in university classrooms. Answers to 3 research questions are sought using the PRISMA method with the Scopus research engine. The first question is how IEQ is perceived by students in universities. The second question seeks answers to the IEQ evaluation methodology and what the main indexes parameters in universities are. The third question is what are the personal and contextual factors that influence the comfort perception and learning performance in universities.

How students perceive IEQ is explained with some findings of case studies and their impact on students in the first research question. Questionnaire studies conducted to understand students' IEQ perception, and a summary of the questions used, which comfort domains and what kind of questions (e.g., contextual, behavioral etc.) they include, are presented in a table. The second question aims to explain the IEQ evaluation methodology through case studies. A summary table containing the IEQ evaluation methodology, tools and analysis methods in the reviewed articles, and a summary table of the indexes, parameters and factors used for monitoring are presented. Literature review also presents a summary of the findings of studies on what personal and contextual factors may affect students' comfort perception through case studies with third research question.

1.1 Introduction

According to the IPCC AR5 [6], buildings consume 32% of total global energy use, but they also have strong potential to reduce energy consumption. As a result of increasing renewable energy sources, reducing greenhouse gas emissions, making electricity more strategic in the future [7] , energy use at the global level can be reduced. While achieving this objective, it is important not to compromise on Indoor Environmental Quality (IEQ) which is formed by thermal, acoustic, visual, and indoor air quality domains (Figure 1).

Figure 1: Indoor environmental quality domains.

People spend 90% of their time indoors, therefore indoor conditions have an important impact on comfort, health and well-being, and the quality of indoor conditions they live or work in is very important [8]. IEQ domains can also have an impact on each other and therefore on occupant perception [9]. If the requirements of one of these four domains are not met, the occupant may not be satisfied with the other aspects.

IEQ indexes and parameters are regulated by national and international standards, norms and frameworks. These guides set the boundaries for designers to shape the building according to the optimum conditions of comfort indexes. Additionally, it is important to increase the health, comfort and well-being of occupants and to optimize the energy use of buildings.

The objective assessment of IEQ based on building physics is not sufficient to describe and determine the environmental comfort perception of occupants: even if age, gender, psychological factors, and other personal variables are not considered in the regulations, they affect the indoor environment perception of the building occupants [10, 11]. Research has revealed that even if all physical IEQ conditions are met, not all users are satisfied with the same conditions, since IEQ depends on variables that vary from person to person [10-13]. Good health and well-being is one of the United Nations' seventeen Sustainable Development Goals (SDGs), which makes an urgent call for all countries to act [14]. Indoor environmental quality is vital for comfort, health, well-being and the learning performance and academic achievement of students, as well as the productivity of academic staff [14-17].

The Post-Occupancy Evaluation (POE) method is one of the most common methods to measure occupants' satisfaction with IEQ factors [19-21]. POE surveys are applied for occupants to report their satisfaction in areas such as thermal, acoustic and lighting related to the built environment and how they perceive these areas [19]. These studies can cover the entire physical environment or more specifically a single topic, for example thermal comfort. Some POE studies have produced valuable findings with less than 100 responses on a building, but some POE studies have shown trends and analyzed occupant satisfaction more in detail, with many buildings and more than a thousand responses [19, 22]. The data collected from POE research, where a multitude of responses have been collected, has been compiled and utilized to create benchmarks. Creating a benchmark for a building feature (for example, thermal comfort, or more specifically temperature) is very important in terms of setting standards for future building standards-regulations for building owners and professionals who will be involved in this field [23].

Astolfi and Pellerey proposed a questionnaire for subjective evaluation in their study with high school students [24]. This study underlined the importance of the overall IEQ assessment as well as the effect of domains on overall comfort. As the occupant's age changes, their comfort perceptions could also change, so it is important to conduct similar studies with university students. While there are more studies on Indoor Environmental Quality for primary and secondary education, research on higher education is much more limited [25].

The study conducted under 9 different temperatures and lighting conditions by Pradhan et al. [9] analyzed temperature, lighting range, thermal sensation, thermal comfort, lighting sensation, and lighting comfort. It has been observed that IEQ domains have an impact on each other and overall satisfaction. Therefore, different parameters have effects on different perceptions of occupants (e.g., attention ability, working memory ability, perception ability etc.).

In recent years, researchers have conducted studies to understand the impact of IEQ on students' comfort perception. Ricciardi and Buratti [18] conducted a study involving thermal, acoustic and visual domains with subjective and objective evaluation. Regarding acoustic comfort, they found that background noise was quite effective on acoustic perception, and regarding visual comfort, the measured illuminance had a correlation with the question of dissatisfaction about glare.

In their systematic review study, Wang et al. [26] examined the studies on the effect of IEQ on students' cognitive functions. Studies revealed that IEQ affects students' cognitive functions such as attention, short-time memory, long-term memory, working memory, comprehension, reaction time, reasoning, decision making, problem solving, planning and creativity. Brink et al. [27] found a positive relationship between students' perceived cognitive performance and short-term academic performance, but it became clear that research should continue to be conducted for long-term effects.

Agg and Khimji [28] demonstrated in their studies that Indoor Environmental Quality (IEQ) and students' perceptions are not always aligned, but the perception of comfort significantly impacts well-being. It is understood from these studies that it is necessary to conduct more studies and analyze existing studies well to understand the effect of IEQ on students learning performance and academic achievement. This literature review is based on articles about university buildings.

1.2 Research Methodology

This literature review deals with indoor environmental quality in universities and its effects on students' health, well-being, comfort, academic achievement, and learning performance.

Three research questions related to IEQ in universities were defined, as summarized in Table 3, to answer

i) how IEQ is perceived in universities,
ii) how IEQ is evaluated and what are the main IEQ indexes and parameters in universities,
iii) what are the personal and contextual factors that influence students comfort perception and learning performance in universities.

The first research question deals with the comfort perception of occupants, the subjective evaluation of IEQ. The second research question examines objective evaluation of the IEQ, its indexes and parameters values that determine the minimum and maximum comfort level. The perception of IEQ domains, or the perception of overall comfort, is affected by personal factors as well as contextual and related features. In the third question, these factors (i.e., personal, contextual) that affect the comfort perception of occupants are examined.

The method for this literature review is shown in Figure 2, Figure 3 and Figure 4. "Preferred Reporting Items for Systematic Reviews and Meta-Analyses" (PRISMA) [29] rules were applied, and Scopus search engine was used.

The first step in the selection process of literature review is the definition of keywords. Different keywords were researched for each question. Second additional research was carried out when the initial research did not yield a sufficient number of results.

For each question, the criteria that allowed to refine the results are, only articles and reviews, only articles published between 2018-2023, only articles written in English. The same research was performed to find articles published in 2023-2024.

In addition, articles were excluded if in non-subject areas such as astronomy, medicine, agriculture and biological science, mathematics, molecular biology, and if not considering more than one IEQ domain.

For the three research questions 849, 184, and 326 articles have been selected, respectively. Criteria specified below were applied. 19, 13 and 15 articles were examined for analysis.

During the searches, some same articles were found, resulting in a total of 33 articles on IEQ evaluation in universities. After reviewing the articles, they were examined in relation to the relevant research questions.

Table 3: Research objectives with related questions and keywords used for the research.

TOPIC	SUBTOPIC	QUESTION	SCOPUS KEYWORDS
Indoor Environmental Quality (IEQ)	Perception of IEQ in Universities	How is IEQ perceived in universities?	First Search "University", "Multidimensional comfort", "Discomfort", "Overall Comfort", "Indoor Environmental Quality", "Learning Performance", "Student" Second Search "Subjective evaluation", "Poe", "Questionnaire", "Evaluation", "Indoor Environmental Quality", "Student"
	Evaluation of IEQ Indexes and Parameters	How is IEQ evaluated and what are the main IEQ indexes and parameters in universities?	Third Search "IEQ index", "IEQ parameter", "IEQ", "Indoor Environmental Quality", "Objective evaluation", "University"
	Factors	What are the personal and contextual factors that influence students comfort perception and learning performance in universities?	Fourth Search "Learning performance", "IEQ", "Academic achievement", "Psychosocial factor", "perception" "Contextual variable"

Figure 2, Figure 3 and Figure 4 shows the articles selection process for the first, second and third research questions, respectively.

Search 1: How is IEQ perceived in universities?

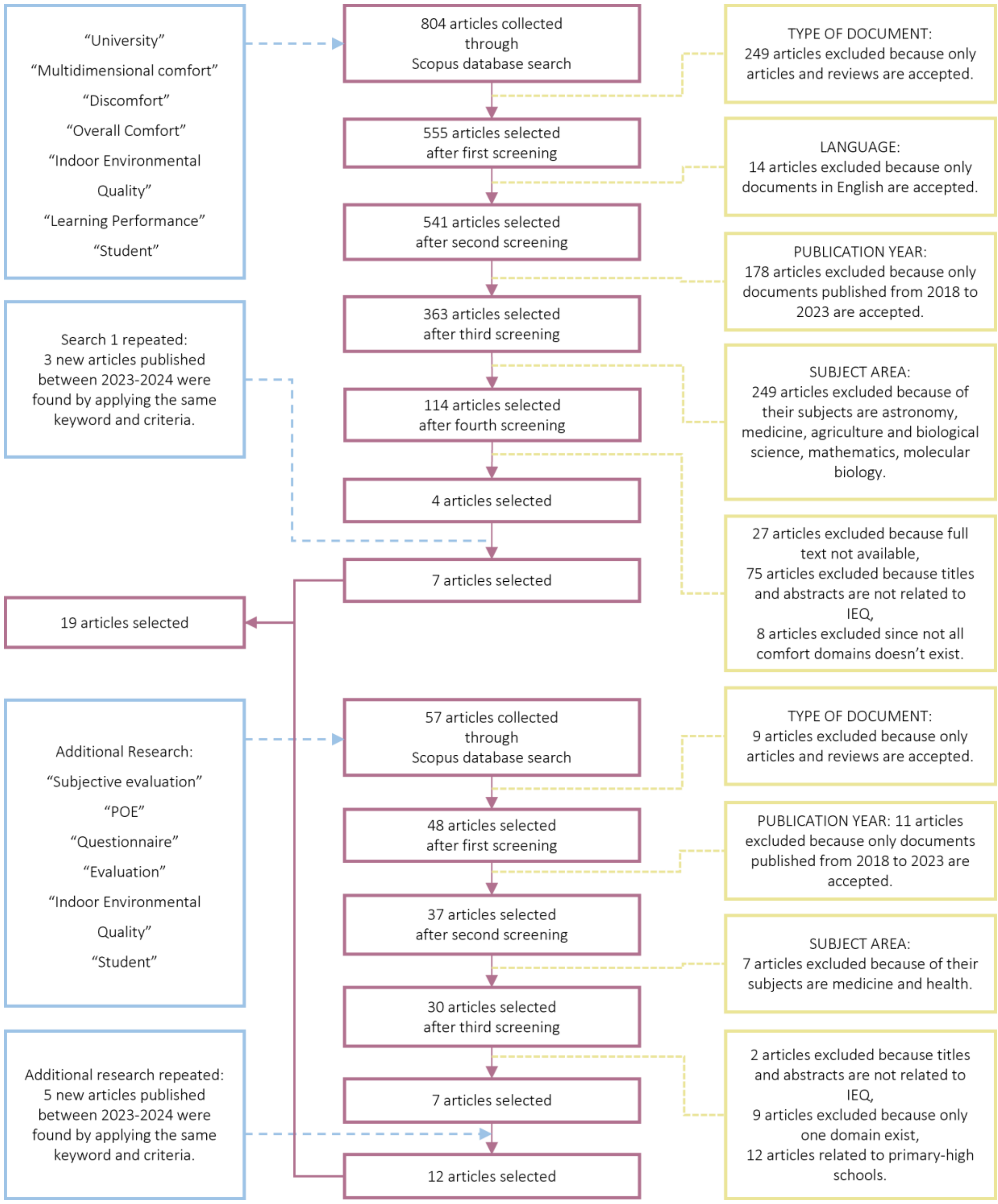

Figure 2: Flow chart of the selection process of the articles complying to the first research question "How is IEQ perceived in universities?".

Search 2: How is IEQ evaluated and what are the main IEQ indexes and parameters in universities?

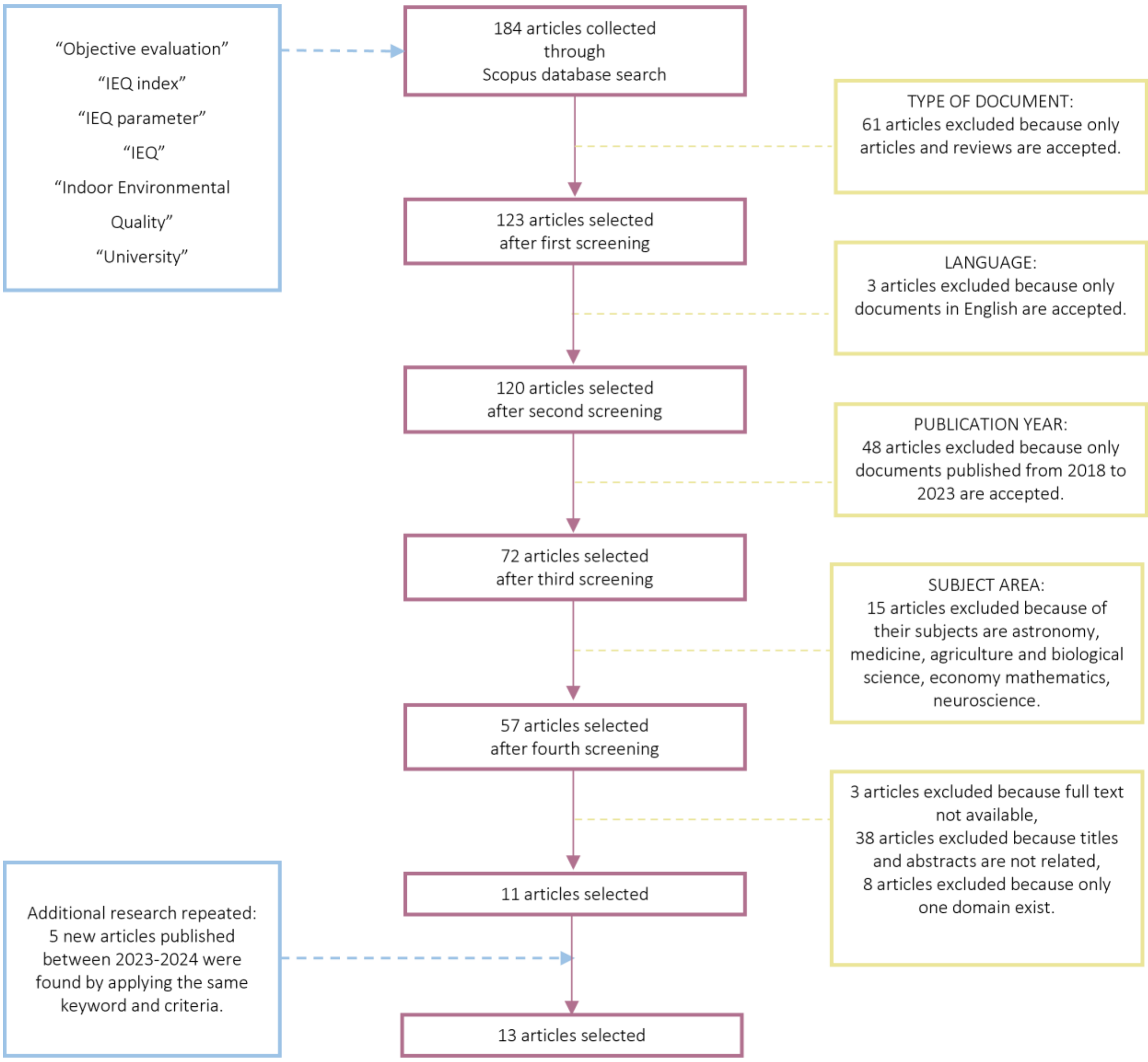

Figure 3: Flow chart of the selection process of the articles complying to the research question "How is IEQ evaluated and what are the main IEQ indexes and parameters in universities?".

Search 3: What are the personal and contextual factors that influence students' comfort perception and learning performance in universities?

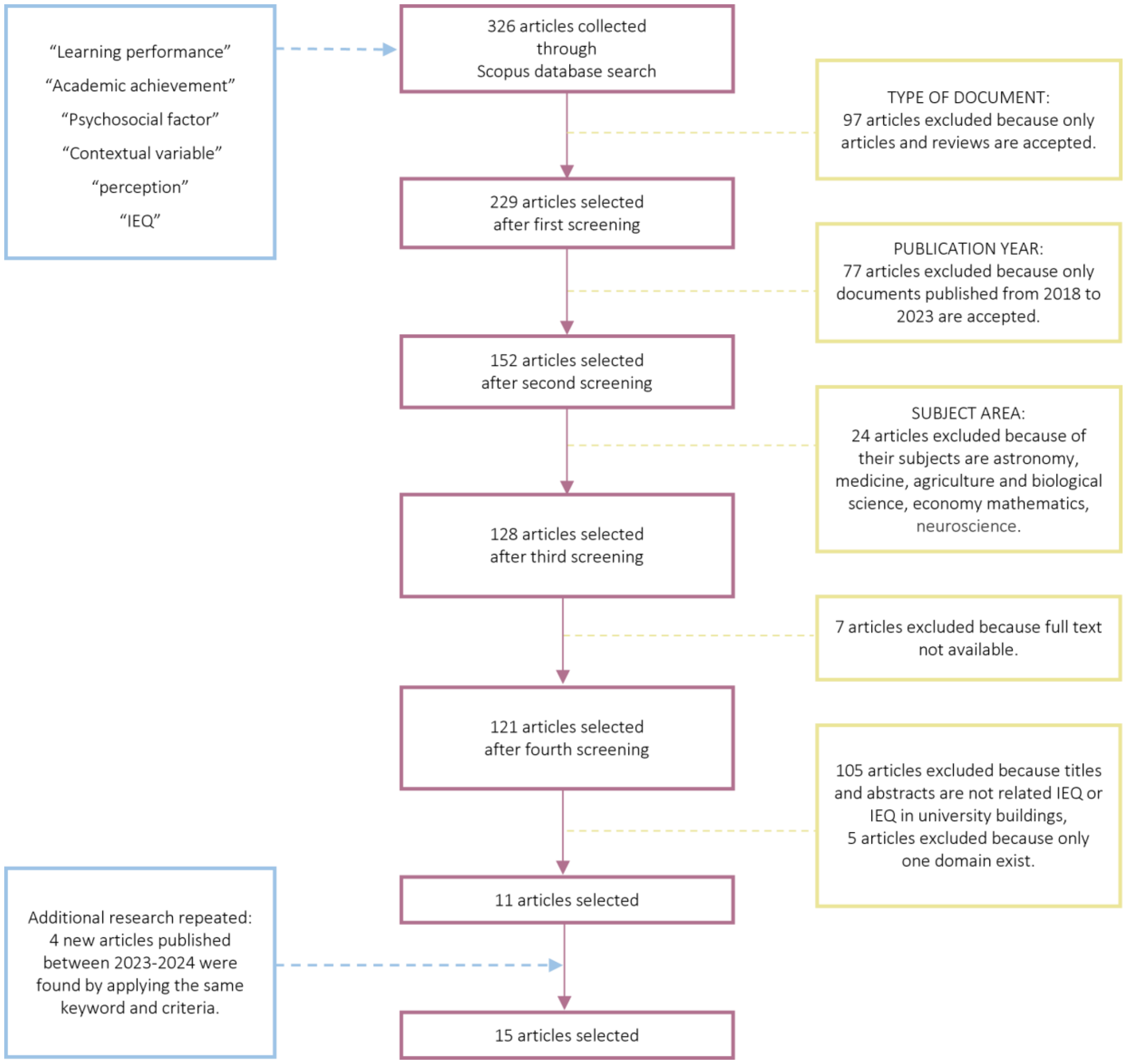

Figure 4: Flow chart of the selection process of the articles complying to the research question "What are the personal and contextual factors that influence student comfort perception and learning performance in universities?".

1.3 How is IEQ perceived in universities?

Environmental comfort is a multifaceted concept influenced by both objective parameters and different factors (e.g., physiological, contextual, behavioral etc.), necessitating thorough investigation across diverse research fields [18]. In recent years, many researchers have been working to understand the relationship between IEQ conditions and students' satisfaction level [15]. Educational buildings generally contain more occupants than other building types and therefore air quality is very closely related to health, well-being learning performance and absenteeism [15]. To discern the correlation between subjective aspects and objective parameters, researchers employ specialized questionnaires, creating a comprehensive overview of classroom environmental quality through a combination of measurements and subjective insights [18].

Scholars have studied the relationship between built environment and building occupants for many years. The POE (Post-Occupancy Evaluation) method is one of the most common methods to measure occupants' satisfaction with IEQ factors [21, 30]. The origins of contemporary POE methodologies can be traced back to the 1960s, during which evaluations were conducted for certain types of buildings such as hospitals, prisons, student dormitories, with a primary focus on the well-being and satisfaction of occupants [23]. The development of building performance evaluation frameworks, coupled with advancements in building construction technologies, has expanded POE to include the technical indicators and energy consumption of buildings [23]. While the operation phase of buildings is the process that takes the longest time in the entire life cycle of buildings and while we are trying to create a low carbon and healthy process, focusing on POE should be a constant for us [31].

Table 4 shows a summary of the questionnaires found in the studies included to the first research question. The location of the study, which comfort domains are included, a general summary of the type of questions, a brief summary of questions, and hours of interest are included.

Table 4: Summary of the questionnaires in the articles examined.

REF.	LOCATION OF STUDY	COMFORT DOMAIN	TYPE OF QUESTION	QUESTIONS	HOUR OF INTEREST
[9]	USA	Thermal, Visual	Physiological, Contextual	Thermal sensation vote (TSV), from -3 for 'cold' to 3 for 'hot', Thermal comfort vote (TCV), from -3 very unsatisfied to +3 satisfied, Lighting sensation vote (LSV), from -3 for 'too bright' to 3 for 'too dim', Light comfort, from +3 very satisfied, -3 very unsatisfied.	*Infor. not provided*
[17]	Spain	Thermal, Acoustic, Visual,	Physiological	Gender, age, type of mask, clothing. Thermal comfort, acoustic comfort, visual comfort, overall comfort. 7-point scale from -3 for "very dissatisfied" to 3 for "very satisfied", Acoustic sensation vote (ASV): from -3 for "very noisy" to 3 for "very silent",	*Infor. not provided*

				TSV: from -3 for "cold" to 3 for "hot, Lighting sensation vote (LSV): from -3 for "very bright" to 3 for "very dark".	
[18]	Italy	Thermal, Acoustic, Visual	Physiological, Contextual	Personal data (age and sex), classroom characteristics and survey date. Thermal questions, position inside room, personal environmental control. Individual perception of noise sources, frequency, quality of sound environment, evaluation of intelligibility of the sound environment. Individual perception of the indoor artificial lighting-natural lighting.	*Infor. not provided.*
[20]	China	Thermal, Visual, IAQ	Psychological, Contextual, Behavioral	Learning Performance (LP) test: Schulte grid, digital filter, graphic overlay, stereo vision, letter search, word color interference, memory scanning, visual learning, continuous addition and subtraction, logical events.	*Infor. not provided*
[27]	Netherlands	Thermal, Acoustic, Visual, IAQ	Psychological, Contextual	Thermal sensation, thermal preference. Quality of air, ventilation, odor character and intensity, moisture. Amount of (day)light, flickering, reflections and glare, color sensation, contrast. Noise from within the classroom, noise from outside the classroom, noise disturbance. Alertness, concentration, memory, perception, problem-solving. Productivity, reading, typing.	In 10-min break of lectures.
[30]	Spain	Thermal, Acoustic, Visual, IAQ	Physiological, Psychological, Contextual	Gender, age, campus name, building number, floor number, room number construction year. Control preference: windows, windows blinds or shades, conditioning unit, heater, fans, thermostat. Building system satisfaction: Structure vibrating, façade covering, doors-windows, elevator, HVAC, lights, aesthetic problems, others. Thermal comfort, acoustic comfort, visual comfort, IAQ.	*Infor. not provided.*
[32]	Denmark	Thermal, Visual, IAQ	Physiological, Contextual, Behavioral	Gender, age, degree, enrolment length, location of time spent, weekly time spent. Opinions on: Energy knowledge and university policies, knowledge of university energy policies and activities, building control system, building control in classrooms, opinions on indoor comfort in classrooms, indoor comfort and energy control on campus, distributed energy resources on campus.	*Infor. not provided.*
[33]	Jordan	Thermal, Acoustic, Visual, IAQ	Physiological, Psychological, Contextual, Behavioral	Gender, age, years of using building, classroom attendance hours per session of the students, study conditions, workload and concentration demand, which classroom environment is stimulating and fascinating. Classroom air temperature, relative humidity, air quality, noise, lighting conditions, overall comfort, and its impact on quality of learning, productivity, and performance. Health related symptoms, current and past symptoms such as headache, dry mouth,	*Infor. not provided*

				nausea, dizziness, difficulty concentrating, burning, irritation, stuffy nose, runny or stuffy nose, hoarseness, dry throat, cough etc. Recommendations to improve the IEQ of classrooms.	
[34]	Netherlands	Thermal, Acoustic, Visual, IAQ	Contextual, Physiological	Name, gender, age. In general, how do you experience the [sub-category] of classrooms? If applicable, what would you change regarding the [sub-category] in the classrooms? Which other aspects [list of related aspects] do you want to discuss?	1 hour for each interview
[35]	Netherlands	Thermal, Acoustic, Visual, IAQ	Physiological, Contextual	Gender, age, time spent at home, study place, lifestyle.	*Infor. not provided.*
[36]	China	Thermal, Acoustic, Lighting, IAQ	Physiological, Psychological, Contextual	Gender, age, location. Thermal comfort, acoustic comfort, visual comfort, IAQ. Learning efficiency, interior space design, and building service performance. Self-reported SBS symptoms.	*Infor. not provided.*
[37]	Portugal-Spain	Thermal, Acoustic, Visual, IAQ	Physiological	Gender, age, mask, clothing. Thermal comfort, acoustic comfort, visual comfort, IAQ. 7-point scale from -3 for "very dissatisfied" to 3 for "very satisfied" ASV: from -3 for "very noisy" to 3 for "very silent" TSV: from -3 for "cold" to 3 for "hot LSV: from -3 for "very bright" to 3 for "very dark"	Last 15 minutes of lectures
[38]	Netherlands	Thermal, Acoustic, Visual, IAQ	Physiological, Psychological, Contextual	Gender, hours of sleep. 1_Perceived physical health, perceived physical health complaints, 2_Perceived cognitive response. 3_Corsi block task, Go-No go task, Stroop task, Wisconsin Card Sorting test. 4_Basic emotional process scale, 5_ Positive and negative affect scale, 6_ Karolinska Sleepiness Scale.	At least 20 min after beginning of lecture
[39]	Spain	Thermal, Acoustic, Lighting	Psychological, Contextual	Learning Environment and Social Interaction (LESI): Teacher-student interaction (lecture classroom), interactions between students (lecture classroom), teacher student interaction (practice classroom), interactions between students (practice classroom), classroom design encourages participation, learning space attachment, lighting satisfaction, ventilation satisfaction, thermal level satisfaction, wall color satisfaction, acoustics satisfaction level, room layout satisfaction, furniture comfort satisfaction, connection with nature satisfaction, importance of professor-student interactions, importance of interactions with professors from other courses, importance of interactions between students, importance of interactions with students from other courses.	*Infor. not provided.*

[40]	Spain	Thermal, Acoustic, Lighting	Physiological, Contextual	Gender, age, clothing, physical environmental parameters, TSV, from -3 for 'cold' to 3 for 'hot' ASV, from -3 for 'very noisy' to 3 for 'very quiet' LSV, from -3 for 'very bright' to 3 for 'very dark' Overall comfort except IAQ, from -3 for 'very dissatisfied' to 3 'very satisfied'.	Last 15 minutes of lectures
[41]	France	Thermal, IAQ	*Infor. not provided.*	Thermal sensation scale ranging from -3 to +3	*Infor. not provided.*
[42]	USA	Thermal, Visual, IAQ	*Infor. not provided.*	Self-reported comfort according to Likert chart.	*Infor. not provided.*
[43]	Canada	Thermal, Acoustic, Visual, IAQ	Physiological, Contextual	Gender, age, degree, years of enrolment. How engineering students utilize classrooms and space. Designed according to ISO 10551 Standard. Signposting of orientation, direction or sorting, identification, information / education. Shape of building, aesthetics perspectives.	*Infor. not provided.*
[44]	UK	Thermal, Acoustic, IAQ	Physiological, Contextual	Gender, age. Knowledge of lecture theatres: frequency of lecture theatre attendance and sitting duration. Subjective perception in terms of temperature, subjective evaluation of the concentration level, subjective sensation of the indoor air, clothing insulation, acoustic environment evaluation, lighting environment evaluation, subjective evaluation of the facility environment.	After first 50 min., before last 50 min.
[45]	Pakistan	Thermal, IAQ	Physiological, Contextual	(0) extremely dissatisfied, (1) very dissatisfied, (2) dissatisfied, (3) slightly dissatisfied, (4) neutral, (5) slightly satisfied, (6) satisfied, (7) very satisfied, and (8) extremely satisfied, question answers are arranged according to this scale. Gender, age, building usage in years, sitting position in the lecture hall, temperature, and temperature feel. The activity level and clothing. The comfort conditions, reasons for dissatisfaction.	*Infor. not provided.*
[46]	France	Thermal	Physiological, Contextual	How do you perceive the indoor temperature at this instant? 'on a scale of five, from "Cold" to "Hot".	*Infor. not provided.*

Personal questions other than age and gender are generally in the minority in the surveys. Generally, there are questions about IEQ perception.

In recent years, researchers have conducted studies to investigate the effect of IEQ on students' perceptions. Researching and improving indoor air quality conditions in classrooms are vital. Lighting, thermal, air quality and acoustic changes cannot be tolerated by students and may reduce academic achievement and learning performance (LP) of students [16, 32].

Ventilation measures increase IAQ by reducing air pollutants [17]. Findings of Bortolini & Forca [30], confirm that there is a correlation between the type of ventilation system and the IEQ of classrooms. The COVID-19 epidemic has proven how important indoor ventilation and IAQ are. When ventilation is reduced, the amount of harmful pollutant and therefore the spread rate of the virus increases. At the same time the virus negatively affects indoor thermal comfort due to the need for natural ventilation and therefore the decrease in indoor temperature during winter periods [17]. In the study conducted at a faculty of architecture in Jordan [33], students participated in the questionnaire to evaluate the IEQ conditions of the classrooms. From the answers given by the students to the questionnaire, it was observed that 24.8% had low concentration, 16.5% had dry skin, 12.4% had nasal congestion, and 10% had headache. A significant majority, exceeding 70%, established a relationship between these symptoms and the quality of the internal atmosphere in design studios [33]. Similarly, in the Netherlands, instructors and students who participated in the questionnaire stated that IEQ conditions cause health problems and some symptoms (e.g., dizziness, sweating, eye irritation, tired feeling etc.) [34]. Weng et al. [36] conducted a study with one classroom each from green, retrofitted, and conventional college buildings. In the research, occupant satisfaction was analyzed and compared with point-to-point testing, long-term monitoring, and self-reported Sick Building Syndrome (SBS). The effects of IEQ on student satisfaction, SBS symptoms and student learning performance were researched. Examining the relationship between SBS symptoms and learning efficiency by Pearson correlation analysis revealed that SBS symptoms were significantly related to learning efficiency [36]. Poor IEQ conditions may cause lecturers to finish their lectures early, take breaks more often than necessary, and cause students' concentration loss.

According to [30], the age of the building is related to user satisfaction, and faculty members prefer new buildings (since they spend longer time in the buildings). Bortolini & Forcada [30] revealed that the cooling system is not as common in university buildings as it is in offices, therefore the level of insulation in windows significantly affects the satisfaction level of students in classrooms. In this study, there is no relationship between window insulation or heating type and thermal comfort in winter if the heating system of the classrooms is well dimensioned. In another study [32] conducted with students from engineering faculty in Denmark (who are also knowledgeable about issues such as energy control, energy policies, and distributed energy sources) it resulted that they considered themselves more affected by thermal comfort, compared to visual comfort, due to very high and very low temperature values.

Ma et al. [20] in their experimental studies, performed to investigate the relationship between classroom indoor physical environment and LP, it is revealed that different parameters (e.g., RH, C_{CD} or T_a etc.) affect different elements of students' learning performance with a positive correlation. The study conducted under 9 different temperatures and lighting conditions by Pradhan et al. [9] analyzed correlation between temperature, lighting range, thermal sensation, thermal comfort, lighting sensation, and lighting comfort. They found that temperature was positively correlated with thermal sensation, thermal comfort, and lighting sensation. Lighting range has a positive correlation with thermal comfort but a negative correlation with lighting comfort, that is, as the lighting range increases, and the environment becomes brighter, thermal comfort increases but lighting comfort decreases. As can be understood from all these correlations, IEQ domains have an effect on each other and therefore different parameters have an effect on the different perceptions of occupants (e.g., attention ability, working memory ability, perception ability etc.). This study revealed that people's physiological responses also change at different temperature and lighting values. Under different temperature and lighting conditions, physiological responses such as heart rate, skin temperature, mental stress, alertness, mental fatigue, valence, and arousal have changed. While mental workload increases in a brighter room, mental stress increases in low lighting conditions. Although thermal comfort is one of the most important IEQ factors, other comfort elements must be considered in order to evaluate global comfort in classrooms [18].

Lighting is very important in the visual perception of academic staff and students, and [18] have shown that natural lighting is preferred over artificial lighting. If students are not satisfied with artificial lighting, they are less likely to be satisfied with the classroom [21]. Weng et al. [36] showed that there is a positive correlation between desktop illuminance and learning efficiency. According to [30], the Window Wall Ratio (WWR) rate in offices does not affect the lighting comfort perception, because artificial lighting is acceptable for occupants. However, the situation is not the same for educational buildings. According to [30], in educational buildings as WWR increases, lighting satisfaction increases. In another study conducted in Denmark [32], while some of the students stated that the automatic light adjustment did not affect their concentration, some of them stated that they were affected by this situation. In particular female students do not agree with frequent changes in lighting, and students in general believe that frequent changes in indoor comfort may affect their concentration and learning performance [32]. Another subfactor that influences visual comfort is the outside view. According to study of Hamida et al. [35] students prefer to have an outside view, whether they are working from home or on a university campus. Particularly, the comfort preferences of undergraduate students studying architecture, a profession where visuality is important, may differ from students studying at other levels.

Acoustic condition is also very effective on students' comfort perception. In their experimental study, Brink et al. [38] revealed that reducing reverberation time had positive effects on students' perceived quality of learning. It was observed that as the horizontal lighting level increased, perceived lighting comfort increased. Therefore, the quality of students' learning performance, their emotional status and perceived health were also positively affected. However, it was observed that these positive effects did not influence short-term academic performance [38].

Studies have been conducted in educational buildings to investigate and understand the effects of acoustic conditions on students. In their study, Brink et al. [34] found that there is excessive reverberation and low speech level at the back of the classrooms. This may affect students' acoustic comfort. Another important subfactor is noise that occurs for different reasons. Performed interviews of Brink et al. [34] revealed noise disturbances have a negative impact on the concentration of faculty members and students. According to Weng et al. [36], external noise in educational buildings has a direct impact on users' acoustic perception and satisfaction, and students are less tolerant to noise than other factors of the indoor environment. Students are mostly acoustically influenced by outdoor traffic noise, other outdoor noise, people talking in neighboring areas of the classroom [17]. Noisy ventilation systems, and factors such as difficult course material and less visual in the course material can affect acoustic comfort [18, 47]. Among the students who participated in the research conducted at the faculty of architecture in Jordan [33], while a majority of students (60%) stated that they were satisfied with the quality of lighting, 55% stated that they were dissatisfied with the noise level. In this study, a correlation was seen between self-reported concentration assessment and classroom evaluation, suggesting that if students' IEQ perceptions increase, their concentration and therefore their grades may increase.

Hamida et al. [35], in their study by creating nine different student profiles, they saw that there are also student profiles that do not attach much importance to sounds in their study environments. However, this study proves that generalizing all case studies is not a correct perspective and different student profiles are more sensitive to different IEQ domains.

All these studies need to be expanded and carried out in more university buildings. Creating criteria for the students' IEQ satisfaction in universities is crucial for adding a layer of quality to education, and it is highly important for the attainment of well-being [21]. Studies analyzing factors affecting IEQ have become more common in recent years, and although it is not possible to develop a single model, research needs to be expanded to find the reality [39].

1.4 How is IEQ evaluated and what are the main IEQ indexes and parameters in universities?

Table 5 below provides a summary of the case study locations, study periods, IEQ evaluation methodology, and analysis methods used in the case studies.

Table 5: IEQ evaluation methodologies in the analyzed case studies. The following information is provided: reference; location; study period; questionnaire, i.e., questionnaire typology, number of questions, response; monitoring, device; analysis used for evaluation. Long-term monitoring. (L.T.M.), spot measurement (S.M.), questionnaire typology (Q.T.), number of response (N.R.), method (M.).

REF.	LOCATION	STUDY PERIOD	IEQ EVALUATION				ANALYSIS
			QUESTIONNAIRE		MONITORING		
			Q.T.	N.R.	M.	DEVICE	
[9]	North Dacota State University, USA	*Infor. not provided.*	*Infor. not provided.*	17	*Info. not prov.*	Empatica E4 for record heart rate, skin temperature Emotive EPOC X for record brainwaves Thermal meter, illumination meter	Kolmogorov-Smirnov Test Spearman Correlation Two-Way Analysis Of Variance Multiple Linear Regression Analysis Durbin-Watson Statistical Measure
[17]	Fuente Nueva Campus, Spain	January and July 2021	*Infor. not provided.*	*Infor. not provided.*	L.T.M.	HOBO® MX1102 for temperature, RH, CO_2 HOBO® MX1104 for lighting HD403TS2 Delta OHM® for air velocity, Imperum-R TECNITAX® Ingenier í a for sound pressure level	Probability Plots (P-P) Kolmogorov-Smirnov Test Mann-Whitney U Test Levene's Test For Equality Of Variances Parametric Pearson Correlation (IBM SPSS Statistics 23.0)
[18]	University of Pavia, Italy	Spring and Autumn 2015	*Infor. not provided.*	*Infor. not provided.*	L.T.M.	Delta Ohm DO9847 for external climatic conditions BABUC acquisition system for thermal-hygrometric measurements Mavolux 5032 for the luxmeter Bruel & Kjaer 2260 type 0 analyzer	*Infor. not provided.*

[20]	Zhejiang Sci-Tech University, China	March and April 2021	APCD evaluation method	*Infor. not provided.*	S.M.	T-type Thermocouple-GRAPHTEC Midi Logger GL220 for temperature Thermo Recorder TR-72Ui for relative humidity Hotline Anemograph Testo 425 for air velocity Light Sensor RS485 for illuminance CCD Handheld for CO_2 concentration 7755	APCD (Attention, Perception, Comprehension, and Deduction) Evaluation Method
[27]	Hanze University of Applied Sciences, Netherlands	February 2020	*Infor. not provided.*	163 responses	L.T.M.	ATAL VLK-60W for the indoor air quality, CO_2, particulate matter (PM_{10} and $PM_{2.5}$), and volatile organic compounds, air temperature, RH, ATAL ENV-MB350NV for temperature and CO_2 VOLTCRAFT MS-1300 for horizontal illuminance level	Multiple Regression Analyses Quantile-Quantile (Q-Q) Plots Shapiro-Wilk Tests Poisson Regression One-Tailed Spearman Correlation (IBM SPSS Statistics 28.0)
[30]	In 2 campus buildings	October 2017	POE Survey	1013 responses	-	-	Goodman And Kruskal's Gamma Spearman Correlation Chi-Square Tests
[32]	University of Southern Denmark, Denmark	2019	*Infor. not provided.*	267 responses	-	-	*Infor. not provided.*
[33]	University of Petra, Jordan	October 2022 to February 2023	*Infor. not provided.*	16 instructor and 117 students	S.M.	Temperature sensor, RH sensor, CO_2 sensor, Sound Sensor, Lighting sensor	Chi-Square Tests (IBM SPSS Statistics)
[34]	Hanze University of Applied Sciences, Netherlands	February and March 2022	Interview	35 responses	-	-	Sankey Diagrams
[35]	TU Delft, Netherlands	March 2021, October 2021, March 2022	*Infor. not provided.*	451 responses	-	-	Chi-Square Tests Analysis Of Variance (ANOVA) Test Twostep Cluster Analysis

							(IBM SPSS Statistics 26.0)
[36]	Hangzhou, Zhejiang, China	*Infor. not provided.*	CBE Survey	184 for Conventional building 65 for Green building 150 for Retrofitted building	L.T.M. S.M.	SENSIRON SHT30-DIS for air temperature, relative humidity Sense Air S8 LP for CO_2 concentration PMS70003 for $PM_{2.5}$ concentration ROHM BH1750FVI for illuminance PR-ZS-BZ for sound pressure level	The Mann-Whitney U Pearson Correlation Multiple Regression Analysis (IBM SPSS Statistics 20.0)
[37]	University of Minho, Guimarães, Portugal University of Granada, Spain	September to November 2021	*Infor. not provided.*	*Infor. not provided.*	L.T.M.	FPA805GTS AHLBORN for mean radiant temperature HD403TS2 Delta OHM® for air velocity FHAD 46-C41A AHLBORN for air temperature and relative humidity HOBO® MX1102 for CO_2 concentration HOBO® MX1104 for light intensity Imperum-R TECNITAX® Ingenier í a for sound pressure level	Kolmogorov-Smirnov Test The Mann-Whitney U Test Kruskal-Wallis Test Spearman Correlation (IBM SPSS statistic 23.0)
[38]	Hanze University of Applied Sciences, Netherlands	September 2020 to January 2021	*Infor. not provided.*	*Infor. not provided.*	L.T.M.	VLK-60W multi-sensor for air temperature, CO_2 concentration, RH, particle matter $PM_{2.5}$, and TVOC DeltaOhmHD32.3TCA as thermal microclimate sensor VOLTCRAFT MS-1300 for horizontal illuminance	Mixed-Effects Linear Models (IBM SPSS Statistics 28.0)
[39]	University of Coruña, Spain	*Infor. not provided.*	Learning Environment and Social Interaction Scale (LESI)	796	-	-	Multiple Linear Regression Analysis The Pearson Correlations
[40]	University of Granada, Spain	September 2021 to June 2022	*Infor. not provided.*	*Infor. not provided.*	*Info. not prov.*	FHAD 46-C41A AHLBORN for air temperature FPA805GTS AHLBORN for mean radiant temperature HD403TS2 Delta OHM for air velocity FHAD 46-C41A AHLBORN for RH HOBO MX 10112 for CO_2 concentration	(BIM Revit® v. 2023 and IBM SPSS Statistics 23.0)

						HOBO MX 10114 for lighting Imperum-R TECNITAX Ingeneria for SPL	
[41]	EPF School of Engineering, France	January 2015 to December 2017	*Infor. not provided.*	*Infor. not provided.*	L.T.M.	Multifunctional sensor developed by Institut d'Electronique et des Systèmes	PMV, PPD
[42]	Virginia Tech University Blacksburg Campus, USA	*Infor. not provided.*	*Infor. not provided.*	*Infor. not provided.*	*Info. not prov.*	BME 280 for temperature, barometric pressure, and humidity LTR-599 for lighting level MICS 6814 for volatile organic compounds PMS 5003 for PM levels	Artificial Intelligence Of Things (Aiot)-Based Framework
[43]	University of Alberta, Canada	October 2018 to March 2019	*Infor. not provided.*	*Infor. not provided.*	S.M.	Omega AQM-102 for CO_2 concentration, RH and temperature Omega HHSL-101 for sound level Scientific Mini Environmental Quality Meter (850027) for pressure, air speed, lighting	One-Way Analysis Of Variance Quantile-Quantile (Q-Q) Plots Kruskal-Wallis (K-W) Tests Wilcoxon Signed-Rank Tests Multivariate Analysis Of Variance (Microsoft Excel and IBM SPSS Statistics 25.0)
[44]	University College London, UK	September to December 2019	*Infor. not provided.*	669 responses	*Info. not prov.*	*Infor. not provided.*	Exploratory Factor Analysis For Questionnaire Multiple Linear Regression Chi-Square Test Kaiser-Meyer-Olkin (KMO) Test Bartlett's Test (IBM SPSS Statistics 22.0)
[46]	The University Institute of Technology, France	January to March	*Infor. not provided.*	*Infor. not provided.*	L.T.M.	Elsys, Class'Air for CO_2 concentration, relative humidity, RH	*Infor. not provided.*
[48]	National University of Ireland, Ireland	20 June 2016 to 6 June 2017	CBE Survey	144 responses	L.T.M. S.M.	LASCAR (EL-USB-2+) for temperature and humidity FLIR T335 for thermal imaging	*Infor. not provided.*

						CE-450 Real time Sound Level Meter	
[49]	University of Pisa, Italy	October 2018 to December 2018	*Infor. not provided.*	1468 responses	S.M.	Delta OHM for microclimatic measurement NDIR sensor for indoor air quality Bruel & Kjaer (B&K) 2250 for acoustic Hagner S4 for lighting measurement	*Infor. not provided.*
[50]	University of Salerno, Italy	May 2019	*Infor. not provided.*	557	*Info. not prov.*	*Infor. not provided.*	-
[51]	Texas Tech University, USA	March 29 to April 6, and June 1 to 8	-	-	L.T.M.	Telaire® T7001 for CO_2 and ventilation rate, Kestrel 3500 Weather Meter for temperature and humidity rate Extech VFM200 VOC/Formaldehyde Meter for VOC and CH_2O, EXTECH Digital Sound Level Meter Model 407736, the Fluke Ti480 PRO Infrared Camera for thermal images Onset's HOBO Temperature/Relative Humidity Data Logger model MX1101 Color Meter; Sekonic C-800-U Spectromaster Spectrometer and Exposure Meter; Sekonic L-858D-U Speedmaster Light Meter	Building Performance Simulation with IES-VE
[52]	Hong Kong Polytechnic University, China	September 2018 to June 2019	*Infor. not provided.*	224 responses	L.T.M.	HOBO data logger for RH and temperature Dantec low air velocity meter Telaire 7001 for CO_2 concentration Luntron LX-101A for illuminance B&K 2270 for noise continuous equivalent level B&K 7841 Dirac for reverberation time and speech transmission index	Combined Fuzzy Comprehensive Evaluation (FCE) and Analytic Hierarchy Process (AHP) Method

In the studies examined, only monitoring was presented in some studies for IEQ evaluation. A study conducted at the University of Alberta in Edmonton [43] evaluated IEQ with monitoring. Gender of students and professors were visually counted and recorded every ten minutes, and the use of microphones and lighting systems was noted. In this study, in addition to indoor environment, outdoor environment (i.e., outdoor relative humidity, outdoor pressure and outdoor temperature) and HVAC conditions were also considered. It has been proven that occupant behavior, microphone voice volume, lighting conditions, building location and HVAC system are quite dominant in evaluation of the IEQ. This study is important because it reveals the effect of outdoor conditions in addition to the effect of building physical conditions and HVAC on IEQ [43]. In another study [51] carried out in 2 different university buildings, only monitoring and building performance simulation were conducted to ensure energy efficiency and to improve IEQ. It would be possible to simulate the current condition of the building using monitoring data and improve the IEQ by making improvement suggestions. According to the findings of this study, by modeling the IEQ monitoring data and through simulations, it is possible to make suggestions (in this study, i.e., replacing existing windows with a double-glazing system, replacing fluorescent lamps with LED lamps, adding a PV panel) and understand how IEQ will be affected.

The study conducted under 9 different temperatures and lighting conditions by Pradhan et al. [9] analyzed relation between temperature, lighting range, thermal sensation, thermal comfort, lighting sensation, and lighting comfort. Students participated in an experimental trial equipped with biosensor headsets and wristbands. Classrooms are arranged in 9 different conditions: temperature (20-23 °C, 23-26 °C, and 26-29 °C) and lighting levels (100-300lx, 300-600lx, and 600-900lx). As physiological responses, the subjects' heart rate, skin temperature, mental stress, alertness, mental fatigue, valence, and arousal were analyzed for their effects on both attention ability and memory ability. The results of this study and its effects on students' perceptions are explained in 1.3. This study is different from the other studies reviewed in this section; it does not take place in a real classroom environment. It is a controlled experimental study; therefore, it may be a clearer study in terms of observing correlations and understanding the effects of IEQ on LP. This study only covers temperature and lighting range and needs to be expanded, it is important to cover acoustic and air quality as well as overall comfort. However, this study is different from studies conducted in a university environment, and this difference should be investigated in future research on whether the results are the same in a real classroom condition.

In the study conducted at a faculty of architecture in Jordan [33], both objective and subjective evaluation were performed. Thermal conditions, level of humidity, air quality, lighting quality and noise level were measured. To evaluate objectively, personal questions, IEQ perceptions and self-reported SBS were asked to the students. In addition, students' beliefs about peer collaboration, workload, concentration demands, study conditions, and difficulty level of study were analyzed with questionnaire. It is rarely encountered in case studies of universities in this literature review that the survey questions ask students' beliefs about SBS symptoms and working conditions, other than IEQ perception. This study is distinguished by its contribution to the literature by analyzing these questions, albeit in a self-reported manner.

Weng et al. [36] conducted a study with one classroom each from green, retrofitted, and conventional college buildings based on subjective and objective evaluation. Occupant satisfaction was analyzed and compared with point-to-point testing, long-term monitoring, and self-reported Sick Building Syndrome (SBS). A 1-year POE questionnaire compared student satisfaction, SBS, and indoor conditions between 3 buildings. In the study, parameters of four domains were monitored and students' indoor satisfaction was analyzed with POE. By self-reported SBS, the correlation between air temperature, relative humidity, CO_2 concentration and $PM_{2.5}$ concentration and SBS symptoms was analyzed by The Mann-Whitney U test. Parameters positively correlated with SBS symptoms. At the same time, the relationship of these symptoms with learning efficiency was also examined. According to long term monitoring results, green building is better than retrofitted and conventional buildings. The retrofitted building does not seem to give better results than the traditional building. This comparative study is a step to improve the conditions of the buildings by observing the differences in the IEQ and IEQ perception across three types of buildings.

Another study conducted with both objective and subjective evaluation methodology is [40]. The methodology proposed in this study is significant not only because includes IEQ monitoring and questionnaire methodology, but also for transferring sensor data to the BIM model and using it by facility managers to keep the comfort at the desired level. Zuhaib et al. [48] also conducted their IEQ evaluation studies with both questionnaire and monitoring in a partially retrofitted building. This study helps understand the relationship between partially retrofitted facade and IEQ by showing the difference in IEQ in retrofitted and non-retrofitted building parts. In addition, it emphasizes that steps should be taken to prevent partial retrofitting measures and to retrofit strategies in older buildings to optimize IEQ and energy performance.

In their study, Yang and Mak [52] examined the analysis methods of previous studies (e.g., multivariate linear regression, Pearsons' coefficient with overall satisfaction, multivariate logistic regression, etc.). In the case study, Fuzzy Comprehensive Evaluation-Analytic Hierarchy Process (FCE-AHP) analysis was proposed. FCE method is an evaluation index system based on fuzzy mathematics and used to avoid the dominant effect of a single factor (such as too noisy) [52]. AHP is based on arranging pairwise comparisons in a hierarchy. With this method, the effect of each parameter on another parameter was tried to be understood.

Chao and L· pez-Pena [39] carried out a study based on Learning Environment and Social Interaction Scale (LESI). LESI investigates factors such as the impact of classrooms on social interactions, the impact of social interaction on learning, and classroom environment satisfaction on students. Through the questions asked to the students, it was learned how satisfied they were with the conditions (i.e., wall colour, acoustics, interaction with students from other courses, student-professor interaction, ventilation) of the classrooms or the learning environment. This study presents a distinct methodology than other studies examined because it does not include monitoring.

A summary of the factors, parameters and indexes used to understand IEQ in the monitoring phase of the studies and in which articles they were used are given in Table 6 below.

Table 6: Summary of the factors, indexes, parameters for each IEQ domain in the articles belong to all research questions.

CATEGORY	FACTORS - INDEXES - PARAMETERS	REF.
THERMAL	Temperature	[9, 17, 20, 27, 33, 36-38, 40-43, 45, 48-52]
	Relative humidity	[17, 18, 20, 27, 33, 36-38, 40-43, 45, 48-52]
	Outdoor temperature	[17, 18, 38, 41, 43, 48]
	Outdoor relative humidity	[43, 45, 48]
	Air velocity	[17, 20, 37, 40, 41, 45, 48-50, 52]
	PMV	[18, 41, 45, 48-50]
	PPD	[18, 41, 48-50]
	Outdoor pressure	[42, 43]
	Air flow speed	[18, 43]
	Mean radiant temperature	[37, 40, 41, 48-50]
	Dry bulb air temperature	[18, 48]
	Wet bulb air temperature	[18]
	Dew point temperature	[18]
	Globe thermometer temperature	[18]
	Temperature of the floor surface	[18, 50]
	Temperature of the air at the height of ankle	[18]
	Turbulence intensity (TU)	[18]
ACOUSTIC	Sound pressure level	[17, 36, 37, 39, 48, 49]
	Background noise	[12, 18, 27, 43, 49, 51]
	Reverberation time	[18, 27, 38, 49, 52]
	Speech transmission index (STI)	[18, 49, 52]
	Sound level	[43, 48, 51]
	Speech intelligibility	[38, 43]
	Noise level	[33, 48]
	Verbal noise	[17]
	Outside noise	[17]
	Clarity index	[18]
	Definition index	[18]
	Early decay time	[18]
	Noise equivalent continuous level	[52]

VISUAL	Illuminance	[9, 17, 18, 20, 36, 38, 40, 42, 43, 48, 49, 51, 52]
	Light intensity	[17, 33, 37, 48]
	Illuminance ratio	[49]
	Natural lighting	[30, 33, 52]
	Direct glare	[51, 52]
	Color temperature	[51, 52]
	WWR	[30]
	Artificial lighting	[33]
	View of outside	[35]
	Desktop illuminance	[27, 36]
	Illuminance uniformity	[52]
IAQ	Carbon dioxide	[17, 20, 27, 33, 36-38, 40, 41, 43, 48, 49, 51, 52]
	Volatile organic compounds	[27, 36, 38, 42, 51]
	PM	[27, 36, 38, 42]
	Ventilation rate	[38, 51]
	Type of ventilation	[36, 48]
	Formaldehyde	[36, 51]
	Dust and odors	[33]
	Carbon monoxide	[42]
	Nitrogen dioxide	[42]
	Ammonia level	[42]
	Freshness	[52]

1.5 What are the personal and contextual factors that influence student comfort perception and learning performance?

Factors affecting IEQ have been studied in recent decades. The factors searched are mostly related to monitoring data, technical features of the building, energy consumption, and health and comfort of the users [39]. Nevertheless, physiological, geographic, socio-related, climatological factors and their effects on the occupants should also be investigated.

1.5.1 Personal factors

In some studies [33, 35, 50], it has been observed that male and female students perceive IEQ differently.

Attaianese et al. [50] conducted research on both perception of IEQ and perception of the interior spaces. In their research on IEQ perception, they could not record sufficient data for the change in perception according to the year of enrollment.

Table 7 presents personal factors that influence student comfort perception and learning performance.

Table 7: Personal factors that influence student comfort perception and learning performance.

PERSONAL FACTORS		
CATEGORY	**FACTOR**	**REFERENCE**
Physiological	Gender	[33, 35, 50]
	Age	[33]
	Health	[35]
Psychological	Emotional state	[9]
	Preference towards thermal environment	[35]
	Preference towards acoustic environment	[35]
	Preference towards lightings	[35]
	Preference towards indoor air	[35]
	Expectations for natural lighting	[35]
Social	Lifestyle	[35]
University	Number of years in the building	[33, 50]
	Occupancy density	[30]
	Hours per week spent in the classroom	[33]

1.5.2 Contextual factors

In recent years, campuses have ceased to be just a physical and visual space where the act of learning takes place, and have become a cultural, organizational and emotional space [50].

In the study conducted at a faculty of architecture in Jordan [33], both objective and subjective evaluation performed. Thermal conditions, level of humidity, air quality, lighting quality and noise level were measured. To evaluate IEQ, both personal questions, IEQ perceptions and self-reported SBS were asked to the students. In addition, students' beliefs about peer collaboration, students' workload, concentration demands, study conditions, and difficulty level of study were analyzed with questionnaire.

In their study in Spain, Chao & Pena [39] examined the relationship between peer effect, IEQ satisfaction and place attachment using the Learning Environment and Social Interaction scale (LESI). LESI investigates 5 factors affecting the learning environment, these are classroom design, IEQ satisfaction in classrooms, place attachment, working satisfaction, and the relationship between learning and social interaction. Two variables were observed to affect the learning outcome directly and inversely, student and professor interaction and students' interaction with students in other courses. It was understood that communication and interaction with the professor had a positive effect on understanding the subject, and interaction with students in other courses had a negative effect. Even though this seems like a consistent result, it requires a larger study because it may be a result of students coming from outside reducing the interaction in the classroom.

In their study to investigate the correlation between building characteristics and IEQ perception, Bartolini and Forcada found that as WWR increases in classrooms, lighting satisfaction increases and curtains-blinds were negatively correlated with lighting satisfaction, meaning that students directly preferred natural lighting [30]. They also found that during summer, facade insulation is important in classrooms without cooling systems. There was a relationship between a type of cooling and thermal satisfaction. Bartolini and Forcada revealed that there was no relationship between the thermal insulation of windows and thermal satisfaction if the heating was well dimensioned. It has been observed that the year of construction of the building is also important.

According to Pradhan et al. [9], positive emotions and focus ability increase in bright lighting conditions. It has been observed that brighter lighting conditions increase concentration ability. One of the most important findings of this study is that it shows that learning performance depends on the type of task. Accordingly, it depends on environmental factors that play a stronger role depending on the type of task. Students' emotional states also affect their motivation and therefore their performance.

In addition, during academic activities that stress students, such as exams, the IEQ conditions may be poor depending on the subjective evaluation [16].

Table 8 presents contextual factors that influence student comfort perception and learning performance.

Table 8: Contextual factors that influence student comfort perception and learning performance.

CONTEXTUAL FACTORS		
CATEGORY	**FACTOR**	**REF.**
Building characteristics	External view	[35, 36]
	Building location	[43]
	Building type	[36]
	Construction year	[30]
	Aesthetic aspect of building	[50]
Classroom characteristics	Classroom orientation	[50]
	Classroom layout	[49]
	Operating area of windows	[50]
	Daylight	[30, 35]
	Ventilation type and ventilation rate	[30, 35, 50]
	Heating type - cooling type	[30]
	Blinds and shades	[30]
	Window-Wall Ratio (WWR)	[30]
	Desktop illumination	[35, 36]
	Façade insulation	[30]
	Seat location	[36, 39]
	Classroom design	[39]
	Wall color	[39]
Lecture characteristics	Student number, occupancy density	[30, 43]
	Instructor performance	[33]
	Professor-student interaction	[39]
Social factors	Peer effect	[33, 39]
Environmental factors	Outdoor climate conditions	[17, 18, 38, 41, 43, 48]
	Wind	[18, 43]

Future research should consider the development of methodologies that will investigate all factors such as IEQ satisfaction level, student behavior, physiological factors, and physiological factors on students' learning performance [37].

1.6 Conclusion

This literature review provides an overview of the evaluation of IEQ in universities through three research questions using the PRISMA method and Scopus search engine. What POE is and why questionnaires are conducted are briefly explained. In questionnaire studies, the effect of IEQ domains on Indoor Environmental Comfort (IEC) has mostly been investigated. Among the reviewed articles, the most evaluated domains with questionnaires are thermal, visual, IAQ and acoustic, respectively. Studies investigating personal factors that have an impact on IEQ perception are in the minority.

IEQ domains and parameters that have an impact on IEQ perception have been investigated. Self-reported SBS was also used in the studies, and the source of the symptoms occurring in the students was tried to be found in a few articles.

Methodologies used to evaluate university students' IEQ perception vary. The use of subjective and/or objective evaluation varies depending on the factor and domain to be investigated. The majority of the articles examined used both objective and subjective evaluations. Most of the articles have investigated IEQ and its impact on students' perceptions. The analysis methods (i.e., The Mann-Whitney U, Pearson correlation, Spearman correlation, multivariate logistic regression, multivariate linear regression, etc.) used vary between case studies. In future studies, the effect of IEQ parameters on IEQ perception and how the mutual effects of these parameters on each other are reflected in IEQ perception should be investigated in more detail. At the same time, the effects of personal factors should also be further investigated. Even if it is not possible to create a single model, further research is inevitable to find reality [39].

2. Indoor Environmental Quality monitoring and students' feedback collection in four university classrooms in Politecnico di Torino

The aim of the thesis is to examine and evaluate the current state of the P classrooms located at Politecnico di Torino, chosen as the case study. These classrooms are located inside an independent building equipped with autonomous ventilation and air conditioning systems, making easier the implementation of changes based on the collected data. This case study aims to improve the classrooms IEQ and occupants' comfort thanks to a greater awareness on actual conditions and how are perceived by occupants. This study presents a methodology for in-field monitoring of IEQ and students' comfort assessment, to further define which factors affect students' well-being. The indoor environmental conditions of the classrooms were evaluated as follows. Objective evaluation was conducted by collecting data of the four main IEQ domains via Aircare multi-sensor, and subjective evaluation was made with a developed questionnaire online administered. Statistical analysis was conducted to find main correlations regarding subjective feedback, IEQ monitoring results, and physical conditions of the classroom. The next paragraphs will detail the followed methodology, the case study, the IEQ monitoring through the Aircare multisensory, subjective feedback collection through the developed questionnaire, the database creation for statistical analysis.

2.1 Methodology

Initially, an analysis was conducted on the morphology of the building. Factors that would affect the IEQ perception and IEQ evaluation of the classrooms, such as the lighting system of the classrooms, the number of doors and windows, information about the HVAC system, and the number of solar shadings-curtains, were identified.

Additionally, a scrutiny of the weekly lecture schedules (occupancy hours) for the classrooms was carried out. Subsequently, data collection for the joint analysis of IEQ conditions, IEQ perception started. To discern IEQ conditions, 14 parameters were monitored through the Aircare multi-sensor. Simultaneously the physical conditions of the classrooms (e.g., opening of doors, windows, solar shadings, microphone use, etc.) were observed and noted on-site, during monitoring with Aircare multi-sensor.

To reveal their IEQ perception, occupants were asked to answer a questionnaire online, with questions on overall IEQ and the four domains. Additionally, they were asked to answer, on a voluntary basis, some personal questions and also some questions about their health, lifestyle, preferences and expectations regarding classroom conditions. Figure 5 shows the study methodology followed for the case study analysis.

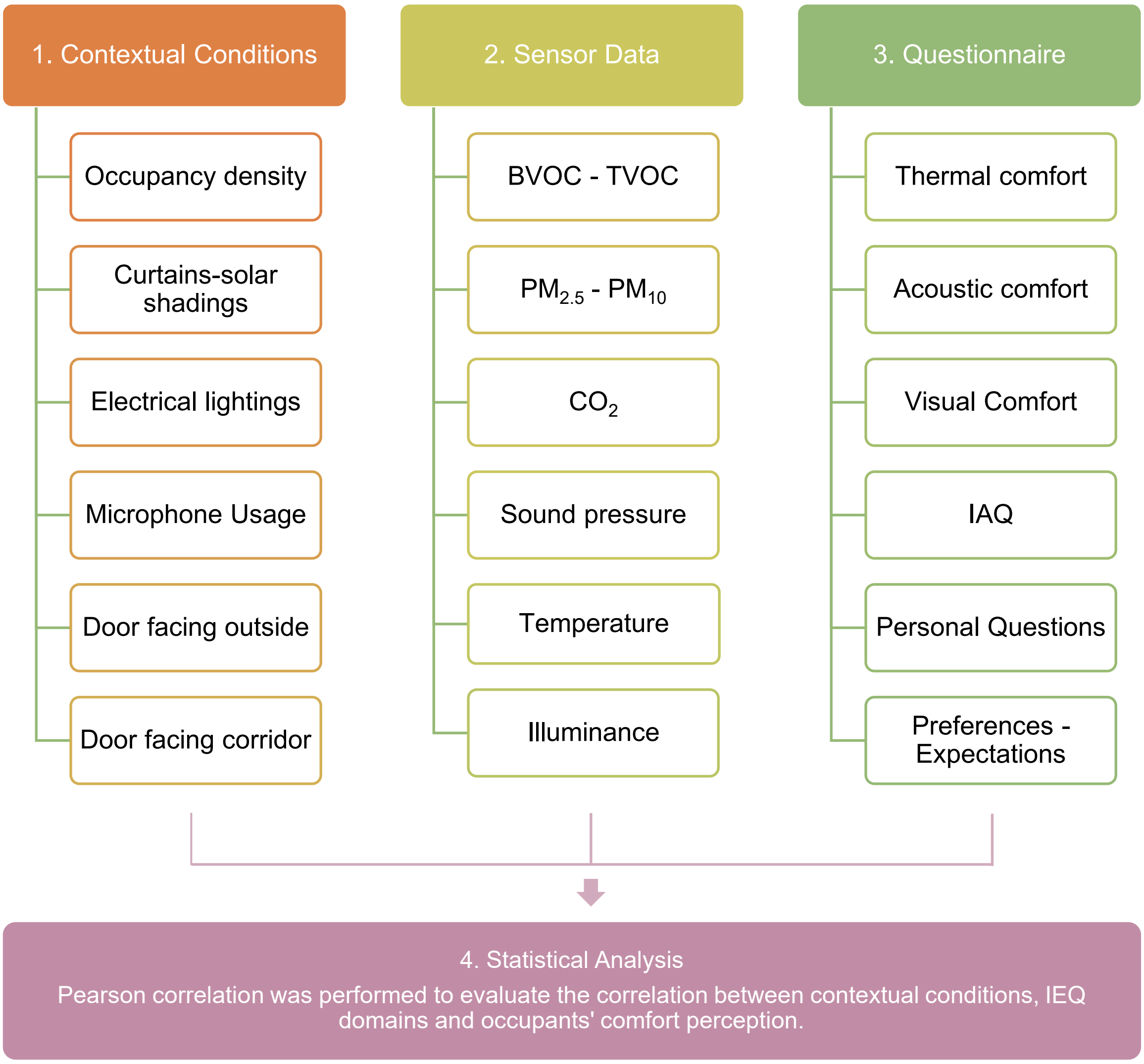

Figure 5: Study methodology.

Statistical analysis of this data was performed with IBM SPSS Statistics software. Mean values and standard deviations were generated and Pearson correlation was performed via software. Bar charts, line graphs and heat maps were used to visualize objective and subjective evaluation in the classrooms.

2.2 Case Study: P Classrooms

Both subjective and objective evaluation of overall IEQ was carried out in an independent building called Aule P (P Classrooms) at the Politecnico di Torino (Polytechnic University of Turin). The building is a single-storey and consists of 4 classrooms.

Figure 6: Image of the Aule P building (Latitude: 45.062° N, Longitude: 7.657° E) via Google maps.

2.2.1 Classroom Features

Below are exterior photographs of the case study building, (Figure 7 and Figure 8) the interior photographs of the classroom 1P (Figure 9 and Figure 10) and the photo of the corridor where a panel with the description of the project is placed (Figure 11).

Each classroom has a volume of approximately 980 m^3 with a length of 19.5 m, width of 11.2 m, and average height of 4.50 m. Classrooms 1P and 3P, located on the south facade of the building, overlook a parking lot. 2P and 4P, located on the north facade of the building, face another building. Classrooms have sound-absorbing panels on the ceilings and some parts of the side walls and dispersing glazed walls on the surfaces facing outside. It is equipped with autonomous air conditioning and ventilation system. Designed maximum occupation of 220 students in each classroom.

Figure 7: Photo of the case study building 'Aule P'.

Figure 8: Aule 1P façade view.

Figure 9: Classroom 1P interior view.

Figure 10: Classroom 1P interior view.

Figure 11: A panel with the description of the project is placed in the corridor of the P building, there is also a Aircare multi-sensor next to the panel.

In order to understand students' comfort perception and its relationship with IEQ, some contextual factors that affect teaching activities in the classrooms were noted. Figure 12 briefly shows some classroom features.

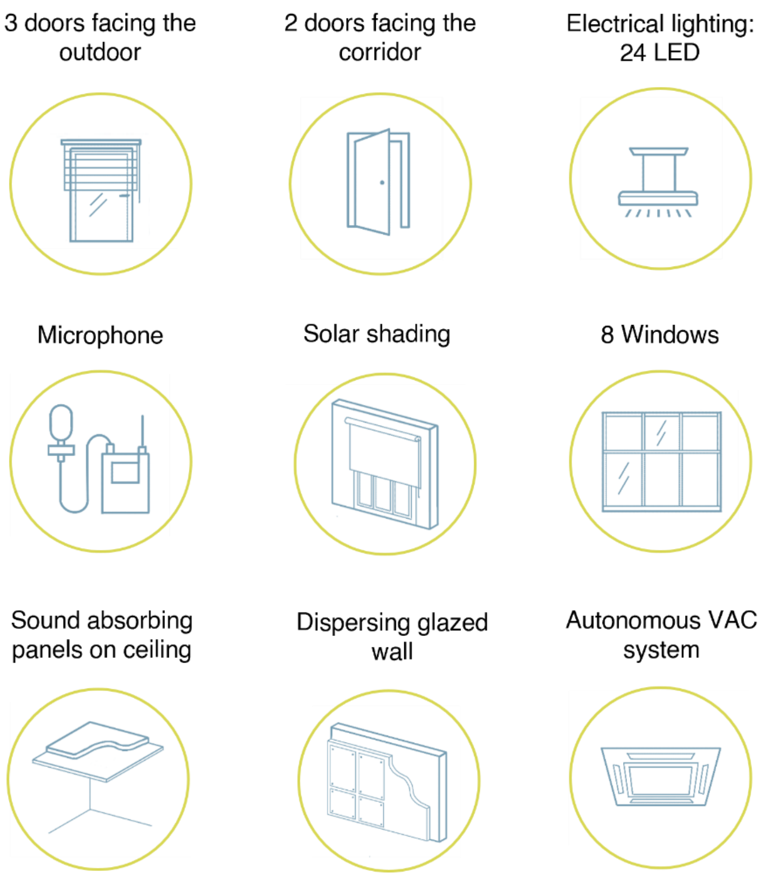

Figure 12: Summary of classrooms features.

To ensure accurate statistical analysis through proper classification and segregation of all data, period of the year, date, hour of the day and classroom information are used as basis. Since the university's courses are in the form of 1.5-hour block courses, 1.5-hour slots were used as basis for data analysis. Table 9 exemplifying the slots.

Table 9: Example of the teaching activities program in classroom 1P.

DATE	TIME	AULA	TYPE OF ACTIVITY	COURSE	PROFESSOR
15.05.2023	08:30-10:00	1P	Lecture	Progetto di missioni e sistemi spaziali	A
15.05.2023	10:00-11:30	1P	Lecture	Progetto di missioni e sistemi spaziali	B
15.05.2023	11:30-13:00	1P	Lecture	Intelligenza artificiale in medicina	C
15.05.2023	13:00-14:30	1P	Lecture	Intelligenza artificiale in medicina	D
15.05.2023	14:30-16:00	1P	Lecture	Impianti elettrici e sicurezza	E
15.05.2023	16:00-17:30	1P	Lecture	Impianti elettrici e sicurezza	F
15.05.2023	17:30-19:00	1P	-		G

Some criteria were determined to better analyze the conditions in the classrooms where the learning activity takes place and their connection with the IEQ, as well as their relevance to the students' perceptions. These criteria are the number of students in the classroom, the open and closed status of curtains and shadings, the open and closed status of doors and windows, the on and off status of lighting and microphone. For statistical analysis, performed by means of the IBM SPSS Statistics software, the status of the classrooms was expressed by using numbering. The on and off status of electrical lighting in classrooms are numbered similarly. There are 24 LED lights in each hall, consisting of 4 LED lights along every 6 rows. It is defined as; 0 if the lighting is completely off, 1 if 4 LED lamps are on, 2 if 8 LED lights are on, 3 if 12 LED lights are on, 4 if 16 LED lights are on, 5 if 20 LED lights are on, 6 if 24 LED lightings (all lightings) are on. Figure 13 shows a ceiling view to better explain the numbers given to the electrical lighting.

Figure 13: The ceiling view shows that there are 4 electrical lightings in each row.

For the microphone, it is noted as 1 if it is used and 0 if it is turned off. Curtains and solar shadings are noted as 0 if they are completely closed, 1 if they are half open, and 2 if they are completely open. At the same time, for exterior-facing doors in the classroom; 0 if they are completely closed, 1 if 1 of them is open, 2 if 2 are open, and 3 if all of doors are open. Figure 14 and Figure 15 show the locations of windows and doors in the classrooms.

Figure 14: View of windows and doors (facing outside) of Aula 1P.

Figure 15: View of windows and doors (facing outside) of Aula 1P.

For doors facing the corridor, 0 if they are completely closed, 1 if 1 door is open, 2 if 2 doors are open. Figure 16 shows the 2 doors of the classrooms facing the corridor.

Figure 16: Doors facing the corridor.

Table 10 provides a summary of the contextual factors of the classrooms to be evaluated in the case study and the numbers assigned to them to perform the statistical analysis.

Table 10: The physical conditions to be examined in the case study and the numbers assigned to them for statistical analysis.

DOORS FACING THE CORRIDOR	**ASSIGNED NUMBER**	**CURTAINS - SOLAR SHADING**	**ASSIGNED NUMBER**
CLOSED	0	CLOSED	0
1 OPEN	1	HALF-OPEN	1
2 OPEN	2	OPEN	2
DOORS FACING THE OUTSIDE	**ASSIGNED NUMBER**	**ELECTRICAL LIGHTINGS**	**ASSIGNED NUMBER**
CLOSED	0	CLOSED	0
1 OPEN	1	4 OPEN	1
2 OPEN	2	8 OPEN	2
3 OPEN	3	12 OPEN	3
MICROPHONE USAGE	**ASSIGNED NUMBER**	16 OPEN	4
NO	0	20 OPEN	5
YES	1	24 OPEN	6

2.3 IEQ monitoring through the Aircare multi-sensor

Aircare, a commercial multi-sensor, was used to monitor conditions inside classrooms. Figure 17 shows the installation points and numbers of multi-sensors. Classrooms 1P and 4P are equipped with four Aircare multi-sensors, two connected to the electricity grid and two not connected.

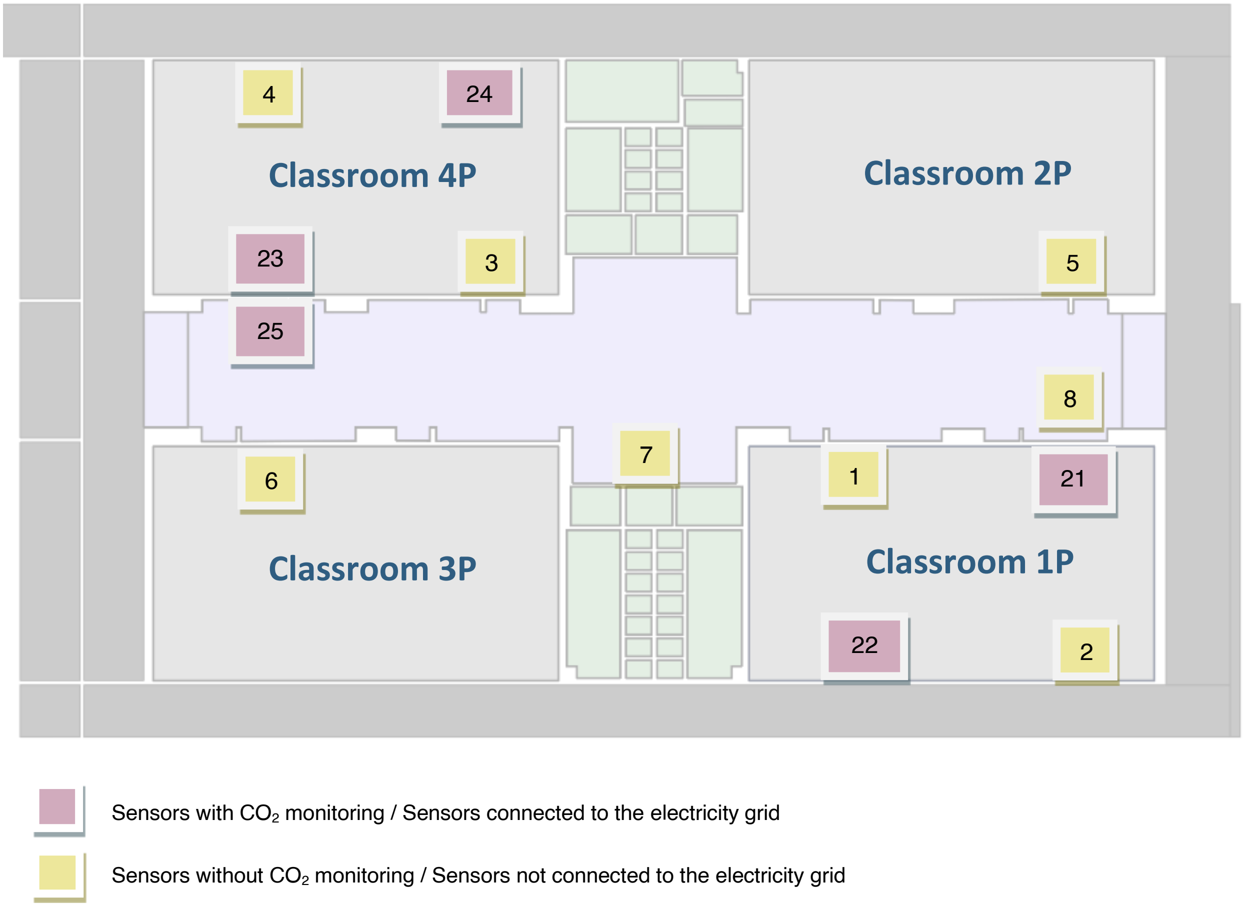

Figure 17: Map of the locations of wall-mounted sensors.

The Figure 18 below shows the Aircare multi-sensor [53].

Figure 18: Picture of Aircare multi-sensor.

Data were collected during two different academic semesters. From 30.05.2023 to 09.06.2023 in the first semester, and then from 08.01.2024 to 19.01.2024 in the second semester. Occupancy hours are considered from 08:30 a.m. to 7 p.m. as stated in 2.2.3.

The parameters monitored are biogenic volatile organic compounds (BVOC), total volatile organic compounds (TVOC), carbon dioxide (CO_2), particulate matter ($PM_{2.5}$ and PM_{10}), sound pressure level (SPL), low frequency level (lf), high frequency level (hf), temperature (T), relative humidity (RH), vertical illumination (E_v), and iaq. Table 11 shows all the parameters measured by the Aircare multi-sensor.

Table 11: Parameters and measurement units measured by Aircare multi-sensor.

PARAMETER	MEASUREMENT UNIT
BVOC	ppb
TVOC	ppb
Co_2	ppm
$Co2_e$	ppm
$PM_{2.5}$	$\mu g/m^3$
PM_{10}	$\mu g/m^3$
Humidity	%
Indoor Temperature	℃
Iaq	absolute (0-500)
Illuminance	lux
Pressure	dBspl
Sound Pressure Level	dBA
Lf Level	kHz
Hf Level	MHz

Classrooms 2P and 3P are equipped with one Aircare multi-sensor connected to electricity grid. Sensor 5 in classroom 2P stopped working after the monitoring started, therefore no data could be collected. During the first period (30/05/2023 to 09/06/2023) all other sensors (except sensor 5) were working. In the second period (08/01/2024 to 19/01/2024), sensors 1,3 and 6 were working but sensors 2, 4, 21, 22, 23 and 24 are not working. Sensors 1, 3 and 6 measure every 5 minutes. Sensors 2, 4, 21, 22, 23 and 24 measure every 15 minutes.

Figure 19 and Figure 20 show the view from the classroom 1P with 4 sensors.

Figure 19: Sensors 1 and 21 mounted on the wall facing the interior corridor in classroom 1P.

Figure 20: Sensors 2 and 22 mounted on the wall facing outside in classroom 1P.

Figure 21 shows the operating status of the sensors within 2 semesters, their locations, distances from each other and heights from the ground.

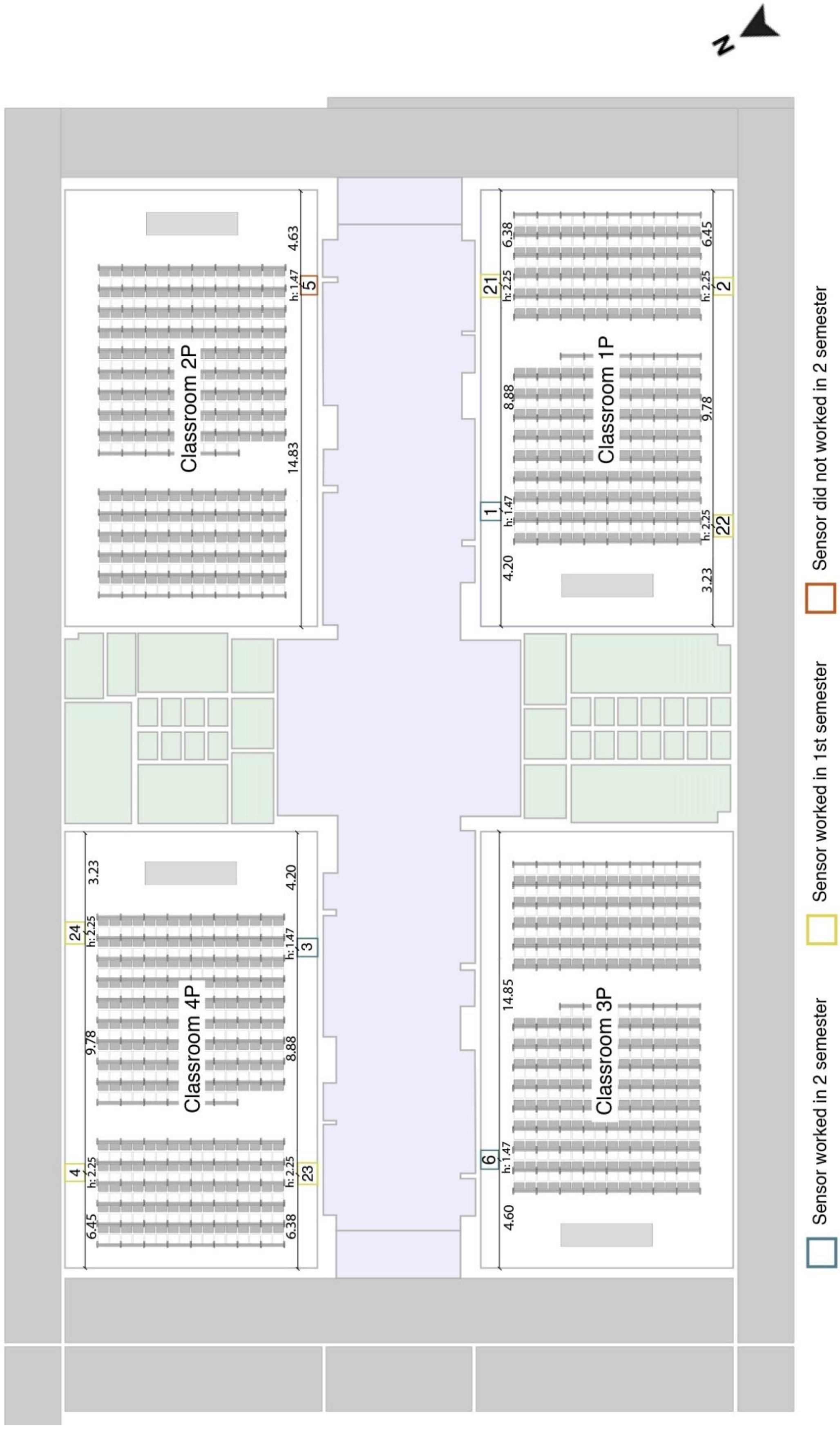

Figure 21: Sensor numbers and their positions in classrooms. Distances between sensors, height from the ground, and operating status.

2.3.1 Parameters and their thresholds used in the evaluation of P classrooms

For the IEQ evaluation of P classrooms, the parameters measured by the Aircare multi-sensor are carbon dioxide (CO_2), particulate matter ($PM_{2.5}$ and PM_{10}), total volatile organic compounds (TVOC), temperature (T), relative humidity (RH), sound pressure level (SPL), illuminance (E_v) was used. The adaptive thermal comfort model was used for thermal comfort [54]. The acoustic quality index was used as threshold ≥ 53,3 dB(A) [55]. A signal to noise ratio of 10 dB is taken as the minimum value for good speech comprehension in classrooms. Background noise was measured (49 dB(A)) in classroom 3P, and the same value was taken as basis in classrooms 1P and 4P. This value and all SPL values monitored with the Aircare multi-sensor have been corrected to -5.7 dB(A). This correction was made in accordance with the standard since sensors are flushing to the walls [56]. Vertical illuminance value for lighting quality was calculated with the linear regression model calculated and defined in line to the standard [57]. EN 16798-1:2019 [58] was used as the standard for CO_2 and PM thresholds, and WELL Building Standard [59] was used as standard for TVOC threshold.

Table 12: Parameters monitored via the Aircare multi-sensor and their thresholds and references for classroom environments.

PARAMETER	THRESHOLD	REFERENCE
Carbon dioxide (CO_2)	≤ 800 ppm	EN 16798-1:2019
Particulate matter ($PM_{2.5}$)	24 h mean ≤ 25 μm/ m³	EN 16798-1:2019 (WHO Guidelines)
Particulate matter (PM_{10})	24 h mean ≤ 50 μm/ m³	
Total volatile organic compounds (TVOC)	≤ 500 μm/m³	WELL Building Standard
Temperature (T)	Winter: (20-24)℃ Summer: (23-26)℃	ISO 7730:2005
Relative humidity (RH)	(30-70) %	ISO 7730:2005
Sound pressure level (SPL)	≥ 53,3 dB(A)	-
Illuminance (E_v)	≥ 500 lx	EN 12464-1:2021

Based on the slots specified in 2.2.1, mean values were calculated from the sensor data for each parameter. Below are the mean values of the 1P as of 30.05.2023. There are 4 sensors each in 1P and 4P. For this reason, firstly, the mean value of each slot was calculated for each sensor. Then, a single mean value was calculated for the classroom out of 4 mean values for each slot. Table 13 summarizes how the mean value calculation is performed.

Table 13: Calculation of mean values (m.v.) of BVOC (in ppd unit) on 30.05.2023.

TIMETABLE	SENSOR 1	SENSOR 2	SENSOR 21	SENSOR 22	M.V.
08:30 - 10:00	853,17	6428,00	3359,50	3850,00	3622,67
10:00 - 11:30	1306,89	8719,67	2711,83	2818,50	3889,22
11:30 - 13:00	584,28	8564,83	2658,17	2689,50	3624,19
13:00 - 14:30	1981,06	5883,33	503,50	507,00	2218,72
14:30 - 16:00	5035,72	3691,17	769,50	976,83	2618,31
16:00 - 17:30	2225,11	2893,17	2256,50	3123,00	2624,44
17:30 - 19.00	3148,78	2275,50	3773,83	4962,17	3540,07

2.4 Subjective feedback collection through the developed questionnaire

Figure 22 shows the diagram of the questions. The dotted lines between the 2 questions indicate that the questions can be seen according to the answers given, not every occupant may see these questions. Solid lines show the next question that you will have to see with your answer to the previous question.

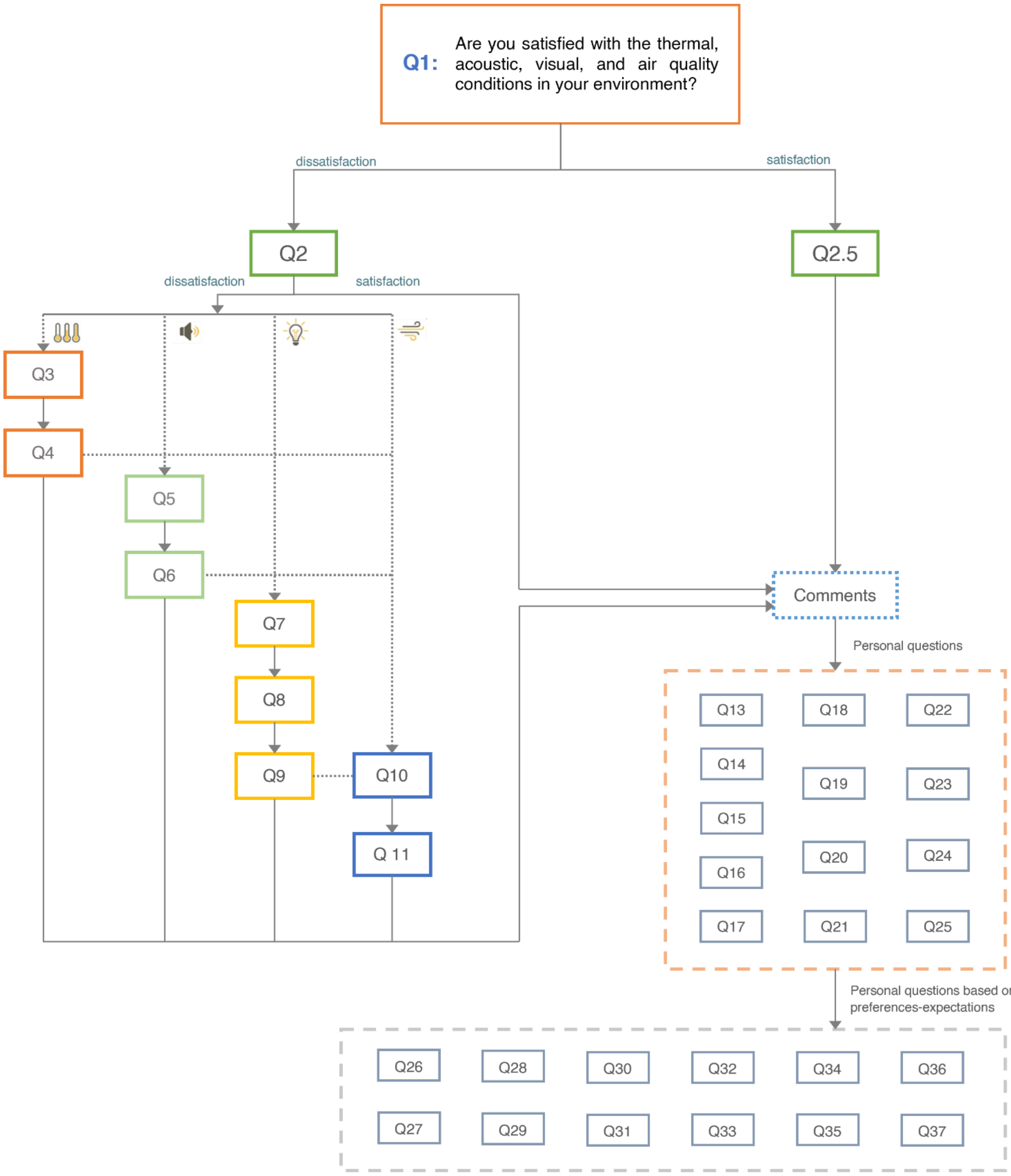

Figure 22: Classification scheme of questionnaire questions.

In addition to the objective analysis made with multi-sensors in the university, a questionnaire (both in Italian and English) was created in order to obtain subjective data by analyzing the indoor comfort perception of the students in detail (Figure 23).

Figure 23: Questionnaire start screen.

The answers correspond to some values in percentage for every domain of the IEC and the formula of the IEC index is given: Thermal Comfort + Acoustic Comfort + Visual Comfort + IAQ) / 4 = IEC [%]. In the representation, a percentage system between 0-100 is used in order to be easy to understand and not confusing [53]. The following paragraphs explains the questionnaire and detailed explanations.

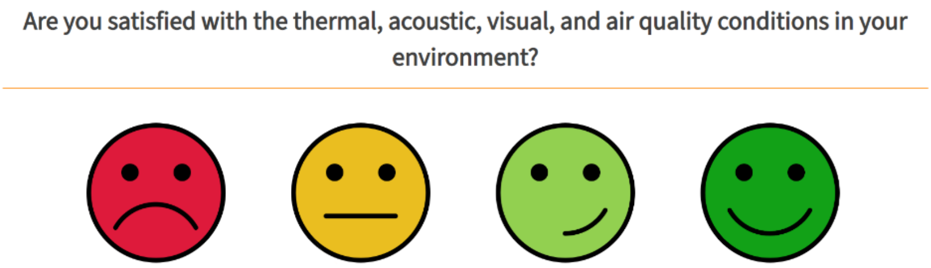

Figure 24: First question of questionnaire.

After expressing a situation regarding your satisfaction with indoor comfort (green faces), the questionnaire directs students to a question about which comfort domains they are satisfied. (Figure 24) If students are dissatisfied, that is, if they have stated the 1st or 2nd dissatisfied situation, students are requested to indicate which domains are caused by this situation. (Figure 25)

Figure 25: Question asking students which domain they are dissatisfied (Question 2).

If students are dissatisfied with thermal comfort, they should evaluate it:

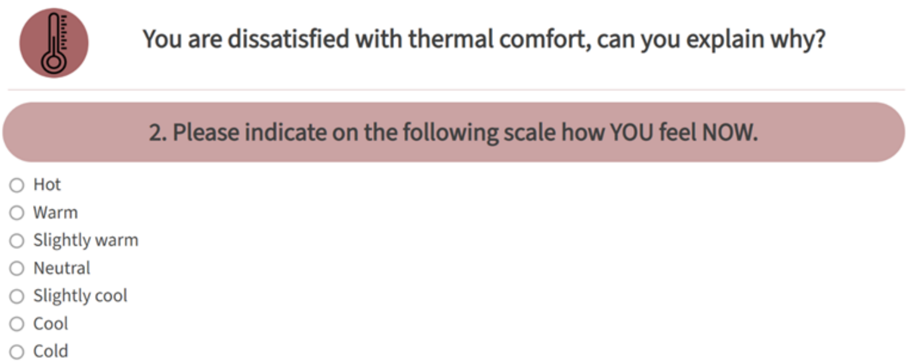

Figure 26: Evaluation of thermal comfort (Question 3).

The answers given by the students in terms of thermal comfort (TC) are given below (Table 14) and expresses comfort in terms of PMV scale (Table 14).

Table 14: Percentages at which responses were converted to represent a TC value are shown.

Hot / Molto caldo	+3	25%
Warm / Caldo	+2	50%
Slightly warm / Poco caldo	+1	75%
Neutral / Neutro	0	100%
Slightly cool / Poco freddo	-1	75%
Cool / Freddo	-2	50%
Cold / Molto	-3	25%

The questions are designed to be simple and clear, questions containing capital letters 'YOU' and 'NOW' are designed to emphasize students' expression of their feelings at that moment. The next question asks students about air velocity, only one option can be selected (Figure 27).

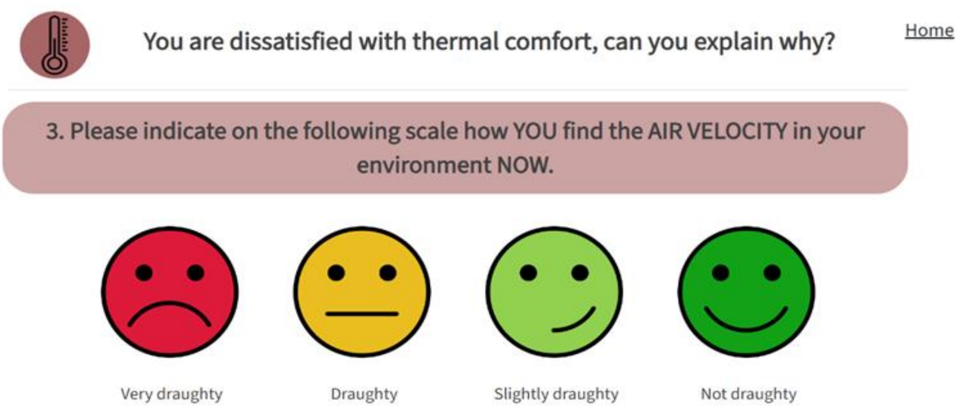

Figure 27: Question performs both TC and IAQ evaluation by asking students about the air velocity in the classroom (Q4).

Table 15: Expression of students' answers as comfort percentages.

Very draughty	25%
Draughty	50%
Slightly draughty	75%
Not draughty	100%

Air velocity is an important factor that affects thermal comfort because it influences perceived temperature. The next question (Figure 28) determines the degree of satisfaction with acoustic environment if dissatisfaction with acoustic comfort is selected and expresses comfort in terms of percentages (Table 16).

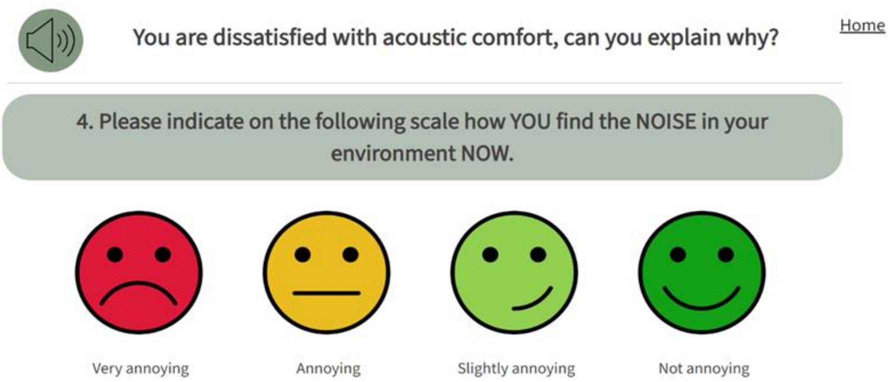

Figure 28:. Question performs AC evaluation by asking students about the noise situation in the classroom (Q5).

Table 16: Expression of students' answers as comfort percentages.

Very annoying	25%
Annoying	50%
Slightly annoying	75%
Not annoying	100%

Then, with the second question, the environmental factor causing acoustic discomfort is asked to the students (Figure 29).

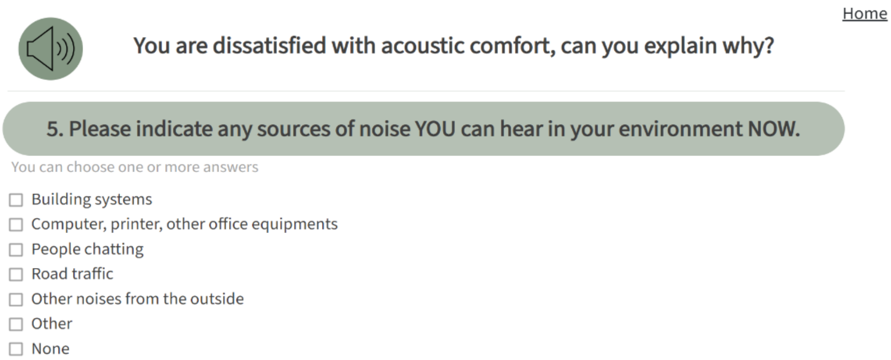

Figure 29: Question about factors that cause acoustic dissatisfaction (Q6).

The next question determines the degree of satisfaction with visual comfort if dissatisfaction with visual comfort is selected (Figure 30).

Figure 30: Question performs VC evaluation by asking students about the visual environment (Q7).

Table 17: Expression of students' answers as comfort percentages.

Very uncomfortable	25%
Uncomfortable	50%
Slightly uncomfortable	75%
Not uncomfortable	100%

Then, with the second question, the environmental factor causing visual discomfort is asked to the students (Figure 31).

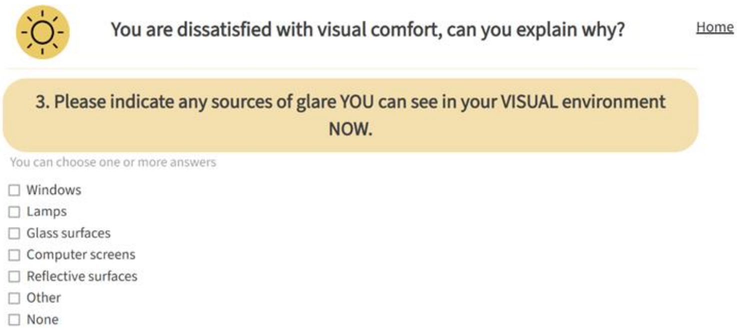

Figure 31: Question about factors that cause visual dissatisfaction (Q8).

The last question asks for illuminance as a subjective preference (Figure 32).

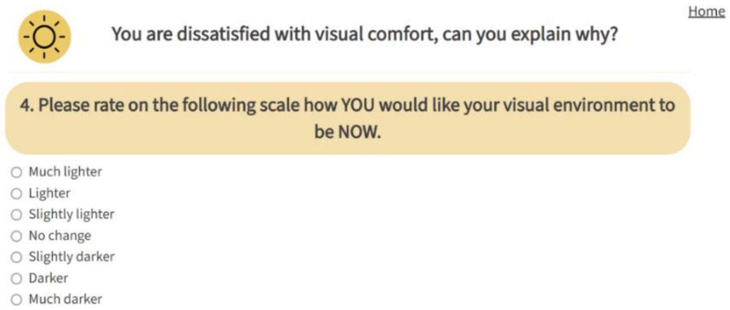

Figure 32: Question asking students visual preference (Q9).

The next question is about indoor air quality (Figure 33), but IAQ is a very complex domain because people's perceptions on this subject may differ from person to person.

Figure 33: Question performs AIQ evaluation by asking students about the air quality in the classroom (Q10).

Table 18: Expression of students' answers as comfort percentages.

Very smelly	25%
Smelly	50%
Slightly smelly	75%
Not smelly	100%

The second question aims to better understand possible pollutants in classrooms (Figure 34, Table 18).

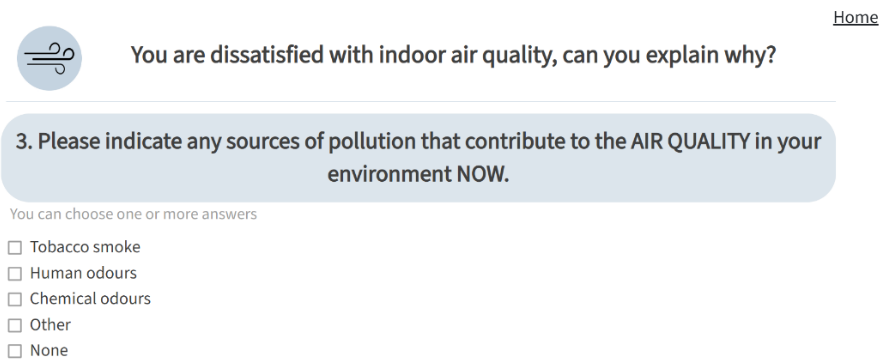

Figure 34: Question about factors that cause dissatisfaction with indoor air (Q11).

At the end of the questionnaire, personal questions such as gender, age, country of birth and educational qualification are asked to occupants. Regarding their health status, they are asked whether they have any visual or auditory problems, whether they smoke, and whether they have a healthy lifestyle. In addition, they are asked whether they think poor IEQ has a negative impact on their learning performance and well-being. And finally, whether they have control over windows opening and closing, solar shading, electric lighting, reducing annoyance from noise, heating and cooling system; and asked whether it was important for them to have control over these factors. Table 19 below contains a list of personal, contextual questions.

Table 19: Personal questions.

Q12) If you want, you can leave other comments.
Q13) Gender
○ Female ○ Male
Q14) Age
○ 18-25 ○ 26-35 ○ 36-50
Q15) Country of birth
Q16) Educational qualification
○ None ○ High School ○ Bachelor's degree ○ Master's degree ○ Ph.D.
Q17) Intended use of the building
○ School
Q18) Ambit/Role
○ Head teacher ○ Teacher ○ Administrative staff ○ Technical staff ○ Auxiliary staff ○ Student ○ Other
Q19) Number of people in the environment
○ 1 ○ 2 to 5 ○ 6 to 10 ○ 10 +
Q20) Visual impairments
○ Yes ○ No
Q21) Hearing impairments
○ Yes ○ No
Q22) Do you smoke?
○ Yes ○ No
Q23) Do you conduct a healthy lifestyle?
○ Yes ○ No

Q24) Does an unsatisfactory Indoor Environmental Quality significantly reduce your work productivity?

- Yes
- No

Q25) Does an unsatisfactory Indoor Environmental Quality significantly reduce your well-being?

- Yes
- No

Q26) Do you have control on windows opening and closing?

- Yes
- No

Q27) Do you have control on solar shading?

- Yes
- No

Q28) Do you have control on electric lightings?

- Yes
- No

Q29) Do you have control on heating system?

- Yes
- No

Q30) Do you have control on cooling system?

- Yes
- No

Q31) Do you have control on reducing annoyance from noise?

- Yes
- No

Q32) Do you think it's important to have control on windows opening and closing?

- Yes
- No

Q33) Do you think it's important to have control on solar shading?

- Yes
- No

Q34) Do you think it's important to have control on electric lightings?

- Yes
- No

Q35) Do you think it's important to have control on heating system?

- Yes
- No

Q36) Do you think it's important to have control on cooling system?

- Yes
- No

Q37) Do you think it's important to have control on reducing annoyance from noise?

- Yes
- No

The questionnaire and a brief description of the project were sent via e-mail to the professors who taught between 15/05/2023 and 09/06/2023, and between 08/01/2024 and 19/01/2024 in classrooms 1P, 2P, 3P and 4P. A short presentation of the project was made to the students in the classrooms, and then the students were asked to fill out the questionnaire. A total of 752 answers were given to the questionnaire in 2 periods.

2.5 Database creation for statistical analysis

Preparation of data for statistical analysis was done via Microsoft Excel and all data is expressed in numbers. Data preparation process started with place and time determining elements such as date, period, classroom and timetable. Establishing descriptive criteria such as classroom number, month, and period is important so that detailed data analysis can provide insight into IEQ and occupant's comfort perception. Course names and professors names are also recorded, and a number is assigned to every course and professor. In detailed analysis, this information can help us understand whether students' comfort perceptions vary according to courses or professors.

The number of students in the classrooms and some physical conditions in the classrooms, as explained in detail in 2.2.3, were noted. These are curtains-solar shading, electrical lighting, microphone use, door facing the outside, door facing the corridor, and outdoor temperature. The relationship between these physical conditions of the classrooms and IEQ and students' comfort perceptions will be analyzed.

As explained in Section 2.3, Aircare multi-sensor measures 14 parameters. The average values of these parameters, calculated as described in the same section, were written into Excel. Moreover, based on the threshold values, acoustic comfort, visual comfort, thermal comfort and indoor air quality values and overall comfort value were calculated and added to the data.

The questionnaire starts with Q1 and ends with Q37. Q1-5 are multiple choice questions where only one answer can be selected. Each answer is assigned a number, as shown in the table below. On the other hand, in questions where more than one option can be chosen, such as Q6-Q8, a yes-no description is used for each answer that can be chosen. In Q12, students were asked to comment as an open-ended question. Following the questions regarding IEQ perception, TC, AC, VC and IAQ values were calculated based on the questionnaire results.

Questions from Q13 to Q37 are in the form of personal, contextual, or based on psychological preferences-expectations, as explained in Section 2.4. The answers to these questions are numbered according to the same logic as explained above, depending on whether more than one answer can be given.

Table 20 shows criteria and parameters used for IEQ evaluation and description of all the data brought together in Excel to be used in statistical analysis.

Table 20: Table consisting of information, parameters, criteria, questionnaire responses and explanations of the factors to be used for statistical analysis.

CRITERIA - PARAMETER	DEFINITION
Date	dd/mm/yyyy,
Period	Spring, Summer, Autumn, Winter
Classroom	1P, 2P, 3P, 4P
Timetable	08:30-10:00, 10:00-11:30, 11:30-13:00, 13:00-14:30, 14:30-16:00, 16:00-17:30, 17:30-19:00
Lecture Name	A number is assigned to every lecture.
Professor Of Lecture	A number is assigned to every instructor.
Capacity Of The Classroom	220
Occupant	The number of students for each slot is noted.
Curtains-Solar Shadings	0=closed, 1=half-open, 2=open
Electrical Lightings	0=closed, 1=4 open, 2= 8 open, 3= 12 open, 4= 16 open, 5=20 open, 6=24 open. (considering from the back of the classroom)
Mic. Usage	0=no, 1= yes
Door Facing The Outside	0=closed, 1=1 open, 2= 2 open, 3= 3 open
Doors Facing The Corridor	0=closed, 1=1 open, 2= 2 open
Outdoor Temperature	℃
BVOC	ppb
TVOC	ppb
CO_2	ppm
CO_2e	ppm
Humidity	%
Indoor Temperature	℃
Pressure	dBspl
Sound Pressure Level	dBA
Illuminance	lux
$PM_{2.5}$	$\mu g/m^3$
PM_{10}	$\mu g/m^3$
Lf level	kHz

Hf level	MHz
IAQ (O)	%
AC (O)	%
TC (O)	%
VC (O)	%
IEQ (O)	%
Q1	1= dark green, 2= light green, 3= yellow, 4= red
Q2 / Thermal Comfort	[1= q2 unsatisfied, 2= q2 unselected, 3= q2.5 unselected, 4= q2.5 satisfied
Q2 / Acoustic Comfort	1= q2 unsatisfied, 2= q2 unselected, 3= q2.5 unselected, 4= q2.5 satisfied
Q2 / Visual Comfort	1= q2 unsatisfied, 2= q2 unselected, 3= q2.5 unselected, 4= q2.5 satisfied
Q2 / Indoor Air Quality	1= q2 unsatisfied, 2= q2 unselected, 3= q2.5 unselected, 4= q2.5 satisfied
Q3	+3= Hot, +2 = Warm, +1 = Slightly warm, 0 = Neutral, -1 = Slightly cool, -2 = Cool, -3 = Cold
Q4	1= dark green, 2= light green, 3= yellow, 4= red
Q5	1= dark green, 2= light green, 3= yellow, 4= red
Q6	0= no answer, 1= Building systems
Q6 / Computer, printer, other office equipment	0= no answer, 1= Computer, printer, other office equipment
Q6 / People chatting	0= no answer, 1= People chatting
Q6 / Road traffic	0= no answer, 1= Road traffic
Q6 / Other noises from the outside	0= no answer, 1= Other noises from the outside
Q6 / Other	0= no answer, 1= Other
Q6 / None	0= no answer, 1= None
Q7	1= dark green, 2= light green, 3= yellow, 4= red
Q8 / Windows	0= no answer, 1= Windows
Q8 / Lamps	0= no answer, 1= Lamps
Q8 / Glass surfaces	0= no answer, 1= Glass surfaces
Q8 / Computer screens	0= no answer, 1= Computer screens
Q8 / Reflective surfaces	0= no answer, 1= Reflective surfaces
Q8 / Other	0= no answer, 1= Other
Q8 / None	0= no answer, 1= None

Q9	+3= Much lighter, +2= Lighter, +1= Slightly lighter, 0= No change, -1= Slightly darker, -2= Darker, -3= Much darker
Q10	1= dark green, 2= light green, 3= yellow, 4= red
Q11 / Tobacco smoke	0= no answer, 1= Tobacco smoke
Q11 / Human odours	0= no answer, 1= Human odours
Q11 / Chemical odours	0= no answer, 1= Chemical odours
Q11 / Other	0= no answer, 1= Other
Q11 / None	0= no answer, 1= None
Q12 / Comments	Students can comment on classroom indoor environmental conditions.
TC(S)	%
AC(S)	%
VC(S)	%
IAQ(S)	%
Q13	0= Male, 1= Female
Q14	1 = 18-25, 2 = 26-35, 3 = 36-50, 4= 65+]
Q15 / Country	1= Italy, 2= India, 3= Iran, 4= Bulgaria, 5= Czechia, 6= Georgia, 7= Poland, 8= Colombia, 9= France, 10= Lebanon, 11= Azerbaijan, 12= Angola, 13= Pakistan, 14= Peru, 15= Romania, 16= Brazil, 17= Brundi, 18= Portugal, 19= China, 20= Turkey, 21= Cameroon, 22= Peru, 23= Republic of the Congo, 24= Kazakhstan, 25= Romania, 26= Guyana, 27= Canada, 28= Albania
Q16	1= Bachelor's degree, 2= Master's Degree, 3= Ph.D.
Q17	1= School
Q18	1= Student, 2= Technical staff, 3= Other, 4= Head Teacher, 5= Teacher, 6= Administrative, 7= Engineering, 8= Chef
Q19	1 = 1, 2 = 2 to 5, 3 = 6 to 10, 4=10+
Q20	0= no, 1= yes
Q21	0= no, 1= yes
Q22	0= no, 1= yes
Q23	0= no, 1= yes
Q24	0= no, 1= yes
Q25	0= no, 1= yes
Q26	0= no, 1= yes
Q27	0= no, 1= yes

Q28	0= no, 1= yes
Q29	0= no, 1= yes
Q30	0= no, 1= yes
Q31	0= no, 1= yes
Q32	0= no, 1= yes
Q33	0= no, 1= yes
Q34	0= no, 1= yes
Q35	0= no, 1= yes
Q36	0= no, 1= yes
Q37	0= no, 1= yes
Q34	0= no, 1= yes
Q35	0= no, 1= yes
Q36	0= no, 1= yes
Q37	0= no, 1= yes

3. Results

In this section, the results of collected data and statistical analysis will be presented. In the 2P, objective data is not presented because sensor 5 is not working, therefore the 2P is not included in the comparison bar charts. In Table 21, mean value (m.v.) and standard deviation (s.d.) of monitored parameter in the spring-summer periods between 30.05.2023 and 09.06.2023 and the fall-winter period between 08.01.2024 and 19.01.2024 are given. Mean values are calculated for occupancy hours, that is, between 08:30 a.m. and 7 p.m., as explained in section 2.2.

Table 21: Mean value (m.d.) and standard deviation (s.d.) values for every monitored parameter for the 1P, 3P and 4P classrooms.

PARAMETER	SPRING/SUMMER PERIOD						FALL/WINTER PERIOD					
	1P		3P		4P		1P		3P		4P	
	m.v.	s.d.	m.v.	s.d.	m.v.	s.d.	m.v.	s.d.	m.v.	s.d.	m.v.	s.d.
T_{in} [°C]	25.4	0.5	26.8	0.5	25.6	0.6	22.8	0.7	21.7	0.6	21.4	0.8
T_{out} [°C]	21.5	2.1	21.5	2.1	21.5	2.1	4.0	1.3	4.0	1.3	4.0	1.3
RH [%]	51.3	3.7	47.1	3.8	49.2	3.8	28.2	4.2	30.5	4.1	31.0	4.4
CO_2 [ppm]	697.5	231.7	688.2	142.4	640.5	203.5	542.2	129.5	558.0	113.6	518.2	83.0
TVOC [$\mu g/m^3$]	203.0	134.6	98.2	78.4	178.5	205.0	80.7	75.1	51.2	55.1	341.9	299.5
$PM_{2.5}$ [$\mu g/m^3$]	8.2	2.5	9.5	2.2	8.3	2.8	9.3	4.4	8.5	3.3	6.7	3.5
PM_{10} [$\mu g/m^3$]	9.2	2.5	10.5	2.2	9.2	2.8	10.4	4.4	9.5	3.4	7.7	3.5
SPL [dB(A)]	43.4	5.7	46.3	7.0	43.9	6.3	49.8	4.5	50.0	5.6	49.6	4.6
E_v [lx]	158.8	72.0	209.0	88.9	151.9	77.8	95.3	34.1	115.2	67.9	95.2	43.4

A total of 752 responses were received to the questionnaire. 211 answers could not be used in the analysis due to sensors not working between 15.05.2023 and 29.05.2023. In the questionnaire conducted simultaneously with monitoring during the summer period (30.05.2023 to 09.06.2023), there was 1 answer for 1P and 11 answers for 3P. Due to the small number of responses, the data in these two classrooms were not reliable and were not considered. 433 responses were received in the winter period and 95 responses in the spring-summer period to be used in the case study. 95 questionnaires were completed in 4P, in the spring-summer period. In the winter period, 110 questionnaires were completed in the 1P and 92, 190, 41 in the 2P, 3P, 4P classrooms, respectively.

In the winter period, students in 1P classroom are satisfied, slightly satisfied, slightly dissatisfied and dissatisfied with overall conditions inside the classroom at 18.2%, 50%, 25.5% and 6.4%, respectively. In winter period students in 2P are satisfied, slightly satisfied, slightly dissatisfied and dissatisfied at 10.9%, 47.8%, 31.5% and 9.8%, respectively and students in 3P at 20.5%, 58.4%, 16.8% and 4.2%, respectively. In winter period, students in 4P are satisfied, slightly satisfied, slightly dissatisfied and dissatisfied at 21.1%, 36.8%, 32.6% and 9.5% respectively, and in spring/summer period, 7.3%, 22%, 39% and 31.7%. These results reveal that students are generally satisfied with 1P, 2P, and 3P during the winter period, with the highest satisfaction in 3P. However, there is overall dissatisfaction with 4P during winter period. During the summer period, the number of satisfied students in the 4P is higher than the number of dissatisfied students (Figure 35).

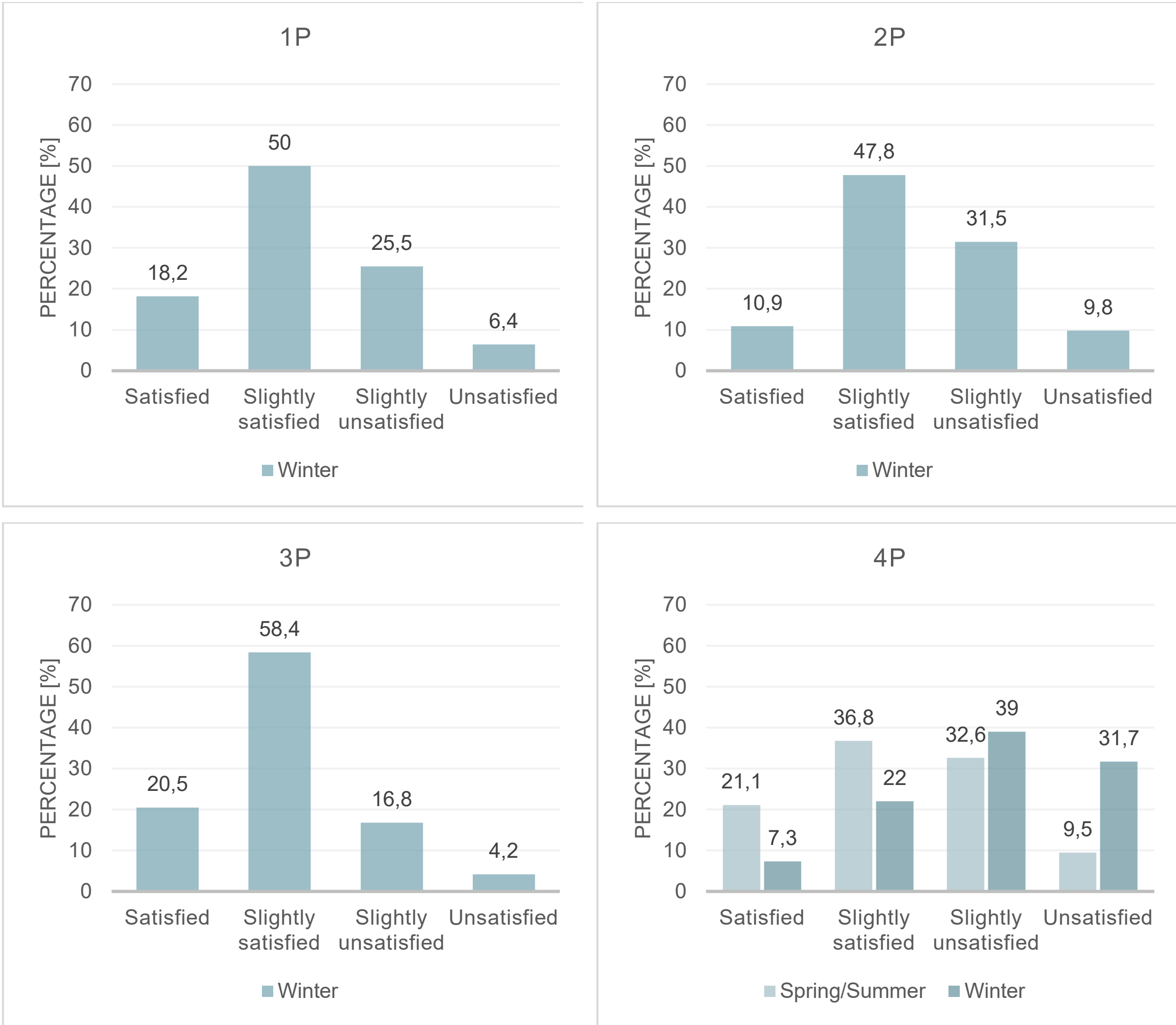

Figure 35: Satisfaction with the overall environment based on students' answers to the first question of the questionnaire in 1P, 2P, 3P and 4P classrooms.

The second question in the questionnaire was used to analyze the students' satisfaction for each domain. Question specifically asks which domain they are satisfied or unsatisfied. If 'satisfied' or 'slightly satisfied' answers were selected in the previous question, students are asked a question about which domains they are satisfied with; in this question, they cannot specify the domains in which they are dissatisfied or neutral. If the answers 'slightly dissatisfied' or 'dissatisfied' were selected in the previous question, students are asked a question about which domains they are dissatisfied with; in this question, they cannot specify the domains in which they are satisfied or neutral. For this reason, the sum of the percentages of a single domain in the classrooms does not reach 100%. Figure 36 shows the thermal condition results. In the winter period, students are satisfied and unsatisfied at 29.1% and 25.5% in 1P, 26.1% and 31.5% in 2P, 32.2% and 16.8% in 3P, 9.8% and 70.7% in 4P, respectively. In the summer period, students are satisfied and unsatisfied at 37.9% and 32.6% respectively in 4P. The highest satisfaction with the thermal environment is in the spring-summer period in classroom 4P (37.9%), the percentage is quite close to 3P (32.2%) in the winter period. In 2 cases, the dissatisfaction rate is higher than the satisfaction rate. The highest dissatisfaction is in 4P (70.7%) in the winter period, the following is in 2P (31.5%) in winter period. The percentage of thermal dissatisfaction in 4P is also in line with the general dissatisfaction in the feedback of the 4P regarding the first question, in winter period.

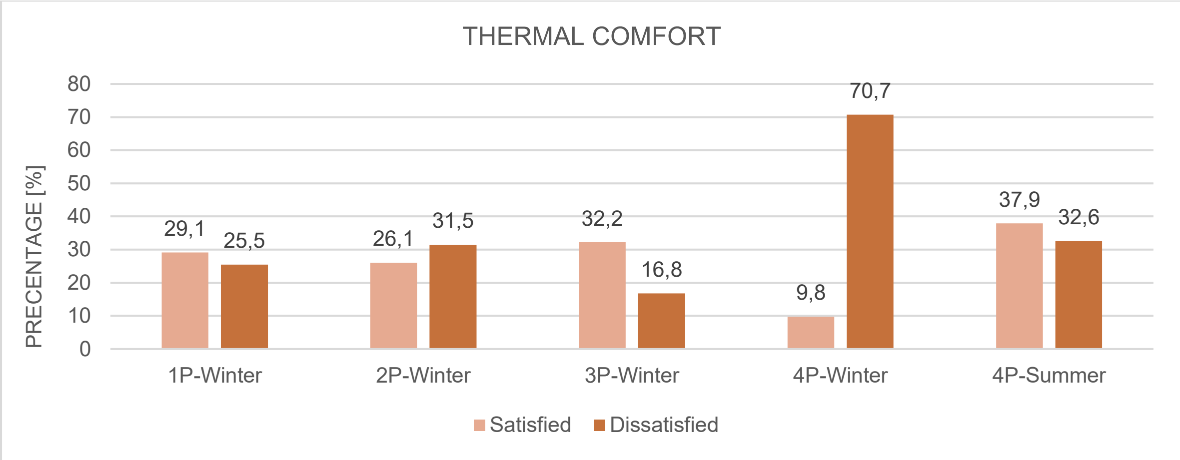

Figure 36: Satisfaction with the thermal environment based on students' answers to the second question of the questionnaire in 1P, 2P, 3P and 4P classrooms.

Figure 37 shows the acoustic comfort results. In the winter period, students are satisfied, unsatisfied at 36.4%, 3.6% respectively in 1P, 26.1%, 15.2% in 2P, 51.1%, 1.1% in 3P, 19.5%, 12.2% in 4P. In the summer period, students are satisfied, unsatisfied at 48.3%, 11.6% respectively in 4P. The highest satisfaction with the acoustic environment is in the 3P (51.1%), in the winter period, with a lower percentage of dissatisfaction compared to other classrooms. The highest dissatisfaction is in 2P during the winter period (15.2%), but even in this condition, most of the students are satisfied with the acoustic conditions in 2P. Students are mostly satisfied with the acoustic conditions in all classrooms.

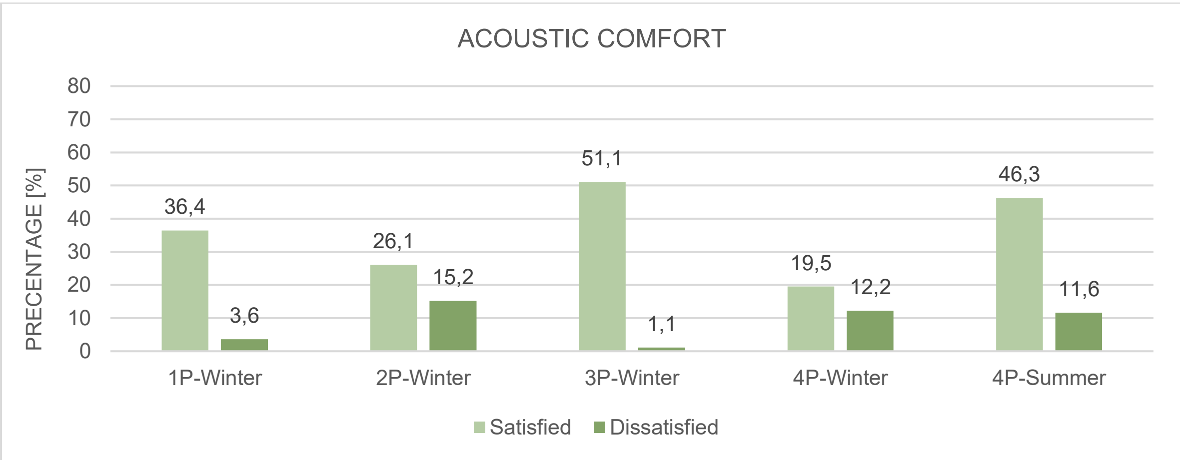

Figure 37: Satisfaction with the acoustic environment based on students' answers to the second question of the questionnaire in 1P, 2P, 3P and 4P classrooms.

Figure 38 shows the visual comfort results. In the winter period, students are satisfied, unsatisfied at 32.7%, 5.5% respectively in 1P, 33.7%, 2.2% in 2P, 42.1%, 4.2% in 3P, 17.1%, 4.9% in 4P. In the summer period, students are satisfied, unsatisfied at 52.6%, 9.5% respectively in 4P. The highest satisfaction with the visual environment is in the 4P, in the spring/summer period (52.6%). Highest dissatisfaction is again in 4P during the spring/summer period (9.5%).

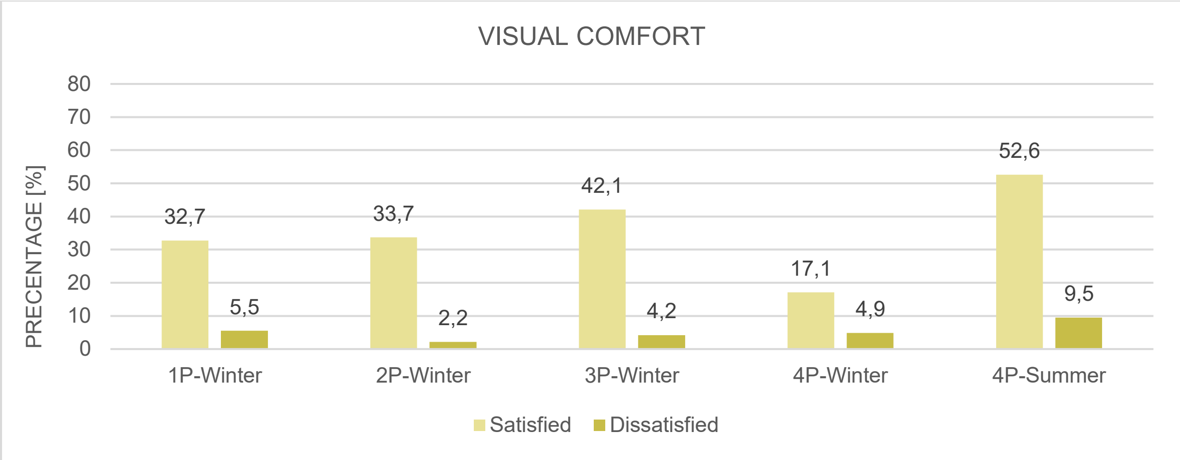

Figure 38: Satisfaction with the visual environment based on students' answers to the second question of the questionnaire in 1P, 2P, 3P and 4P classrooms.

Figure 39 shows the indoor air perception results. In the winter period, students are satisfied, unsatisfied at 20.9%, 14.5% respectively in 1P, 20.7%, 18.5% in 2P, 19.5%, 8.4% in 3P, 12.2%, 17.1% in 4P. In the summer period, students are satisfied, unsatisfied at 30.5%, 34.7% respectively in 4P. The highest satisfaction with the indoor air conditions is in the 4P, in the spring/summer period (30.5%) but highest dissatisfaction is again in 4P during the spring/summer period (34.7%). The results are compatible with the overall satisfaction analysis based on the first question.

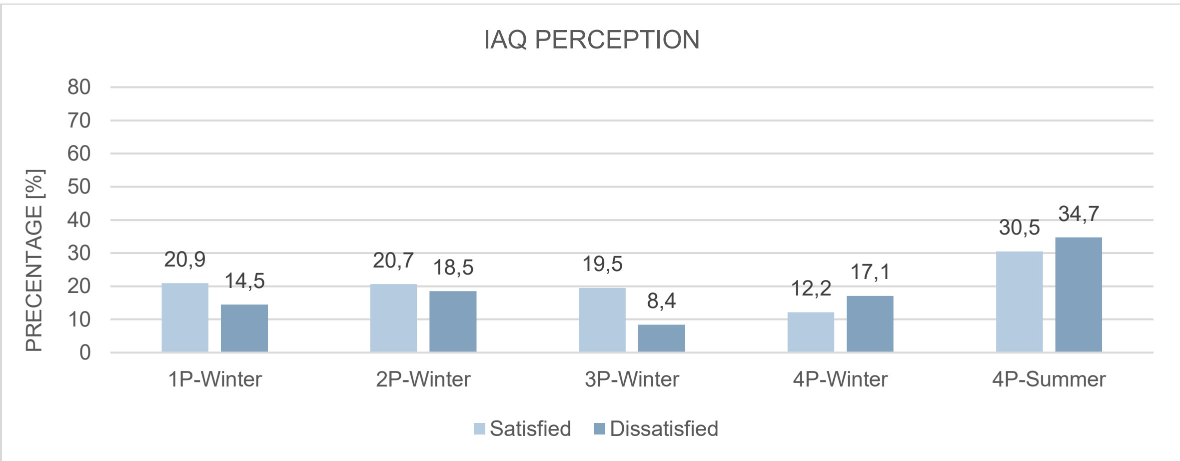

Figure 39: Satisfaction with the indoor air conditions based on students' answers to the second question of the questionnaire in 1P, 2P, 3P and 4P classrooms.

In the Table 22, the students' satisfaction or dissatisfaction percentages according to the second question are given. It can be seen that students generally expressed negative or positive feedback about TC. At the same time, in the spring/summer period in the 4P classroom, students gave more feedback about each domain as satisfied or dissatisfied compared to other classrooms. Conducting the study in every classroom during the spring/summer period with more students will allow us to obtain clearer results.

Table 22: Sum of satisfaction or dissatisfaction percentages in classrooms.

Domain	Classroom / Period				
	1P-Winter	**2P-Winter**	**3P-Winter**	**4P-Winter**	**4P- Spring/Summer**
TC	54,6	57,6	49,0	80,6	70,5
AC	40,0	41,3	52,2	31,7	57,9
VC	38,2	35,9	46,3	22,0	62,1
IAC	35,4	39,2	27,9	29,3	65,2

For thermal conditions, objective evaluation obtained by monitoring is higher than students' satisfaction percentages (Figure 40). In the winter period, objective evaluation percentages are 75.83%, 97.23% and 100% respectively in 1P, 3P, 4P. In spring/summer period, objective evaluation percentage is 91.6% in 4P. In the winter period, subjective evaluation percentages are 56.25%, 58.59% and 47.32% respectively in 1P, 3P, 4P. In spring/summer period, subjective evaluation percentage is 56.45% in 4P. Although the student's satisfaction in the 4P during the winter period is the lowest (47.32%) compared to other classrooms, objective evaluation percentage is 100%. It can be seen in the bar chart in Figure 40 that students are not totally satisfied with the thermal conditions, even though the objective evaluation meets the standards. It is necessary to analyze students' dissatisfaction with thermal comfort better, based on their answers to the question on this subject.

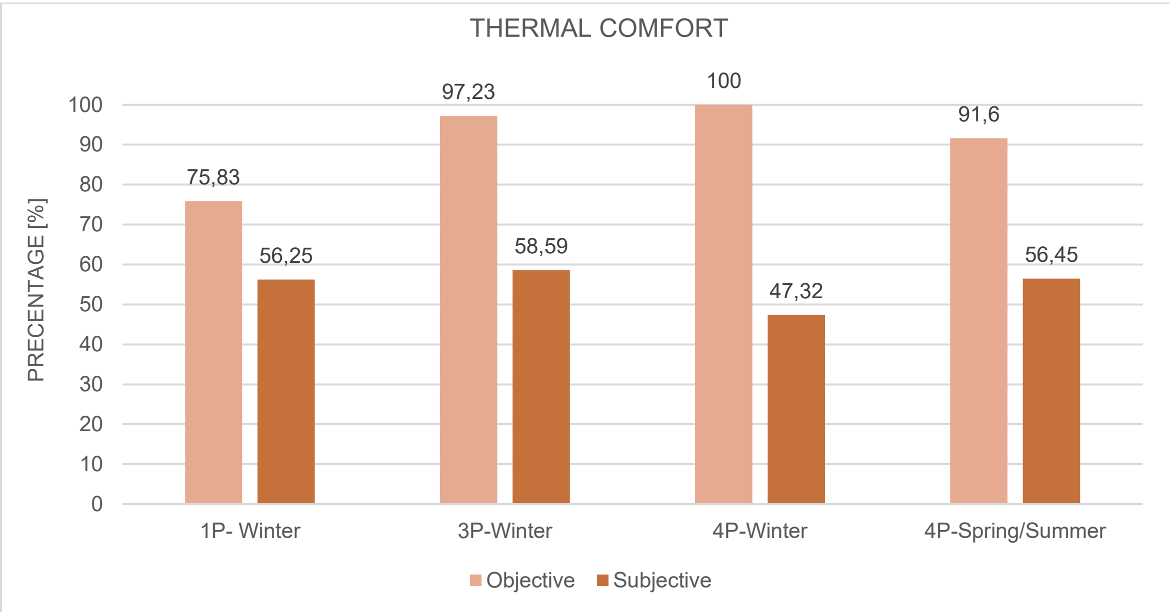

Figure 40: Bar chart comparing objective analysis and subjective feedback on thermal comfort.

During the winter semester, students in classrooms 1P, 2P, 3P and 4P left 11, 13, 23 and 5 comments on the questionnaire, respectively. In 1P, 2 students believe the classroom is hot. 3 students believe it is cold and 1 of the 3 students stated that they felt cold and had a headache when sitting under air conditioning. In 2P, 6 students believed the classroom was cold. One student stated that when students opened the doors facing outside to smoke, cold air entered the classroom. One student expressed he is satisfied with the thermal environment. In 3P, 15 of the 23 students stated that 4P was cold in the winter period and the operation of the air conditioning system became a problem. All students stated that the classroom was cold and the cooling of the air conditioning system in winter caused dissatisfaction in 4P. During spring/summer period, 11 students in the 4P left comments on the questionnaire. 5 students believe there is an overheating problem in the 4P.

For acoustic comfort (AC), in the winter period objective evaluation percentages are 54.51%, 33.94% and 16.43% respectively in 1P, 3P, 4P. In spring/summer period, objective evaluation percentage is 34.82% in 4P. In the winter period, subjective evaluation percentages are 62.5%, 50% and 55% respectively in 1P, 3P, 4P. In spring/summer period, subjective evaluation percentage is 52.78% in 4P. It can be seen that in the winter period in the 4P, although the objective quality is 16.43%, the questionnaire demonstrated students comfort perception is 55%. For AC, students' perceptions have a higher percentage than acoustic quality (Figure 41).

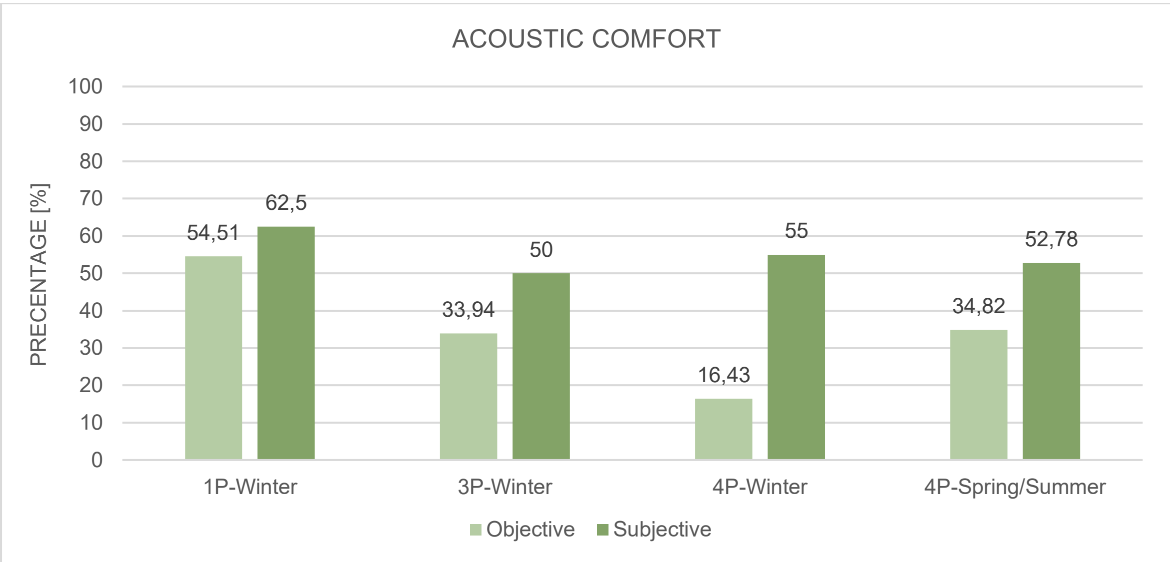

Figure 41: Bar chart comparing objective analysis and subjective feedback on acoustic comfort.

Among the students who left comments on the survey in 2P, 1 student stated that he was dissatisfied with the sound coming from the microphone, and 1 student stated that he was dissatisfied with the sound coming from the air conditioner. 2 students stated that they are dissatisfied with the acoustic environment because of the microphone in 3P.

For visual evaluation, in the winter period objective evaluation percentages are 6.94%, 9.34% and 0.15% respectively in 1P, 3P, 4P. In the spring/summer period, objective evaluation percentage is 1.57% in 4P. In the winter period, subjective evaluation percentages are 41.67%, 62.5% and 50% respectively in 1P, 3P, 4P. In spring/summer period, subjective evaluation percentage is 60.71% in 4P (Figure 42). It is seen that objective evaluation results in classrooms are very low (between 0.15%-9,34). However, despite this situation, the satisfaction of the students is between 41.67% and 62.5%. Student comfort should also be increased by improving the physical condition of the classroom.

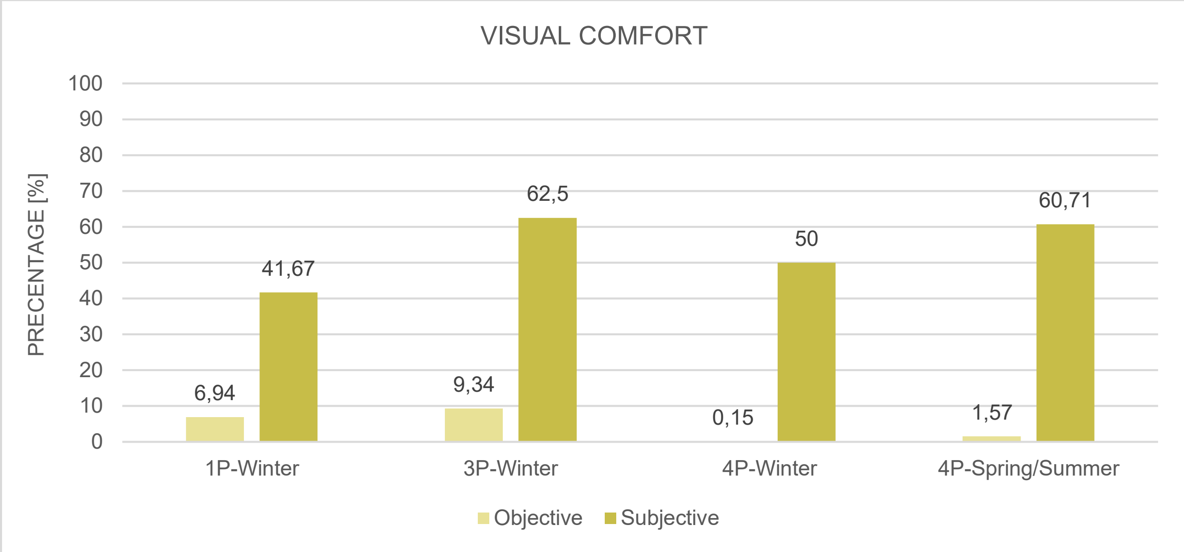

Figure 42: Bar chart comparing objective analysis and subjective feedback on visual comfort.

During the winter semester, students in classrooms 1P, 2P, 3P, and 4P left 11, 13, 23, and 5 comments on the questionnaire, respectively. In 1P, 3 students stated that it was difficult to read the slides because there was a problem on the left side of the projector. In 2P, one student expressed satisfaction with lighting conditions in the classroom. 5 students stated that they could not see the slides in 3P. 4 students stated that they had problems due to too much light hitting the projection wall in the classroom, and 1 student stated that it became difficult to take notes from devices such as tablets that reflected light. In 4P, 2 students stated that they had problems seeing the projection wall in the classroom, and 1 of the students stated that it would be better to turn off the lamps close to the projection wall. 1 student is satisfied with the natural lighting of the 4P.

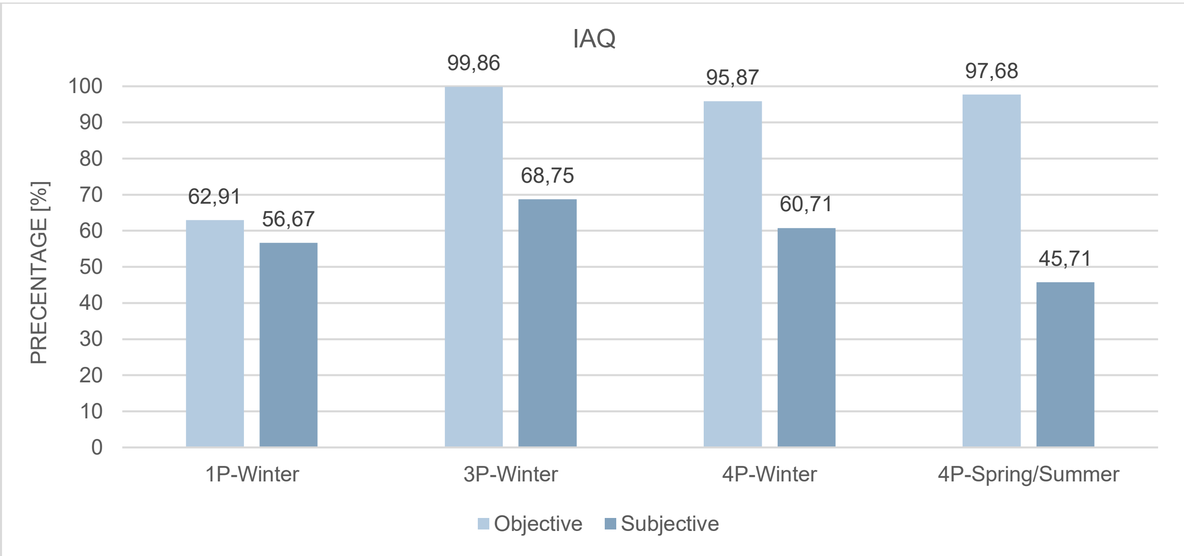

Figure 43: Bar chart comparing objective analysis and subjective feedback on IAQ.

Figure 43 presents the subjective and objective evaluation for IAQ. In the winter period objective evaluation percentages are 62.91%, 99.86% and 95.87% respectively in 1P, 3P, 4P. In spring/summer period, objective evaluation percentage is 97.68% in 4P. In the winter period, subjective evaluation percentages are 56.67%, 68.75% and 60.71% respectively in 1P, 3P, 4P. In spring/summer period, subjective evaluation percentage is 45.71% in 4P. The high TVOC concentration seen in Table 21 may cause students' dissatisfaction. Although objective evaluation meets the standards, subjective evaluation results have a lower percentage.

The reasons for thermal and indoor air discomfort should be better analyzed in following the questionnaire responses. In addition, data from all periods for each classroom should be collected for a more complete analysis, and a longer monitoring and questionnaire should be carried out.

During the winter semester, 11, 13, and 5 students in classrooms 1P, 2P, and 4P, respectively, left comments on the questionnaire. In 1P, 2 students think that they are not satisfied with the indoor air conditions and the classroom should be better ventilated. In 2P, 2 students think that indoor air is not fresh enough. In 4P, 4 students stated the indoor air conditions were not good and that they needed more fresh air. 1 of the 4 students stated he could get fresh air when he sat close to the doors facing outside, however felt uncomfortable when he sat away from the door.

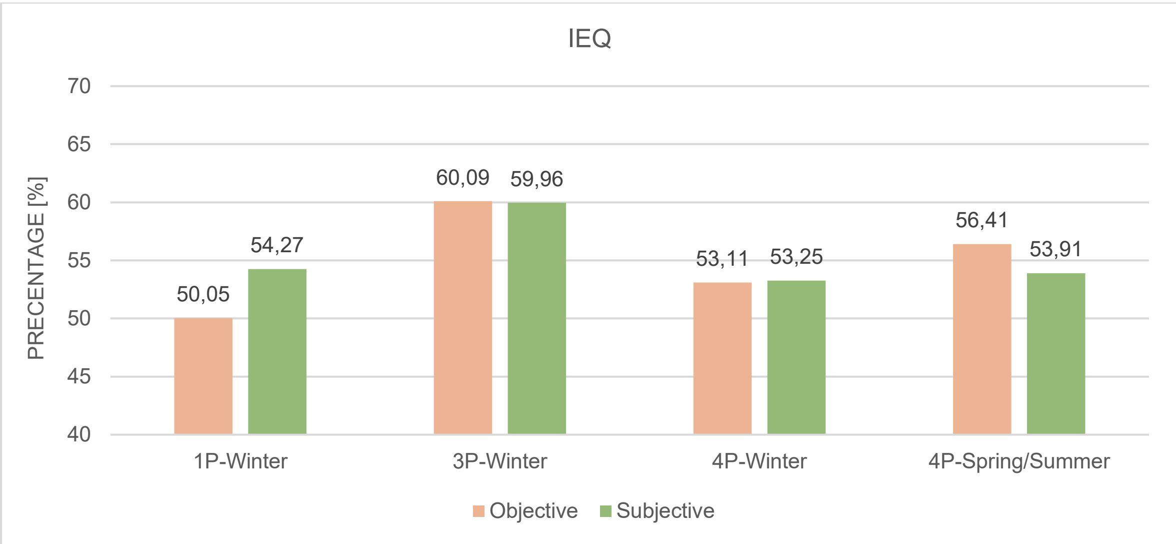

Figure 44: Bar chart comparing objective analysis and subjective feedback on IEQ.

For IEQ, in the winter period objective evaluation percentages are 50.05%, 60.09% and 53.11% respectively in 1P, 3P, 4P. In spring/summer period, objective evaluation percentage is 56.41% in 4P. In the winter period, subjective evaluation percentages are 54.27%, 59.96% and 53.25% respectively in 1P, 3P, 4P. In spring/summer period, subjective evaluation percentage is 53.91% in 4P (Figure 44). In general, it is seen that both objective and subjective evaluation results vary between 50.05% and 60.09%. In order to increase students' health, well-being and learning performance, both acoustic and visual quality should be increased and student satisfaction in the four domains should also be increased. The reasons for students' dissatisfaction with thermal and indoor air quality should be analyzed.

Table 23 shows for the question "How do you find air velocity in your classroom now?", how many students chose the relevant answers and their percentages, as presented in Figure 45.

Table 23: Frequencies (freq.) and percentages (%) of the answers given to the "How do you find air velocity in your classroom now?" in the questionnaire.

Air Velocity	Classroom-Period									
	1P-Winter		2P-Winter		3P-Winter		4P-Winter		4P-Spring/Summer	
	Freq.	%	Freq.	%	Freq.	%	Freq.	%	Freq.	%
Not draughty	3	10,7	1	3,6	2	6,3	1	3,6	7	22,6
Slightly draughty	12	42,9	11	39,3	14	43,8	11	39,3	8	25,8
Daughty	10	35,7	10	35,7	13	40,6	11	39,3	12	38,7
Very draughty	3	10,7	6	21,4	3	9,4	5	17,9	4	12,9

In the winter period, students' perception about air velocity as very draughty, draughty, slightly draughty, not draughty is 10.7%, 42.9%, 35.7%, 10.7%, respectively in 1P, 3.6%, 39.3%, 35.7%, 21.4% in 2P, 6.3%, 43.8%, 40.6%, 9.4% in 3P, 3.6%, 39.3%, 39.3%, 17.9% in 4P. In the summer period, students' perception about air velocity very draughty, draughty, slightly draughty, not draughty at 22.6%, 25.8%, 38.7%, 12.9%, respectively in 4P.

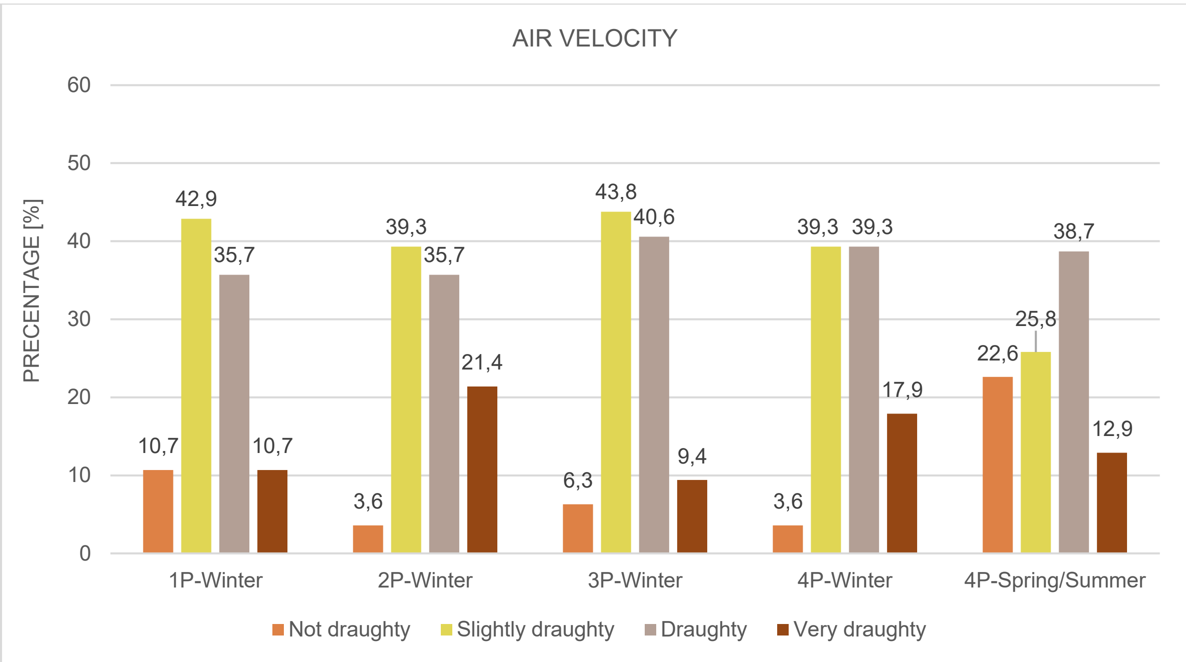

Figure 45: The answer to the question "How do you find air velocity in your classroom?".

Conversion of the answers given by the students to the questions into comfort percentages used in PROMET&O is explained in section 2.4. The answers are not draughty, slightly draughty, draughty, very draughty and their percentages are 100%, 75%, 50%, 25%, respectively. It is difficult to say that there is satisfaction in a situation where students feel draughty (even for the statement slightly draughty). In the 4P (spring/summer period), students answered more 'not draughty' than other classrooms in the winter situation. This answer indicates that the draught may be due to HVAC. In order to understand reason better, research should be deepened with questionnaires and monitoring in all classrooms/periods.

In Figure 46 and Table 24 , the frequencies and percentages of the answers given to the third question "Please indicate on the following scale how you feel now" are given.

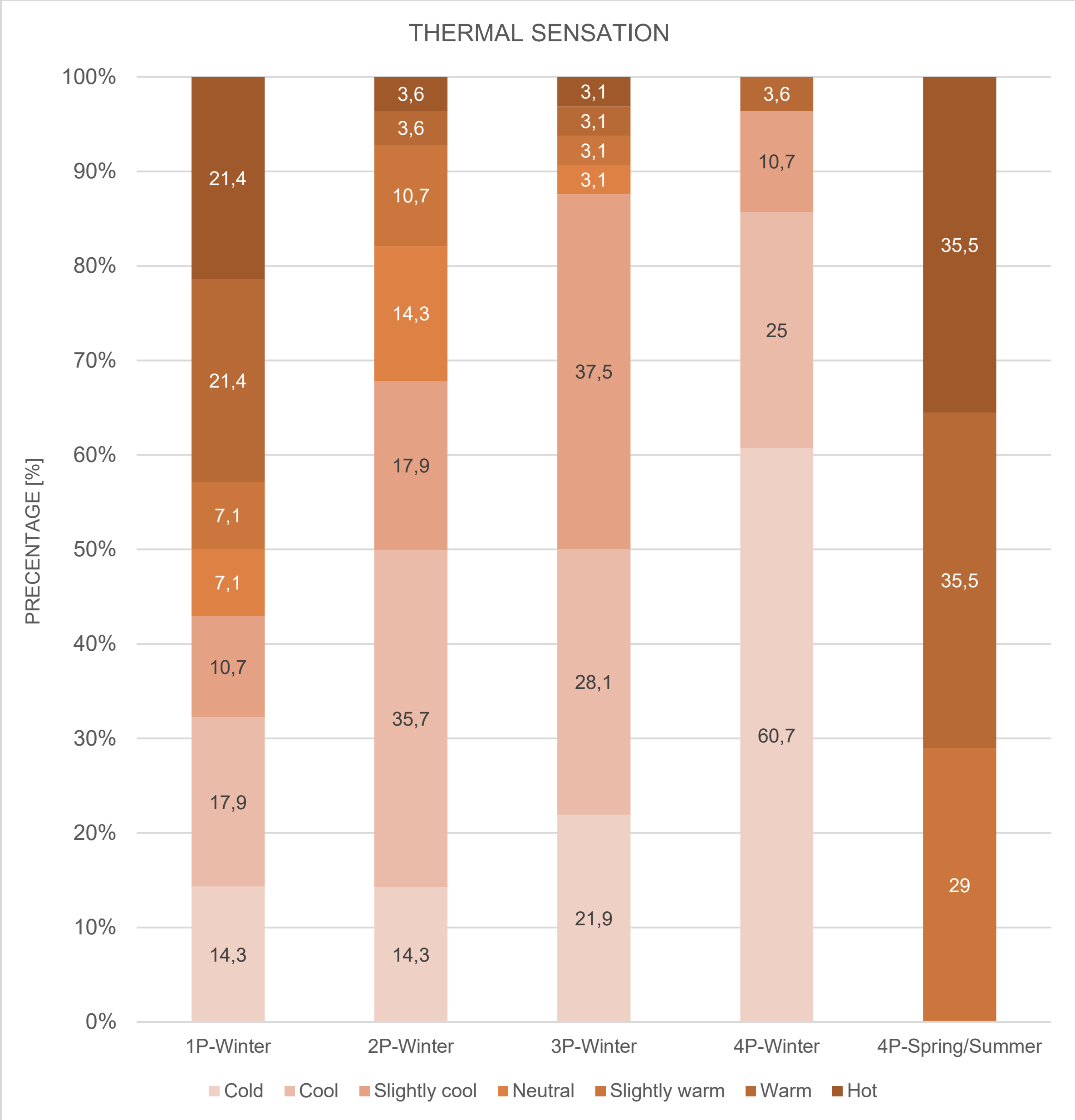

Figure 46: Measuring thermal sensation based on the question "How do you feel now?".

It is aimed to understand students' thermal sensations. The 7-point scale answers to the third question are presented in Figure 46. In the winter period, students feel cold, cool, slightly cool, neutral, slightly warm, warm and hot at 14.3%, 17.9%, 10.7%, 7.1%, 7.1%, 21.4% and 21.4% respectively in 1P, 14.3%, 35.7%, 17.9%, 14.3%, 10.7%, 3.6% and 3.6% in 2P, 21.9%, 28.1%, 37.5%, 3.1%, 3.1%, 3.1% and 3.1% in 3P. In the winter period, students feel cold, cool, slightly cool, and warm at 60.7%, 25%, 10.7%, and 3.6% respectively in 4P. In spring/summer period, students feel slightly warm, warm and hot at 29%, 35,5% and 35,5% respectively in 4P.

In winter period, in 1P, 2P, 3P, students voted for all options on the 7 point-scale between cold and hot, and in 4P, 4 options were voted. However, in the spring/summer period, only 3 options in the slightly warm-hot range were voted in the 4P. In the 1P, the thermal sensations of the students are more evenly distributed among the options; in the 2P, 3P, 4P, the cold-cool options are increasingly chosen, respectively in winter period. In the 4P, 3P, 2P, 1P, the warm-hot options are increasingly chosen, respectively in winter period. Students in the 2P feel more neutral compared to other classrooms.

Table 24: Frequencies (freq.) and percentages (%) of the answers given to the third question in the questionnaire.

Thermal Sensation	Classroom / Period									
	1P-Winter		2P-Winter		3P-Winter		4P-Winter		4P- Spring/Summer	
	Freq.	%	Freq.	%	Freq.	%	Freq.	%	Freq.	%
- 3 / Cold	4	14,3	4	14,3	7	21,9	17	60,7	0	0
- 2 / Cool	5	17,9	10	35,7	9	28,1	7	25,0	0	0
- 1 / Slightly cool	3	10,7	5	17,9	12	37,5	3	10,7	0	0
0 / Neutral	2	7,1	4	14,3	1	3,1	0	0	0	0
+ 1 / Slightly warm	2	7,1	3	10,7	1	3,1	0	0	9	29,0
+ 2 / Warm	6	21,4	1	3,6	1	3,1	1	3,6	11	35,5
+ 3 / Hot	6	21,4	1	3,6	1	3,1	0	0	11	35,5

Table 25 and Figure 47 show students answer to the question "How do you find the noise in your environment?". In the winter period, students find the noise in their environment not annoying, slightly annoying, annoying and very annoying at 25%, 0%, 75% and 0%, respectively in 1P, 0%, 28.6%, 64.3%, 7.1% in 2P, 0%, 0%, 100% and 0% in 3P, 0%, 20%, 80% and 0% in 4P. In the summer period, students find the noise in their environment not annoying, slightly annoying, annoying and very annoying at 11.1%, 0%, 77.8% and 11.1%, respectively in 4P.

Table 25: Frequencies (freq.) and percentages (%) of the answers given to the question "How do you find the noise in your environment now?" in the questionnaire.

Noise	Classroom-Period									
	1P-Winter		2P-Winter		3P-Winter		4P-Winter		4P-Spring/Summer	
	Freq.	%	Freq.	%	Freq.	%	Freq.	%	Freq.	%
Not annoying	1	25,0	0	0	0	0	0	0	1	11,1
Slightly annoying	0	0	4	28,6	0	0	1	20,0	0	0
Annoying	3	75,0	9	64,3	2	100,0	4	80,0	7	77,8
Very annoying	0	0	1	7,1	0	0	0	0	1	11,1

Results show that the majority of the students believe the classroom is acoustically annoying. A minority of the students believe that only 1P in the winter period and 4P in the spring/summer period are not annoying. However, as mentioned before, evaluation should be continued with more students and noise sources should be asked.

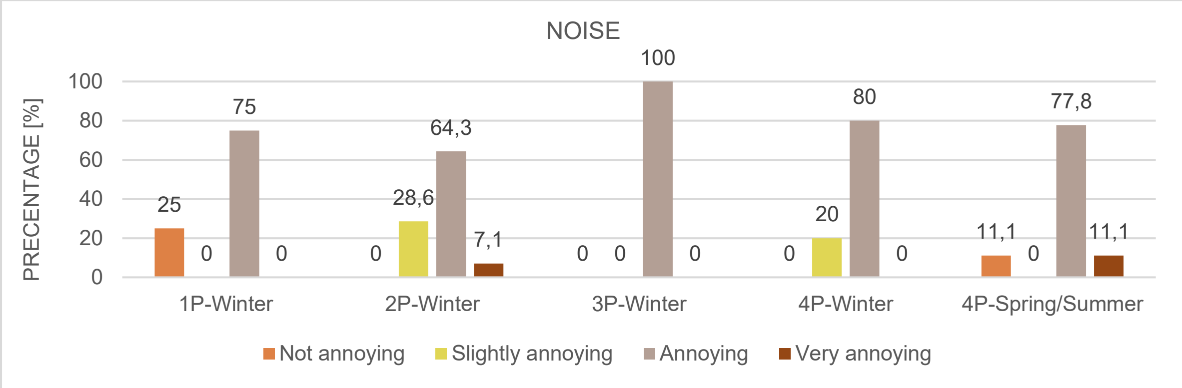

Figure 47: The answer to the question "How do you find the noise in your environment?".

Table 26 shows students answer to the question "How do you find visual environment now?". In the winter period, students find the visual environment not uncomfortable, slightly uncomfortable, uncomfortable, very uncomfortable at 0%, 16.7%, 33.3%, 50%, respectively in 1P, 0%, 50%, 50%, 0% in 2P , 0%, 50%, 50%, 0% in 3P, 0%, 0%, 100%, 0% in 4P. In the summer period, students find visual environment in their environment not uncomfortable, slightly uncomfortable, uncomfortable, very uncomfortable at 14.3%, 14.3%, 71.4%, 0%, respectively in 4P. Students are mostly dissatisfied with the visual conditions (Figure 48).

Table 26: Frequencies (freq.) and percentages (%) of the answers given to the question "How do you find visual environment now?" in the questionnaire.

Visual Environment	Classroom-Period									
	1P-Winter		2P-Winter		3P-Winter		4P-Winter		4P-Spring/Summer	
	Freq.	%	Freq.	%	Freq.	%	Freq.	%	Freq.	%
Not uncom.	0	0	0	0	0	0	0	0	1	14,3
Slightly uncom.	1	16,7	0	0	0	0	0	0	1	14,3
Uncomfortable	2	33,3	1	50,0	5	50,0	2	100,0	5	71,4
Very uncom.	3	50,0	1	50,0	5	50,0	0	0	0	0

Considering Figure 42, it is seen that the classrooms objectively do not match the threshold values and according to subjective feedback, the students are not satisfied. However, this response amount is quite low. The questionnaire should be repeated with more students and the reasons should be researched.

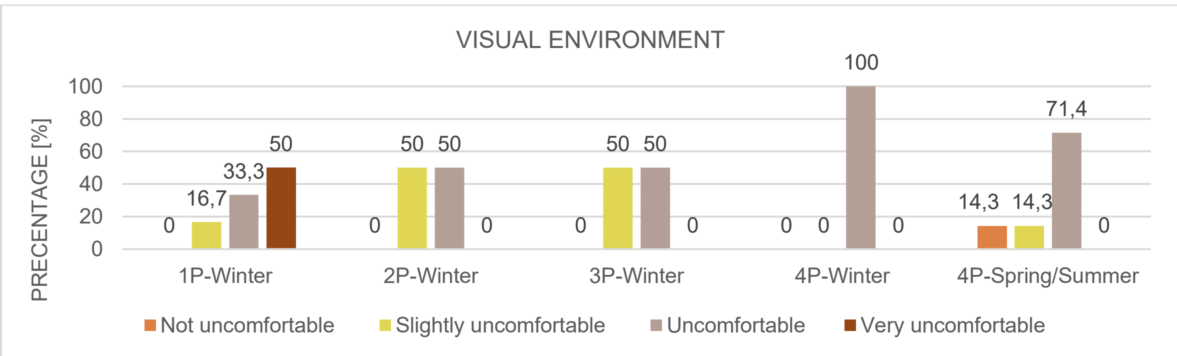

Figure 48: The answer to the question "How do you find visual environment now?".

In the winter period, students would like their visual environment much darker, darker, slightly darker, no change, slightly lighter, lighter and much lighter at 0%, 0%, 16.7%, 33.3%, 33.3%, 16.7% and 0% respectively in 1P, 50%, 0%, 50%, 0%, 0%, 0% and 0% in 2P, 0%, 0%, 12.5%, 37.5%, 12.5%, 12.5% and 25% in 3P, 0%, 0%, 50%, 0%, 0%, 0% and 0%, in 4P. In the summer period, students would like their visual environment slightly darker, no change, slightly lighter, lighter at 14.3%, 14.3%, 28.6% and 42.9% respectively in 4P (Figure 49, Table 27).

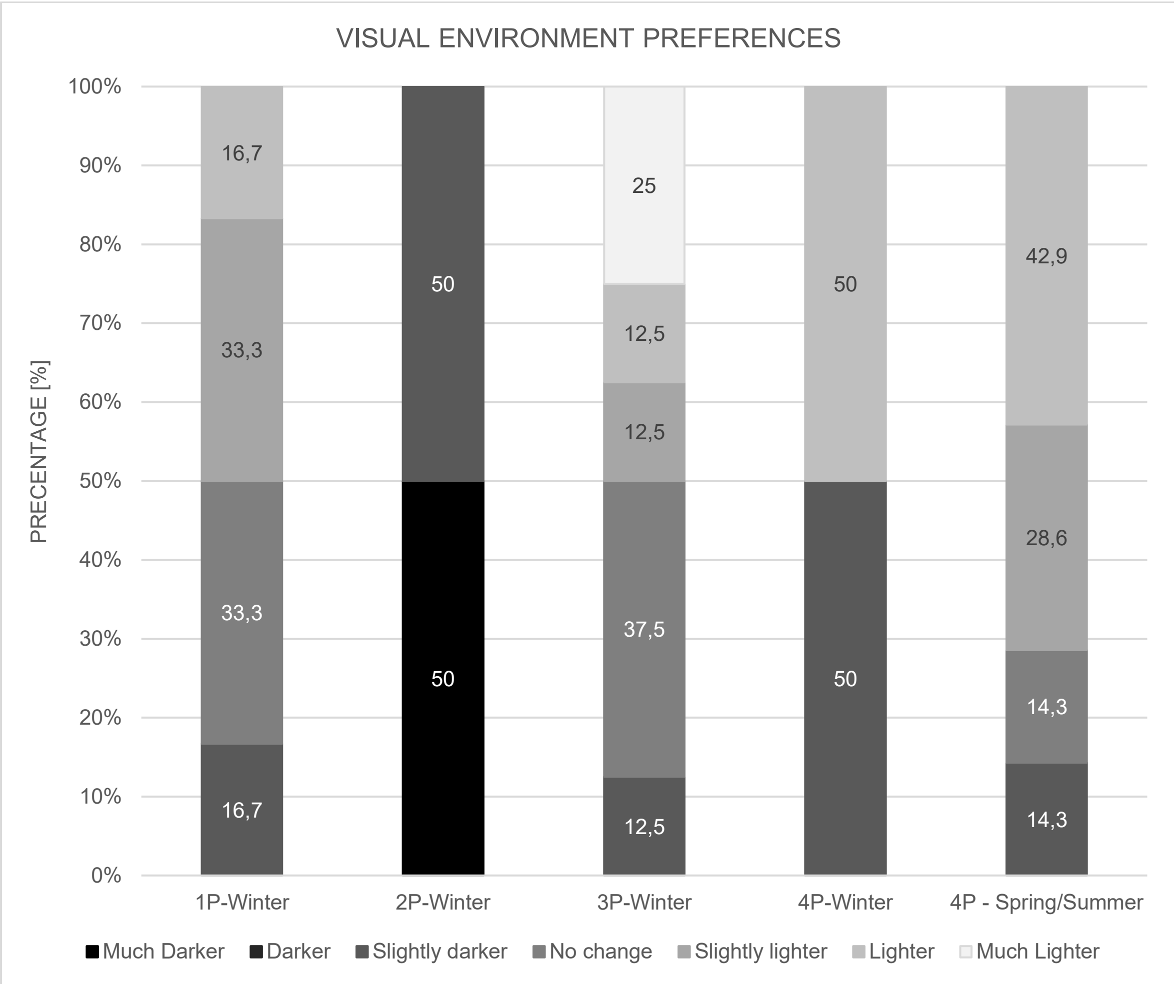

Figure 49: Survey questions measuring visual preferences based on the question "How you would like your visual environment to be now?".

In the 2P during the winter period, students stated that they preferred the classroom as slightly darker or much darker (only 2 students), but since objective data is not available, visual quality of 2P is unknown. Students in 1P and 3P mostly want the classroom lighter. The situation for the 4P in the winter period is unclear, the situation will become clear with the participation of more students. In the spring/summer period, the majority of the students in 4P prefer the classroom lighter. In the winter period, only 2 students each from classrooms 2P and 4P were able to answer this question. The number of responses in 1P and 3P in winter and 4P in spring/summer period are also less than 10 students per classroom. Therefore, it should be stated again that the study should be continued with more students and at all periods in order to achieve clearer results.

Table 27: Frequencies (freq.) and percentages (%) of the answers given to the question "How would you like your visual environment to be now?".

Visual Preferences	Classroom / Period									
	1P-Winter		2P-Winter		3P-Winter		4P-Winter		4P- Spring/Summer	
	Freq.	%	Freq.	%	Freq.	%	Freq.	%	Freq.	%
- 3 / Much darker	0	0	1	50,0	0	0	0	0	0	0
- 2 / Darker	0	0	0	0	0	0	0	0	0	0
- 1 / Slightly darker	1	16,7	1	50,0	1	12,5	1	50,0	1	14,3
0 / No change	2	33,3	0	0	3	37,5	0	0	1	14,3
+ 1 / Slightly lighter	2	33,3	0	0	1	12,5	0	0	2	28,6
+ 2 / Lighter	1	16,7	0	0	1	12,5	1	50,0	3	42,9
+ 3 / Much lighter	0	0	0	0	2	25,0	0	0	0	0

In the winter period, students find the indoor air quality not smelly, slightly smelly, smelly, very smelly at 0%, 46.7%, 33.3%, 20%, respectively in 1P, 23.5%, 23.5%, 47.1%, 5.9% in 2P , 18.8%, 37.5%, 43.8%, 0% in 3P, 14.3%, 28.6%, 42.9%, 14.3% in 4P. In the summer period, students find the indoor air quality not smelly, slightly smelly, smelly, very smelly at 0%, 5.7%, 71.4%, 22.9%, respectively in 4P (Figure 50,Table 28).

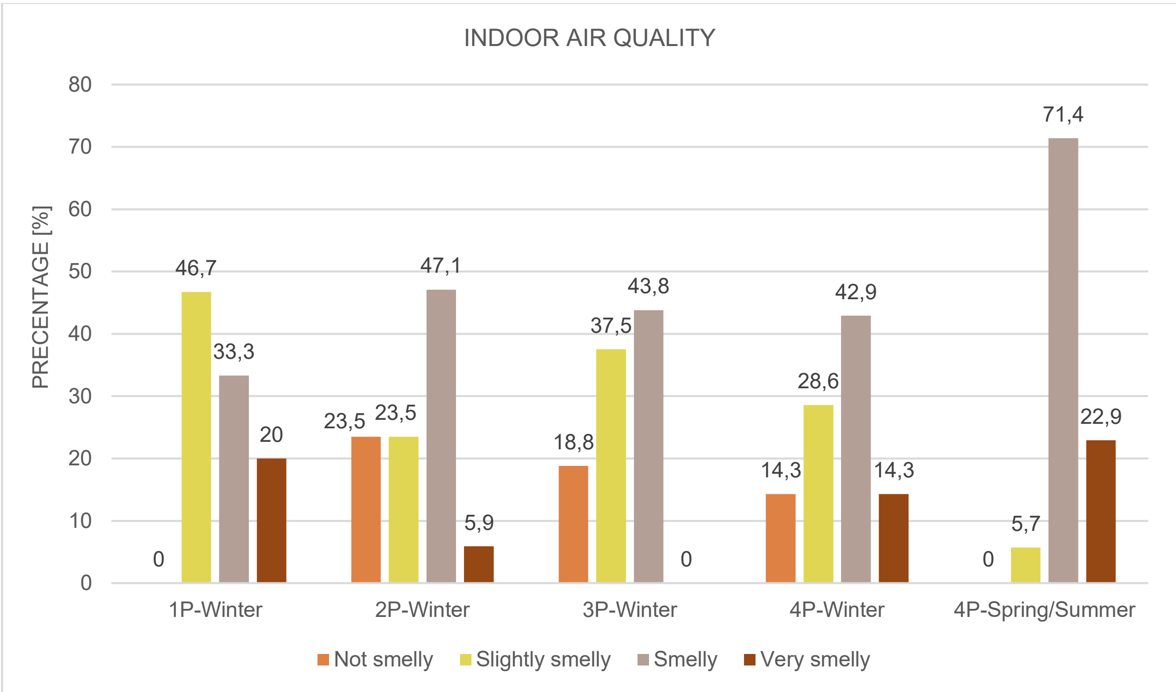

Figure 50: The answer to the question "How do you find the air quality in your environment now?".

The majority of the students find the classrooms they are in smelly, especially during spring/summer period 4P is more smelly than other classrooms.

Table 28: Frequencies (freq.) and percentages (%) of the answers given to the "How do you find the air quality in your environment now?".

IAQ	Classroom-Period									
	1P-Winter		2P-Winter		3P-Winter		4P-Winter		4P-Spring/Summer	
	Freq.	%	Freq.	%	Freq.	%	Freq.	%	Freq.	%
Not smelly	0	0	4	23,5	3	18,8	1	14,3	0	0
Slightly smelly	7	46,3	4	23,5	6	37,5	2	28,6	2	5,7
Smelly	5	33,3	8	47,1	7	43,8	3	42,9	25	71,4
Very smelly	3	20,0	1	5,9	0	0	1	14,3	8	22,9

The analyzes below were first conducted separately for all classrooms. However, due to the small number of responses given to each answer, it is seen that it would be clear to evaluate it as a whole for all classrooms (Figure 51, Figure 52, Figure 53).

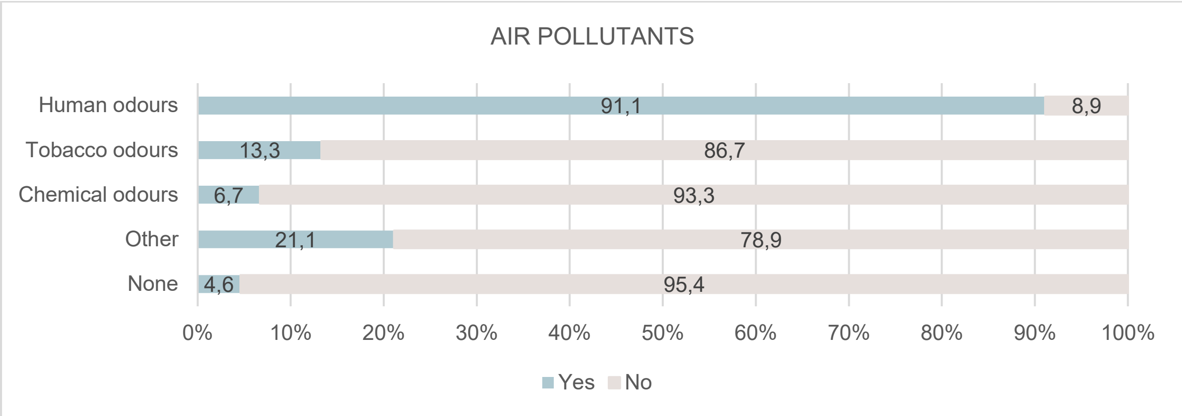

Figure 51: Responses of dissatisfied students with IAQ regarding the air pollutants.

The most unsatisfactory air pollutant for students in classrooms is human odors. This is followed by other, tobacco odours, chemical odours, none, respectively (Figure 51).

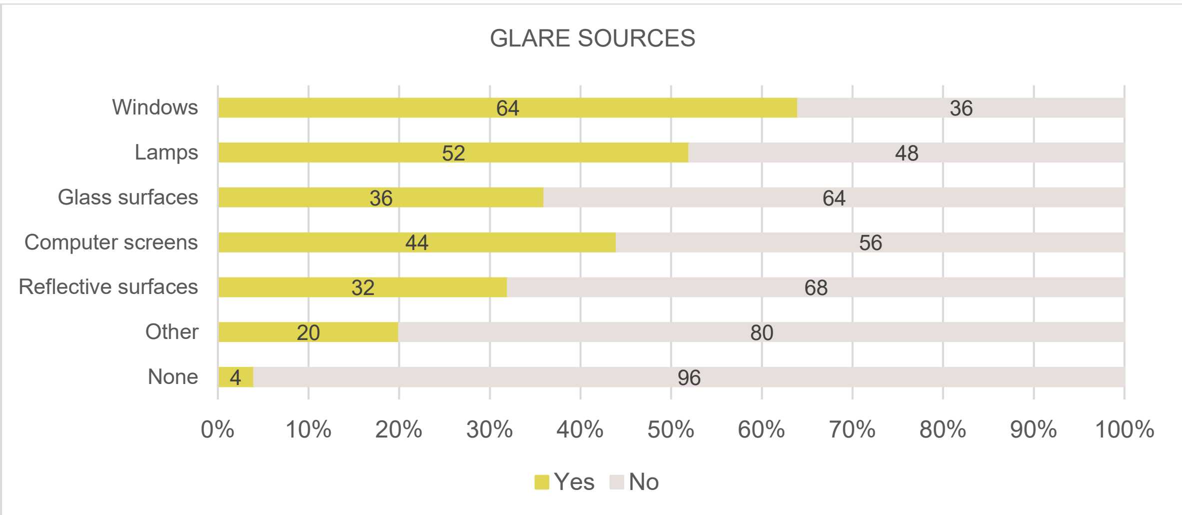

Figure 52: Responses of dissatisfied students with visual comfort regarding the glare source.

The most unsatisfactory glare source of students in classrooms is windows. This is followed by lamps, computer screens, glass surfaces, reflective surfaces, other, none, respectively (Figure 52).

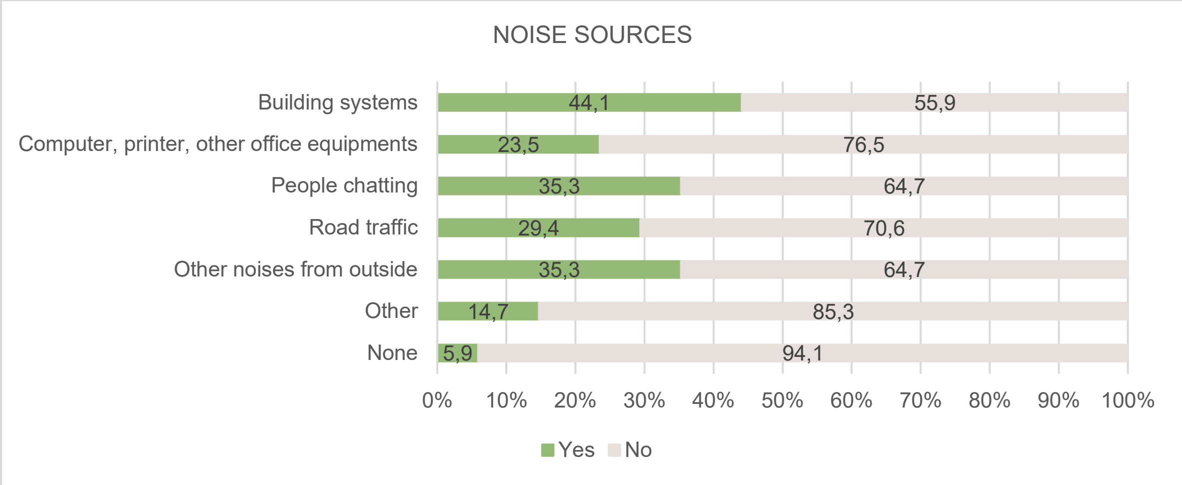

Figure 53: Responses of dissatisfied students with acoustic comfort regarding the noise source.

The most unsatisfactory noise source of students in classrooms is building systems. This is followed by people chatting, other noises from outside, road traffic, computer-printer, other, none, respectively (Figure 53). It was also heard during contextual analysis, there is a noise originating from the HVAC system in the 2P and 4P classrooms, during the winter period, especially in January. Table 29 below contains summaries of the students' answers to the gender, age, degree and profession to the questionnaire.

Table 29: Summary of answers given to questions focused gender, age, degree, profession.

VARIABLE		RESPONSE	PERCENT
GENDER	n/a	222	42,0%
	Female	120	22,7%
	Male	186	35,2%
AGE	n/a	223	42,2%
	18-25	296	56,1%
	26-35	7	1,3%
	36-50	2	0,4%
DEGREE	n/a	235	44,5%
	Bachelor's degree	267	50,6%
	Master's degree	24	4,5%
	Ph.D.	2	0,4%
PROFESSION	n/a	234	55,7%
	Student	290	54,9%
	Professor	3	0,6%
	Other	1	0,2%

The 42% of the students participating in the questionnaire did not specify their gender, 22.7% answered female and 35.2% answered male (Table 29). Students' answers to the age question are n/a, 18-25, 26-35, 35-50 at 42.2%, 56.1%, 1.3%, 0.4%, respectively. 50.6% of the participants are studying for a bachelor's degree, 4.5% are at master's degree level, 0.4% are at PhD level, and 44.5% did not answer this question. While 55.7% of the participants did not answer the question asking about their profession, 54.9% stated that they were students, 0.6% selected the instructor option, and 0.2% selected the other option. Table 30 presents students' answers to the question of their country of birth.

Table 30: Students' answers to the question of their country of birth.

VARIABLE		RESPONSE	PERCENT
COUNTRY	n/a	227	43,0%
	Italy	277	52,5%
	India	2	0,4%
	Iran	1	0,2%
	Bulgaria	1	0,2%
	Poland	1	0,2%
	Colombia	4	0,8%
	France	3	0,6%
	Lebanon	1	0,2%
	Azerbaijan	3	0,6%
	Angola	1	0,2%
	Pakistan	1	0,2%
	Peru	2	0,4%
	Romania	1	0,2%
	Brazil	1	0,2%
	Brundi	1	0,2%
	Portugal	1	0,2%

Students were asked whether an environment they are unsatisfied affected their learning performance and well-being (Figure 54). 77.6% of the students believe that IEQ is related to well-being and 80.8% believe that IEQ is related to LP (learning performance).

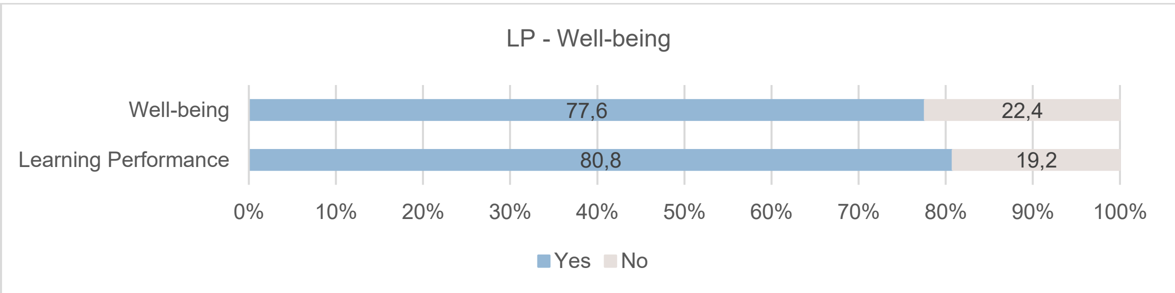

Figure 54: Students' perception on the relationship between LP / well-being and IEQ.

Students were asked which elements in the classroom they did or did not have control. Students have control over windows, solar shadings, and electric lighting, but do not have control over heating, cooling, and noise. The majority of students stated that they had control over windows and electrical lighting, but a majority of 62.6% stated that they did not have control over solar shading. When the situation was analyzed separately for spring/summer and winter, it was revealed that students better perceived they had control over windows and electrical lightings in the spring/summer period. However, during the winter period, the majority of the students are not aware of their control over windows, solar shadings, and electrical lighting.

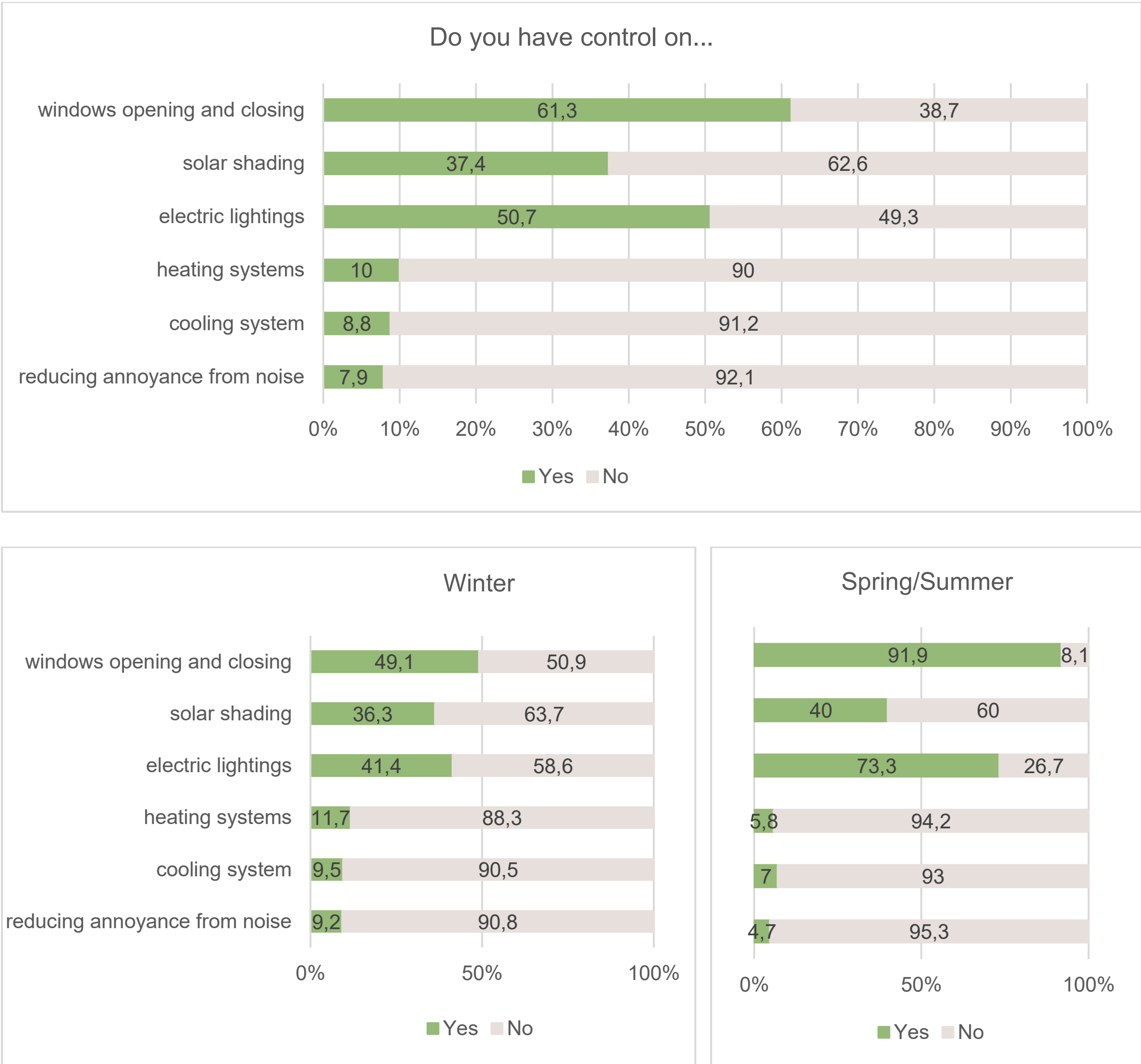

Figure 55: Representation of question "Do you have control on.."

The majority of students believe that it is important to have controls over windows, solar shadings, electrical lighting, heating systems, cooling systems and noise in both spring/summer and winter periods (Figure 56).

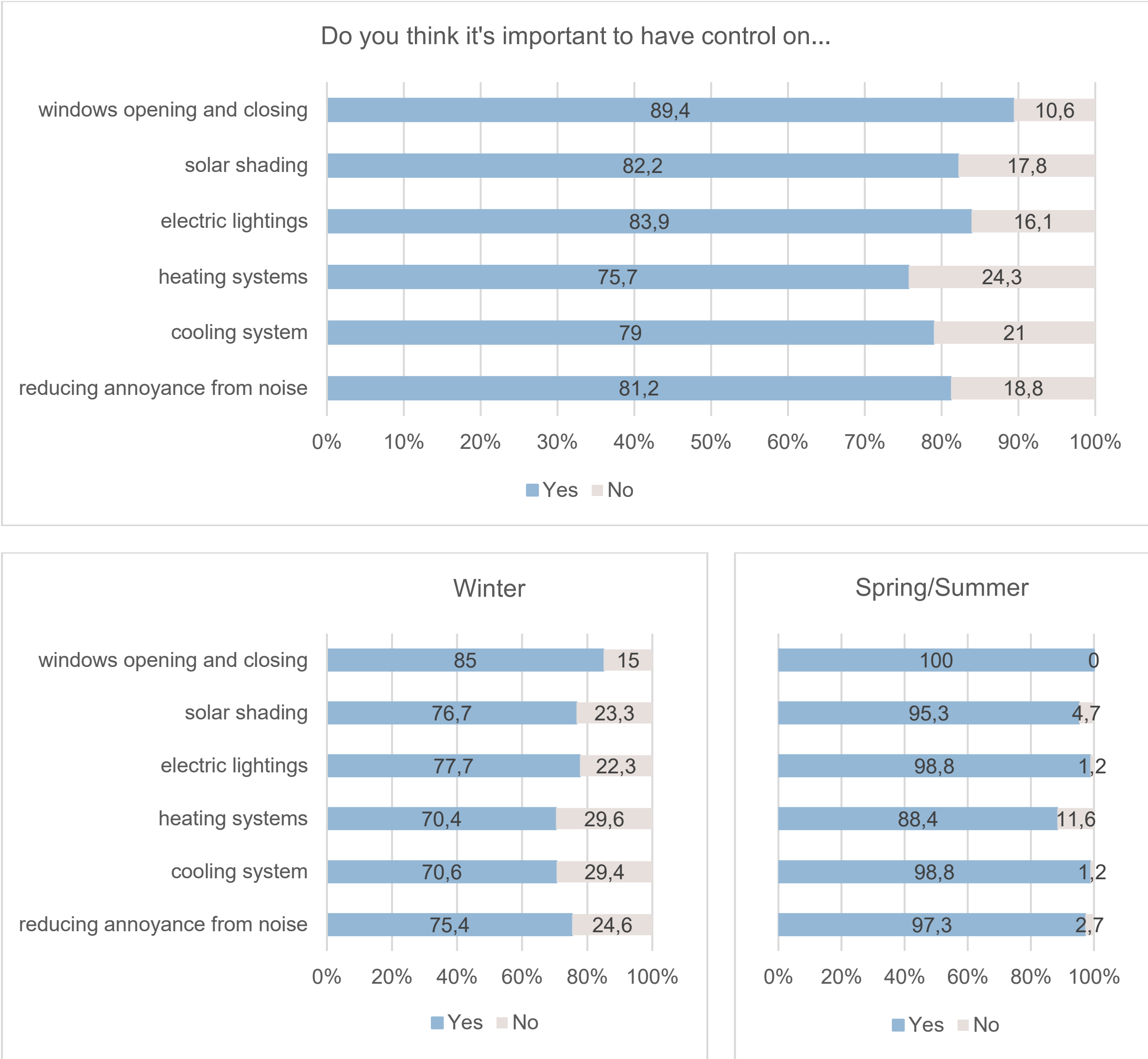

Figure 56: Representation of question "Do you think it's important to have control on.."

Correlation analyzes were performed to find correlation between i.e., overall satisfaction, domains, monitored parameters in the tables below (Table 31-33) using Pearson correlation.

Table 31: Correlations between the students' overall satisfaction and the IEQ domains in four classrooms.

		Thermal Comfort	Acoustic Comfort	Visual Comfort	IAQ
Overall satisfaction	Pearson C.	,824**	,774**	,753**	,769**
	Sig.	,000	,000	,000	,000

*. The correlation is significant at the 0.05 level (2-tailed).
**. The correlation is significant at the 0.01 level (2-tailed).

There is a positive correlation of 0.824, 0.774, 0.753 and 0.769 between overall satisfaction and thermal, acoustic, visual and indoor air quality, respectively (Table 31).

Table 32: Correlations between the students' overall satisfaction and the IEQ monitored parameters in four classrooms.

		TVOC	CO_2	$PM_{2.5}$	PM_{10}	RH	T_{in}	SPL	E
Overall satisfaction	Pearson C.	-,167**	-,095*	,078	,078*	-,043	-,062	-,008*	,083**
	Sig.	0	,048	,104	,102	,368	,196	,870	,082

*. The correlation is significant at the 0.05 level (2-tailed).
**. The correlation is significant at the 0.01 level (2-tailed).

The correlation between overall satisfaction and monitored parameters is shown in Table 33. As CO_2 and TVOC values increase, overall satisfaction decreases with significance 0.05 and 0.01 levels, respectively. Increasing illuminance increases overall satisfaction with a significance at the 0.01 level.

Table 33: Correlation between overall satisfaction and monitored *parameters with Pearson correlation.*

C.	P.		OVERALL SATISFACTION						
			T_{out}	TVOC	$PM_{2.5}$	PM_{10}	T_{in}	E	E_{one}
1P	W	Pearson C.	**,201***	**-,219***	-,164	-,164	**,228***	,145	,145
		Sig.	,035	,022	,086	,086	,017	,131	,131
3P	W	Pearson C.	-,017	,106	,135	,135	-,076	**,181***	**,181***
		Sig.	,820	,145	,062	,062	,299	,013	,013
4P	S	Pearson C.	,025	**-,215***	**-,367****	**-,364****	-,119	-,146	,015
		Sig.	,807	,036	,000	,000	,252	,159	,886
4P	W	Pearson C.	,218	-,024	,047	,047	,318*	,066	-,018
		Sig.	,171	,880	,772	,772	,043	,681	,909

*. The correlation is significant at the 0.05 level (2-tailed).
**. The correlation is significant at the 0.01 level (2-tailed).

The correlation between overall satisfaction and monitored parameters is shown in Table 33. Parameters that do not have a correlation with overall satisfaction are not included in the table. During the winter period, students' overall satisfaction is positively correlated with T_{in} and T_{out} with a significance at the 0.05 level in classroom 1P. The increasing of the TVOC concentrations, overall satisfaction decreases with significance 0.05 level. In 4P, satisfaction decreases at the increasing of the TVOC and PM values, respectively, with a significance at the 0.05 and 0.01 levels during spring/summer period. During winter period, the increasing of illuminance, overall satisfaction increases with significance 0.05 level in classroom 3P.

Table 34: Correlation between thermal comfort and monitored parameters with Pearson correlation.

C.	P.		THERMAL COMFORT									
			T_{out}	TVOC	CO_2	$PM_{2.5}$	PM_{10}	T_{in}	RH	SPL	E	E_{one}
1P	W	Pearson C.	,126	-,145	-,085	-,102	-,102	**,196***	-,065	-,094	,059	,059
		Sig.	,189	,130	,375	,287	,287	,040	,497	,328	,539	,539
3P	W	Pearson C.	-,033	,111	,118	,017	,017	-,092	-,030	,009	,076	,076
		Sig.	,653	,126	,106	,815	,815	,208	,678	,901	,295	,295
4P	S	Pearson C.	,012	-,155	-,069	**-,244***	**-,241***	-,070	**,244***	-,012	-,059	,012
		Sig.	,911	,134	,507	,017	,019	,498	,017	,904	,570	,910
4P	W	Pearson C.	,115	-,178	-,031	-,118	-,118	,211	,138	,114	,028	-,023
		Sig.	,473	,265	,845	,462	,462	,186	,390	,479	,864	,886

*. The correlation is significant at the 0.05 level (2-tailed).
**. The correlation is significant at the 0.01 level (2-tailed).

The correlation between students' thermal comfort and monitored parameters is shown in Table 34. During the winter period, students' thermal satisfaction is positively correlated with T_{in} with a significance at the 0.05 level in classroom 1P. In 4P, satisfaction decreases with the increasing of the PM values with a significance at 0.05 and increasing relative humidity increases overall satisfaction with a significance at the 0.01 level, during spring/summer period.

There is no significant relationship between acoustic comfort and visual comfort, and the monitored parameters.

The correlation between indoor air and monitored parameters is shown in the Table 35 during the winter period, students' perception is positively correlated with T_{in} ,with a significance at the 0.05 levels in classroom 1P. Satisfaction increases with the decreasing of the PM values with a significance at the 0.05 level, during spring/summer period.

Table 35: Correlation between indoor air comfort and monitored parameters with Pearson correlation.

C.	P.		INDOOR AIR									
			T_{out}	TVOC	CO_2	$PM_{2.5}$	PM_{10}	T_{in}	RH	SPL	E	E_{one}
1P	W	Pearson C.	,161	-,173	-,106	-,125	-,125	**,188***	-,068	-,141	,064	,064
		Sig.	,094	,070	,273	,193	,193	,049	,479	,142	,507	,507
3P	W	Pearson C.	-,017	,034	,101	,063	,063	-,052	,018	,053	,110	,110
		Sig.	,811	,637	,164	,391	,391	,480	,809	,470	,130	,130
4P	S	Pearson C.	,066	-,139	-,015	**-,245***	**-,242***	-,049	,180	-,008	-,050	,034
		Sig.	,524	,179	,887	,017	,018	,636	,080	,940	,631	,742
4P	W	Pearson C.	-,056	-,172	,023	-,205	-,205	,040	,247	-,007	-,092	-,095
		Sig.	,728	,284	,886	,199	,199	,804	,119	,967	,566	,556

*. The correlation is significant at the 0.05 level (2-tailed).
**. The correlation is significant at the 0.01 level (2-tailed).

Students were asked whether they have visual or hearing impairment. No correlation was found between the answers to the questions about visual impairments and hearing impairments, and acoustic comfort and visual comfort. It may be useful to re-examine by increasing the response rate given by students to personal questions.

There are 4 sensors in 1P and 4P, the sensors are placed as in the map given in section 2.3. It was explained how the mean values of the sensors were calculated in section 2.3.1. Below are line graphs of the mean values of each sensor and the mean values of the classrooms during lecture hours between 05.06.2023 and 09.06.23 (Figure 57-Figure 68).

Due to the differences in the locations of the sensors, each sensor measures different temperature values, and this difference can be up to 3ºC during the day (Figure 57 and Figure 58). Sensor 1 is exposed to direct sunlight, therefore the value it measures may be higher than other sensors in 1P. Although Sensor 21 is located on the same wall, it is not exposed to direct sunlight because it is located further back (in a location where it does not expose direct sunlight) in the classroom and its height from the ground is higher than Sensor 1.

The minimum and maximum values of relative humidity vary by 10% during the day in both 1P and 4P (Figure 59 and Figure 60). At any given moment during classroom hours, the difference between sensors varies between 3% and 6%. Both temperature and relative humidity changes can have an impact on students' perception of thermal comfort and therefore on other comfort domains and overall satisfaction.

Sensors 1 and Sensor 21 are in 1P, and Sensors 3 and Sensor 23 are in 4P, on the wall opposite the door facing outside. Therefore, these sensors further away from doors facing outside in the classrooms compared to other sensors in these classrooms (Sensor 2 and Sensor 24 in 1P, Sensor 4 and Sensor 24 in 4P). TVOC concentration of Sensor 1 in 1P and Sensor 3 in 4P are higher than other sensors (Figure 61-Figure 62). The reason for high concentration may be the distance of these sensors to the doors facing outside. The reason why the concentration of Sensor 21 and Sensor 23 (sensors mounted on the same wall, far from the doors facing outside) are lower than Sensor 1 and Sensor 3 is that the doors close to the professors' desk do not open and close during the lectures, while the doors far from the professors' desk open and close the doors of the students both in breaks and during the lectures.

$PM_{2.5}$ concentration and SPL values varies within the classrooms depending on the sensors, but it is not possible to give reasons or compare low or high values between sensors (Figure 63, Figure 64, Figure 65 and Figure 66). However, it can be estimated that it has an impact on students' comfort perceptions, like other parameters.

Illumination values in classrooms reach their maximum value in the middle of the day due to the effect of natural lighting (Figure 67 and Figure 68). The difference between sensors in the 1P reaches up to 209 lux between 13:00-14:30 (08.06.2023). In the 4P, it reaches up to 100 lux between 13:00-14:30 (06.06.2023).

There is no system in the questionnaire links sent to students to detect where students located in the classroom. Additionally, no information was requested in the questions, therefore it is not possible to understand the correlation between students' comfort perception and students' location in the classrooms. However, looking at the changes in the monitored parameters in the classroom, it can be seen that the location of the students in the classroom may also have an impact on their comfort perception. In future studies, the location of the students who responded to the questionnaire should be determined in the classrooms and its effects on satisfaction should be analyzed.

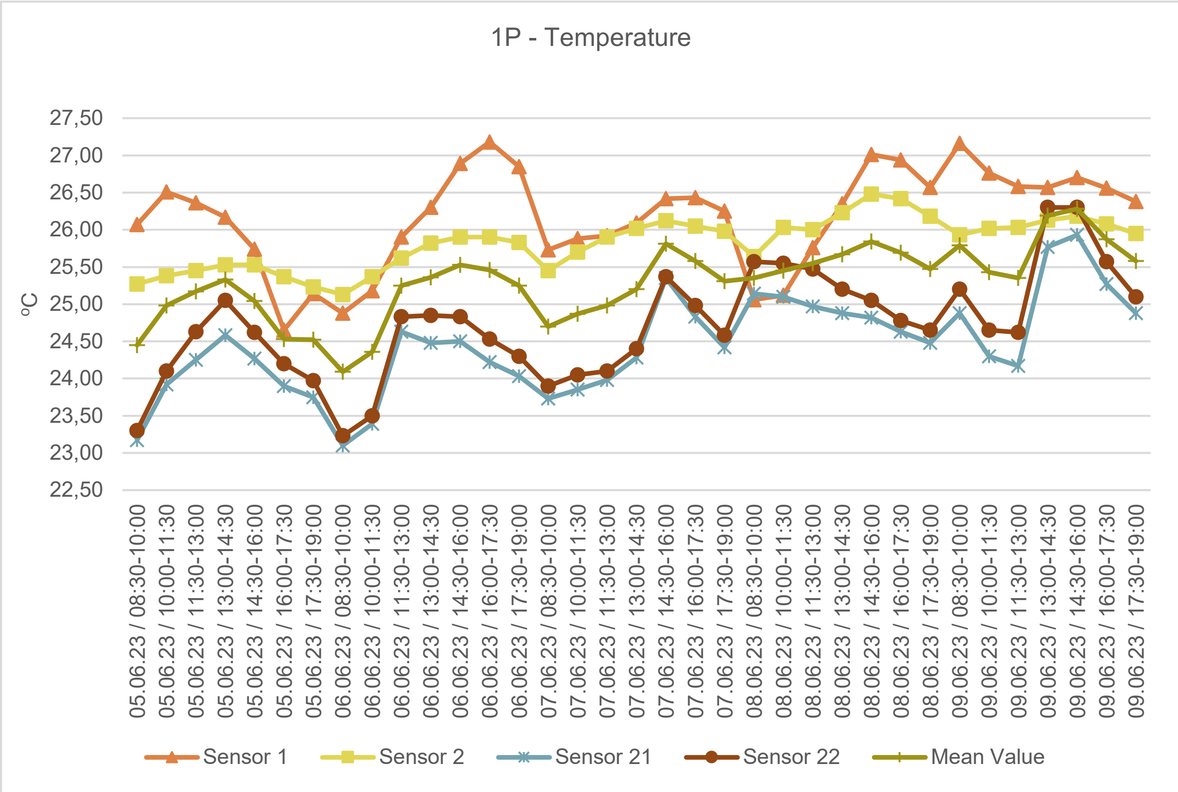

Figure 57: Temperature values of 4 sensors in 1P between 05.06.2023 and 09.06.2023.

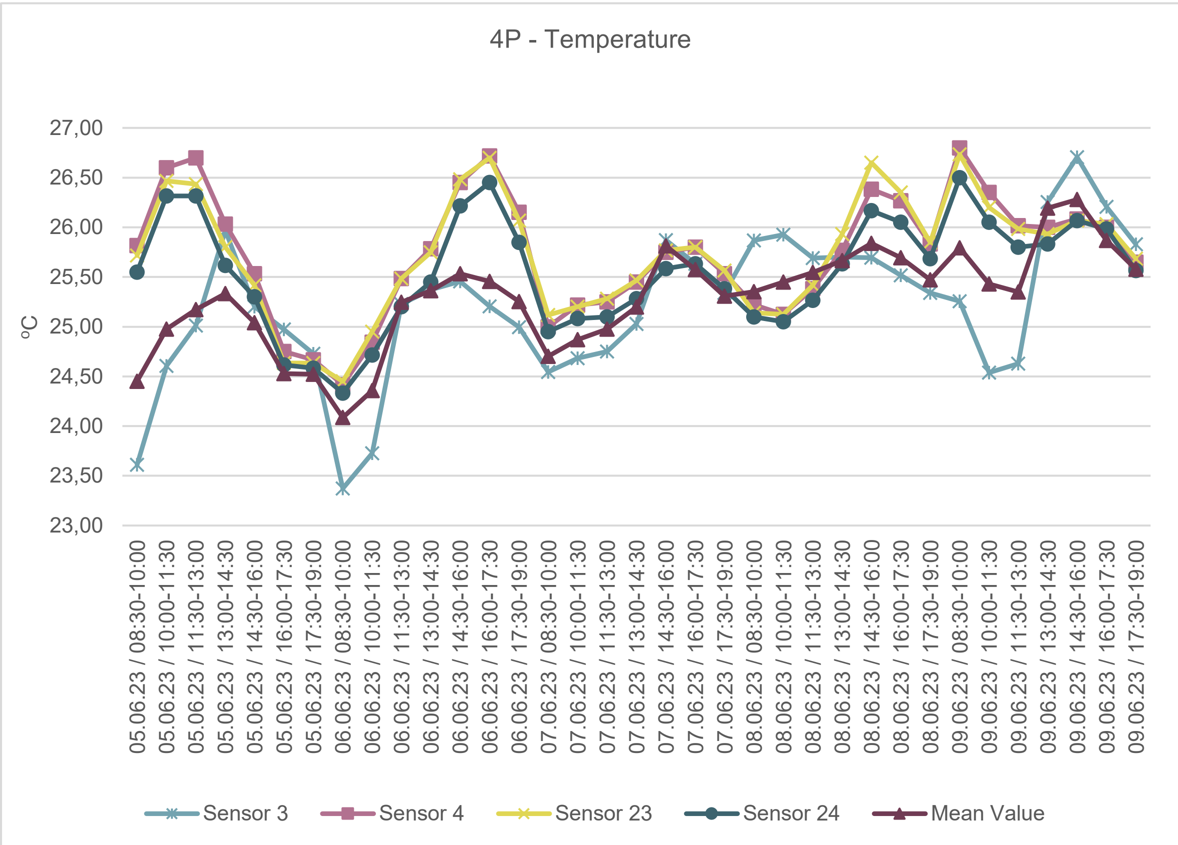

Figure 58: Temperature values of 4 sensors in 4P between 05.06.2023 and 09.06.2023.

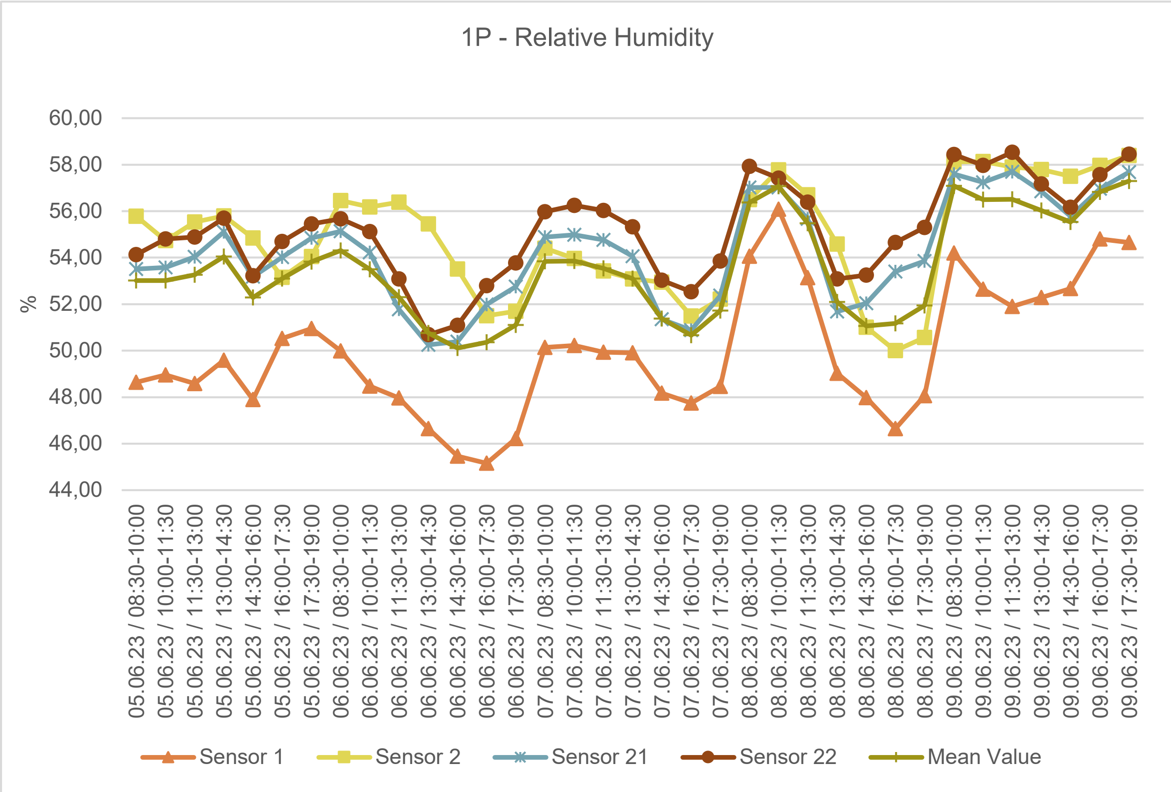

Figure 59: Relative humidity values of 4 sensors in 1P between 05.06.2023 and 09.06.2023.

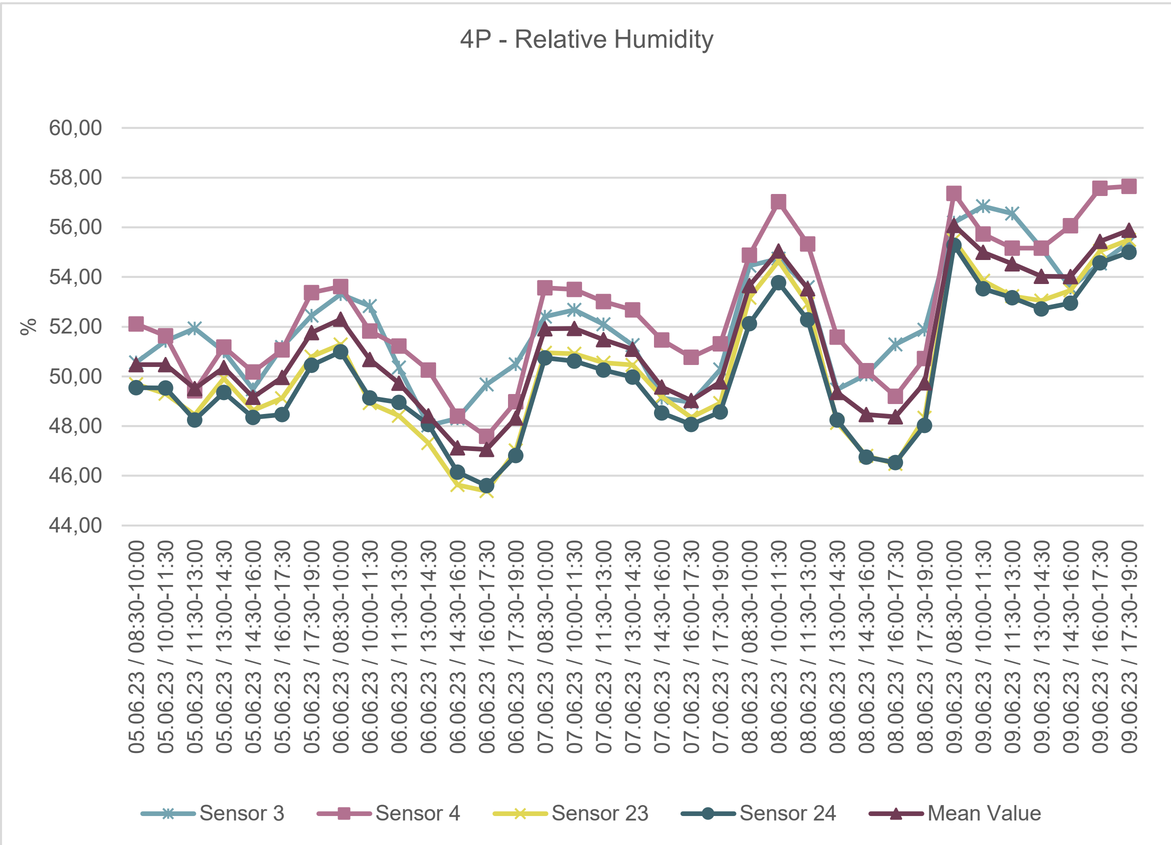

Figure 60: Relative humidity values of 4 sensors in 4P between 05.06.2023 and 09.06.2023.

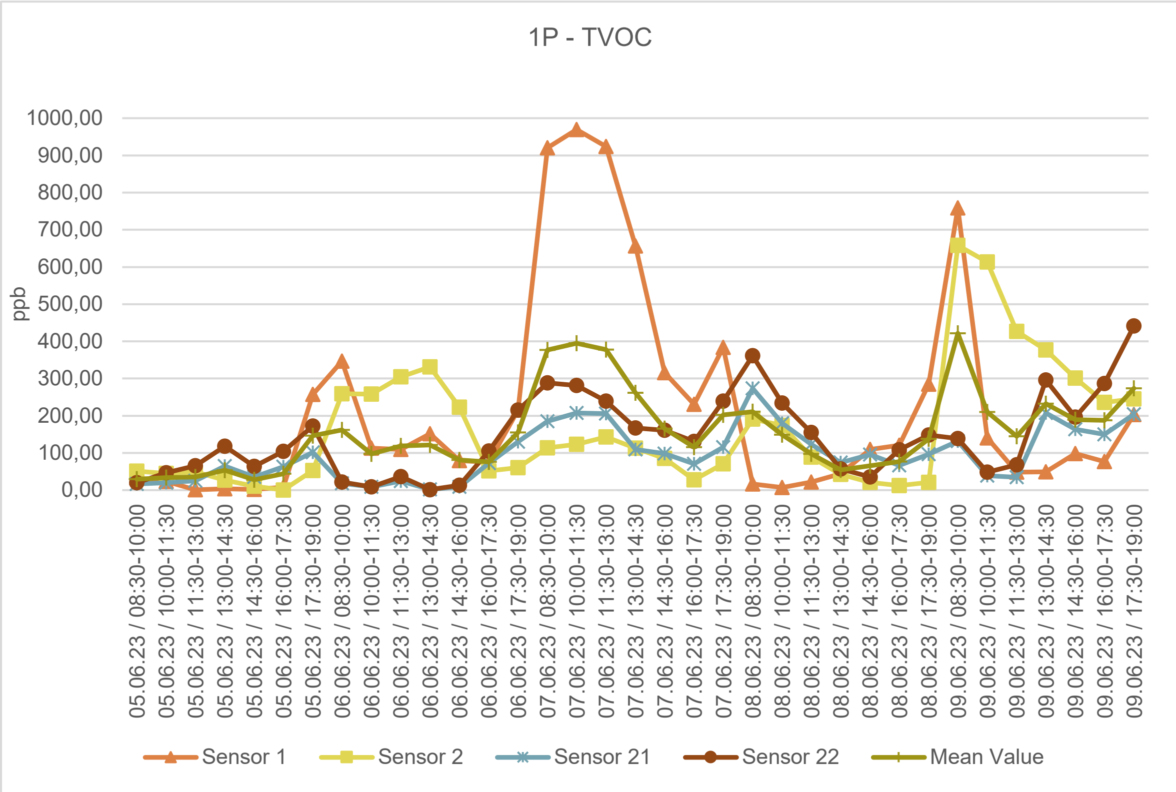

Figure 61: TVOC values of 4 sensors in 1P between 05.06.2023 and 09.06.2023.

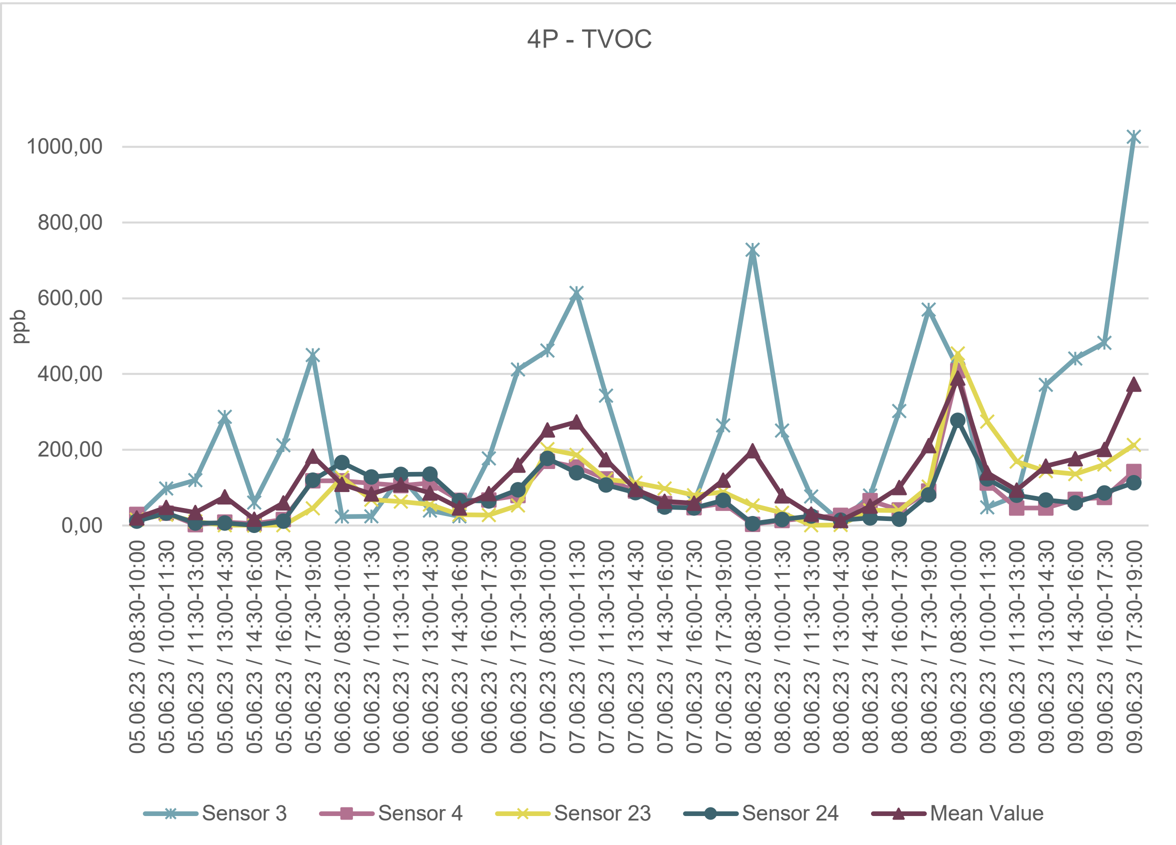

Figure 62: TVOC values of 4 sensors in 4P between 05.06.2023 and 09.06.2023.

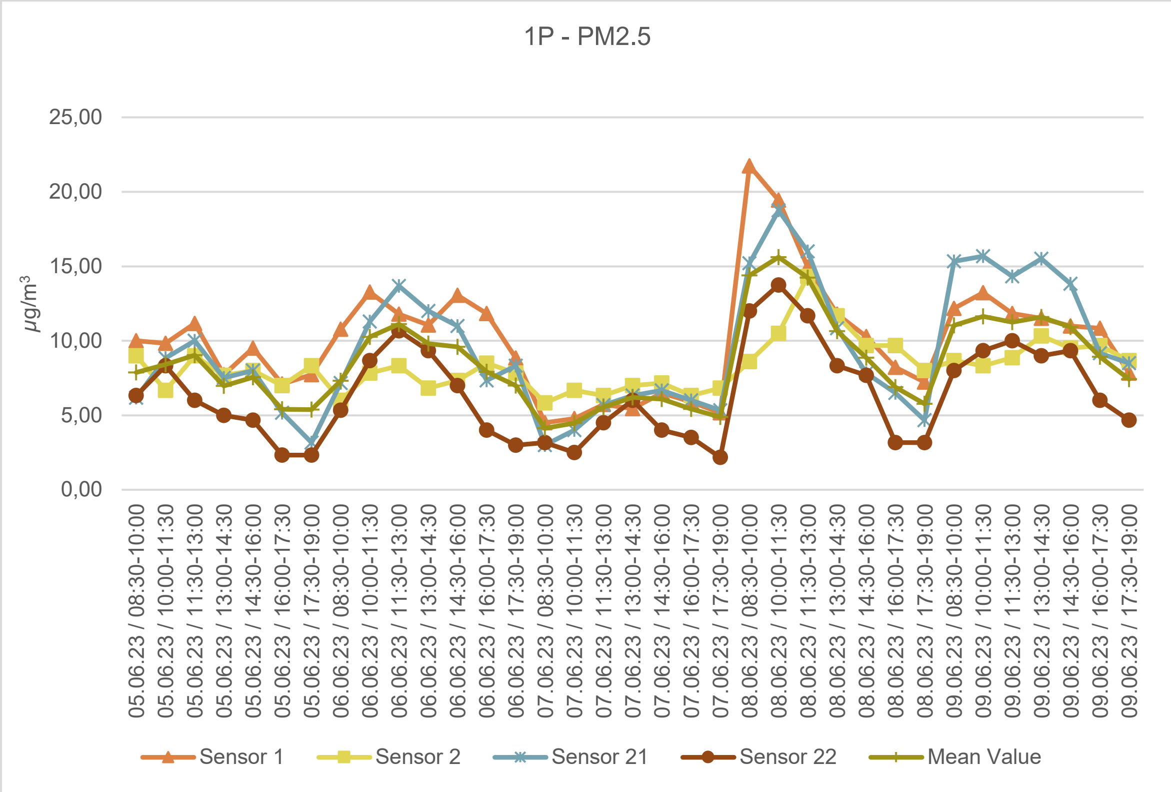

Figure 63: $PM_{2.5}$ values of 4 sensors in 1P between 05.06.2023 and 09.06.2023.

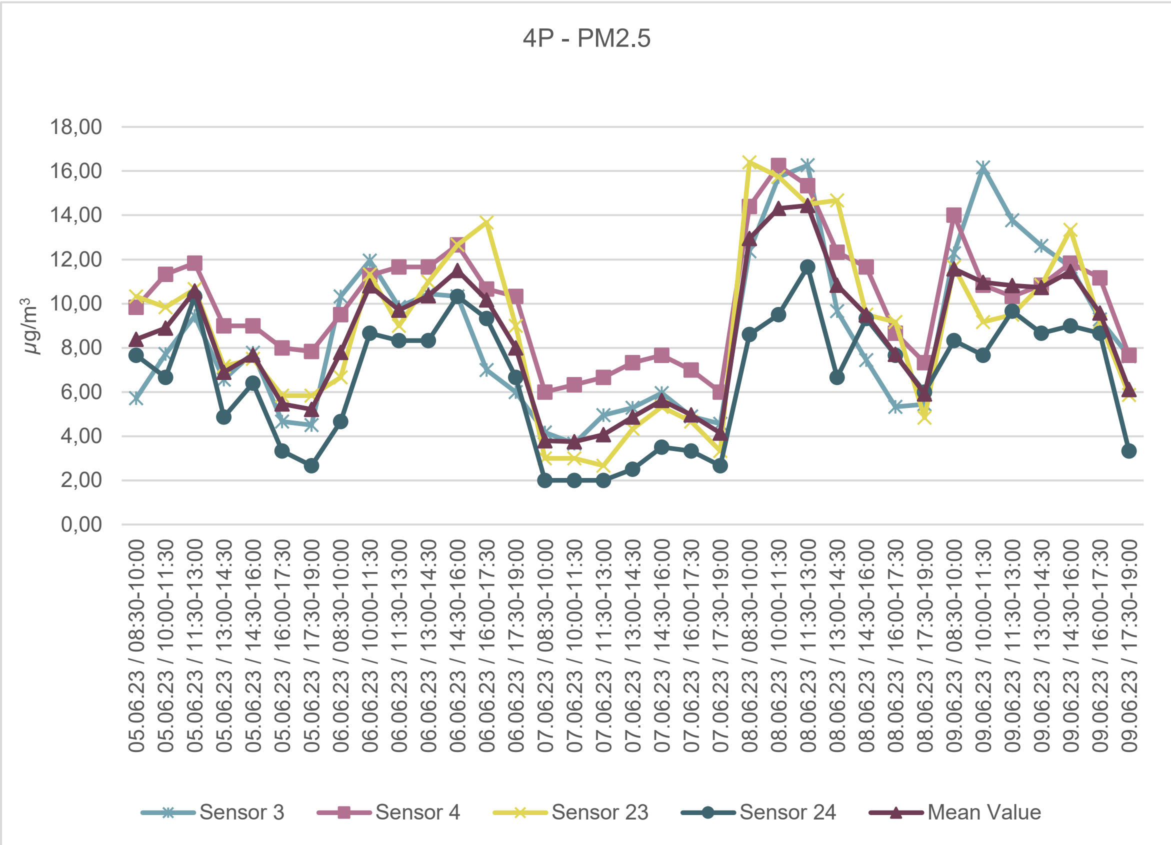

Figure 64: $PM_{2.5}$ values of 4 sensors in 4P between 05.06.2023 and 09.06.2023.

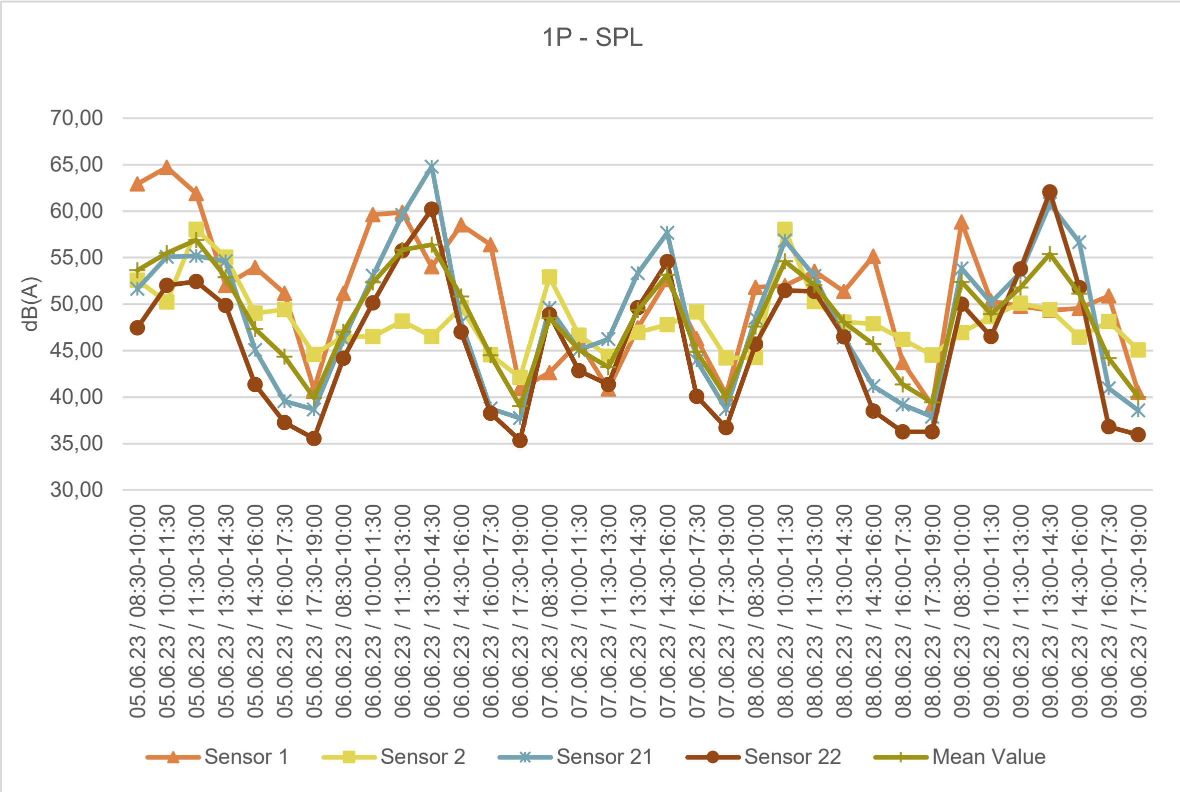

Figure 65: SPL values of 4 sensors in 1P between 05.06.2023 and 09.06.2023.

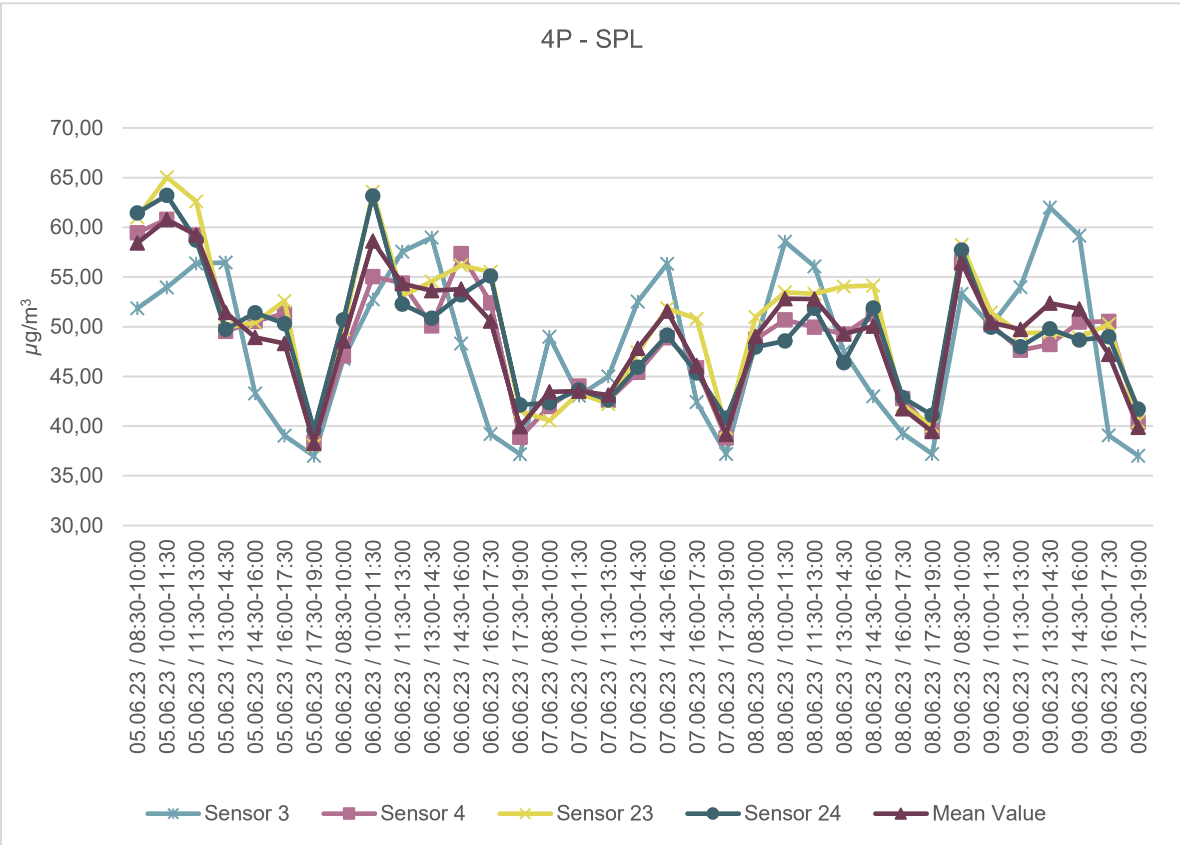

Figure 66: SPL values of 4 sensors in 4P between 05.06.2023 and 09.06.2023.

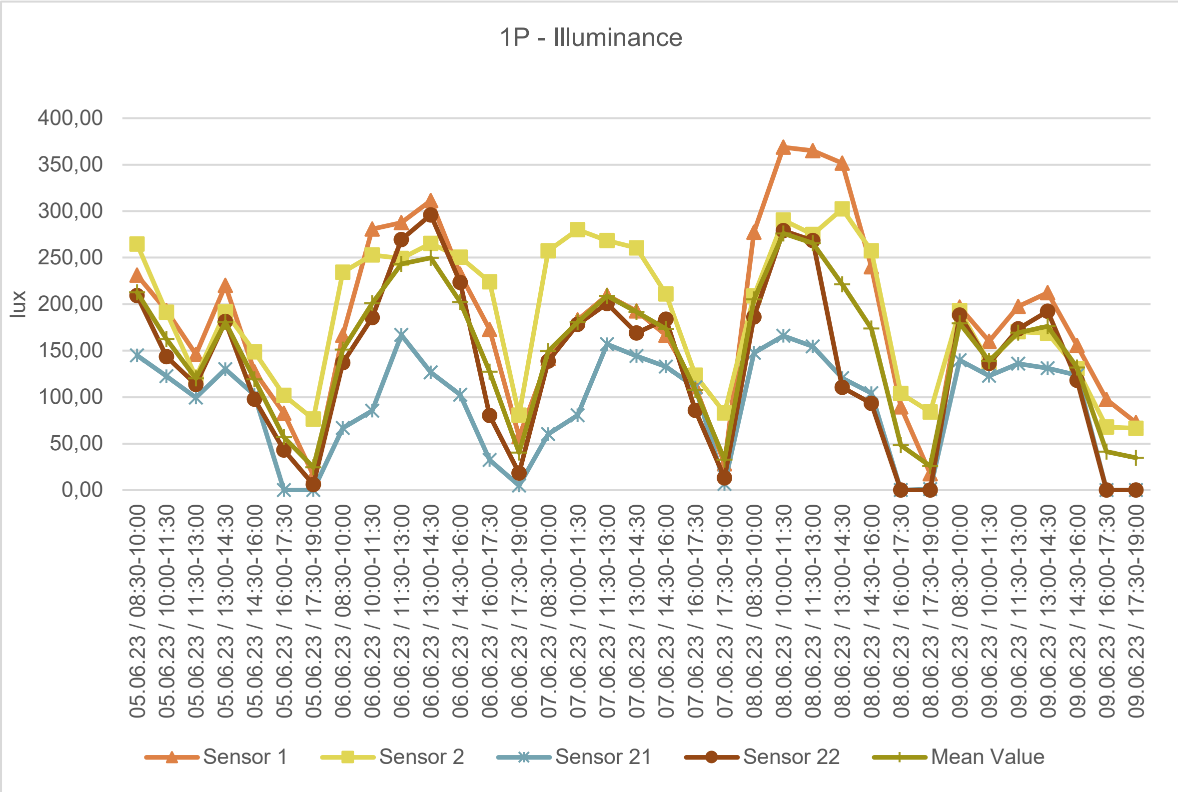

Figure 67: Illuminance values of 4 sensors in 1P between 05.06.2023 and 09.06.2023.

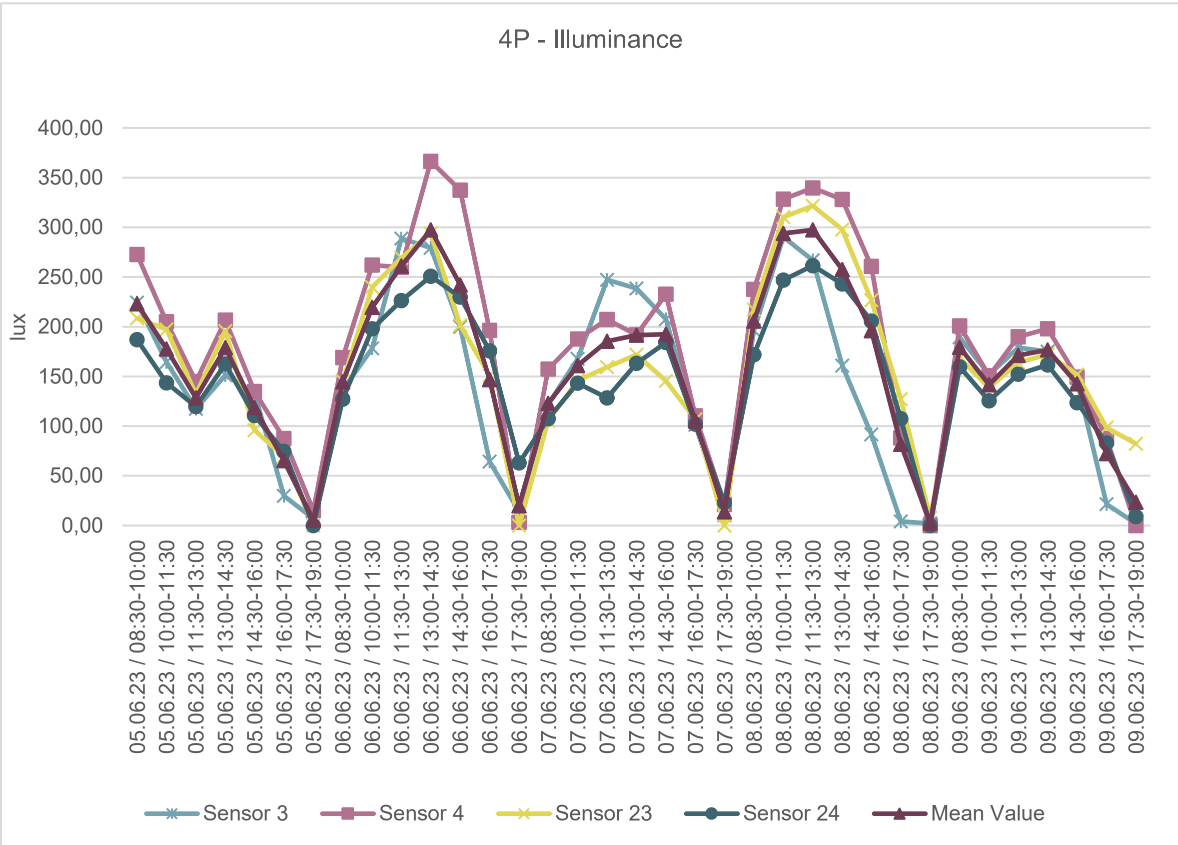

Figure 68: Illuminance values of 4 sensors in 4P between 05.06.2023 and 09.06.2023.

Heat maps of monitored parameters and comfort domains are presented between Figure 69 and Figure 79. The temperature values of Sensor 1, Sensor 3 and Sensor 6 seem close to each other. (These sensors are located on the wall of the classrooms facing the corridor.) Sensor 4 measured higher temperature values than other sensors. As can be seen from Figure 57 and Figure 58, the temperature difference between Sensor 3 and Sensor 4 in the same classroom can cause differences in students' comfort perceptions. It was seen that the temperature in classrooms is high during lecture hours (Figure 69).

TEMPERATURE

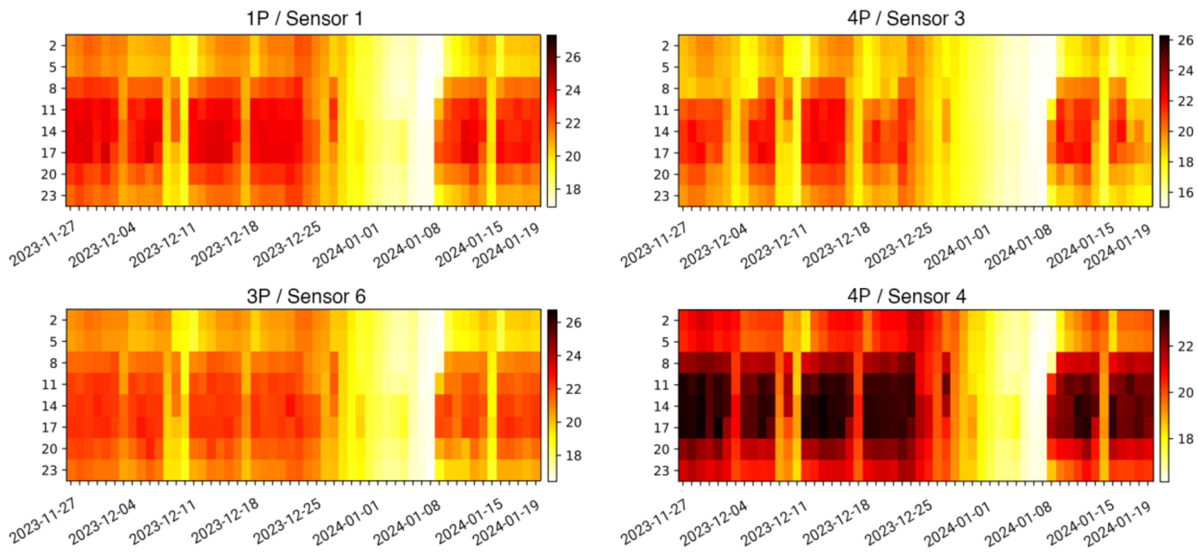

Figure 69: Expression of monitored temperature values of Sensor 1, Sensor 3, Sensor 4 and Sensor 6 between 27.11.2023 and 19.01.2024 in the form of a heat map.

It has been observed that humidity follows the same pattern in all classrooms (Figure 70).

RELATIVE HUMIDITY

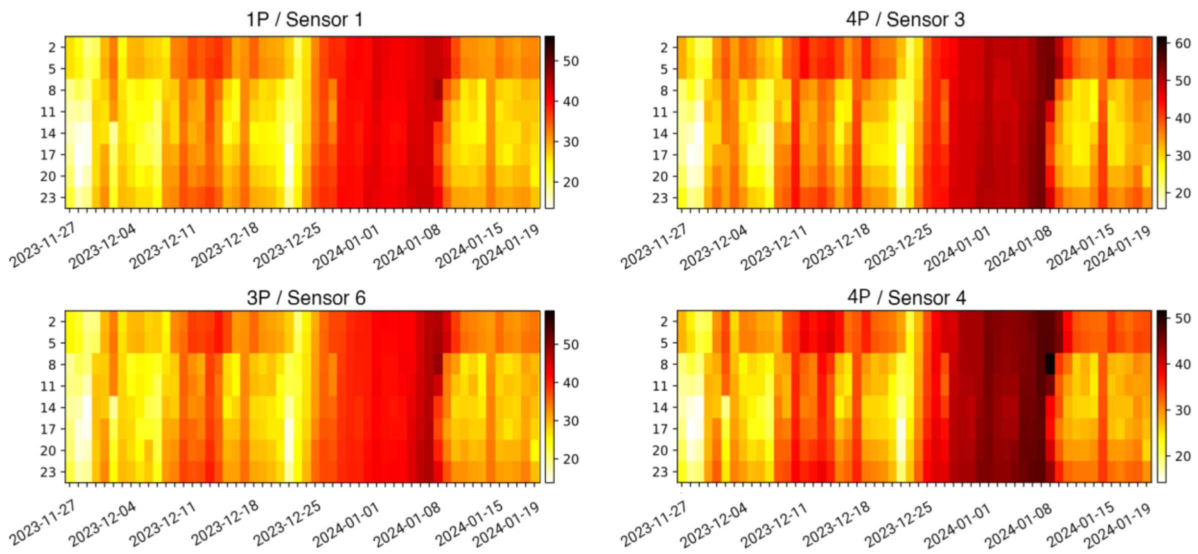

Figure 70: Expression of monitored relative humidity values of Sensor 1, Sensor 3, Sensor 4 and Sensor 6 between 27.11.2023 and 19.01.2024 in the form of a heat map.

It has been observed that the monitored thermal quality in classrooms decreases during lecture hours (Figure 71).

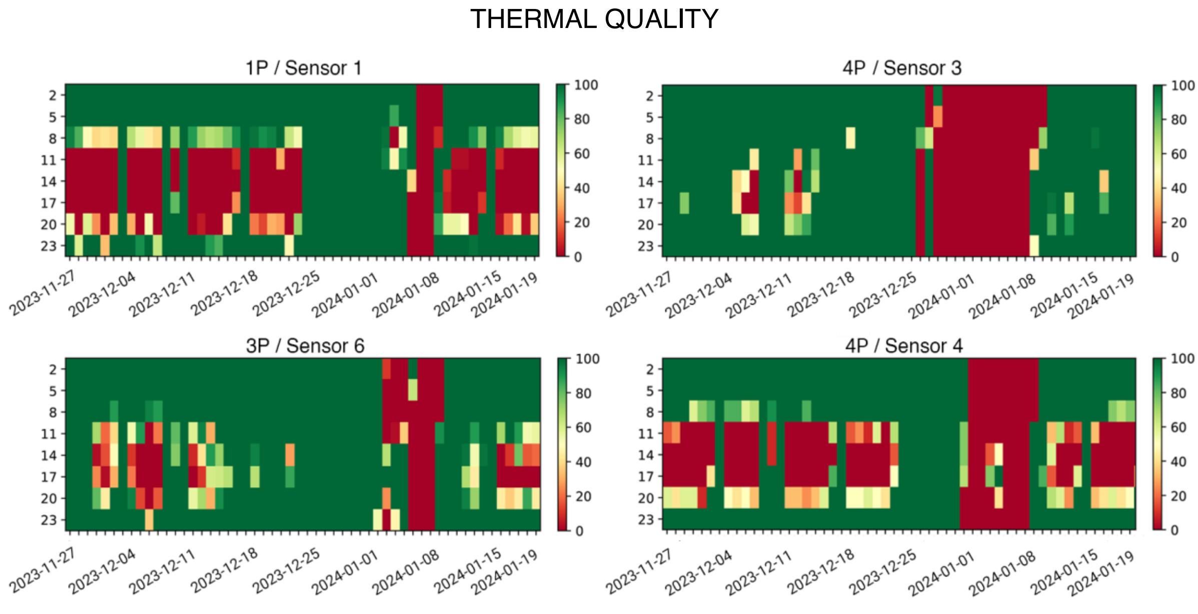

Figure 71: Expression of monitored thermal quality of Sensor 1, Sensor 3, Sensor 4 and Sensor 6 between 27.11.2023 and 19.01.2024 in the form of a heat map.

The days and lecture hours in which the TVOC values measured by the sensors increase and decrease are similar (Figure 72).

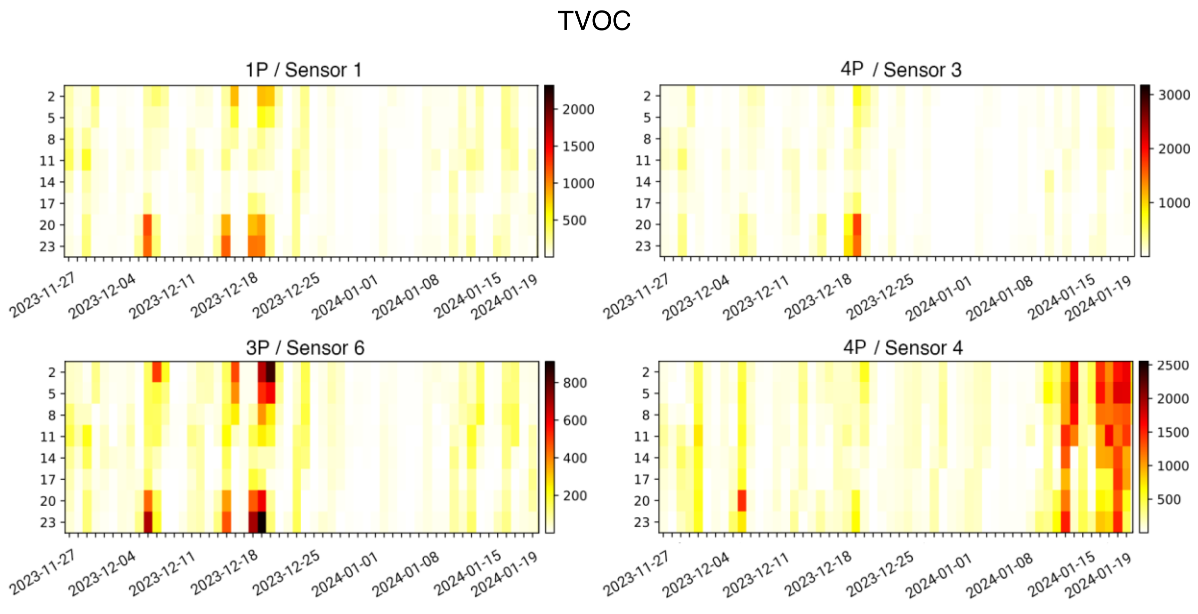

Figure 72: Expression of monitored TVOC concentration of Sensor 1, Sensor 3, Sensor 4 and Sensor 6 between 27.11.2023 and 19.01.2024 in the form of a heat map.

The CO_2 value was not measured by all sensors. Therefore, it was not possible to compare different sensors within the classrooms and between classrooms. However, it can be seen that Sensor 1 and Sensor measured higher CO_2 concentration during lecture hours (Figure 73).

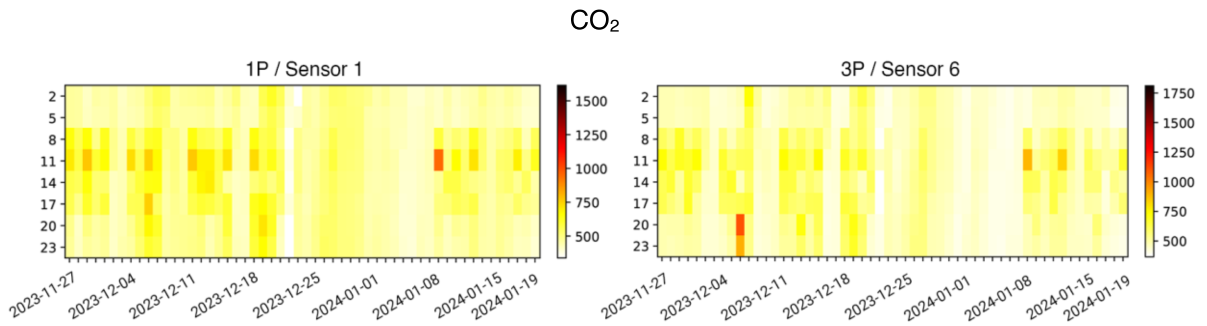

Figure 73: Expression of monitored CO_2 concentration of Sensor 1, Sensor 3, Sensor 4 and Sensor 6 between 27.11.2023 and 19.01.2024 in the form of a heat map.

Figure 74 show PM values. Sensor 1 measured higher concentration than the other sensors. Higher PM values were observed in all classrooms on 19.12.2023. As with TVOC, there are similar patterns in PM values in classrooms.

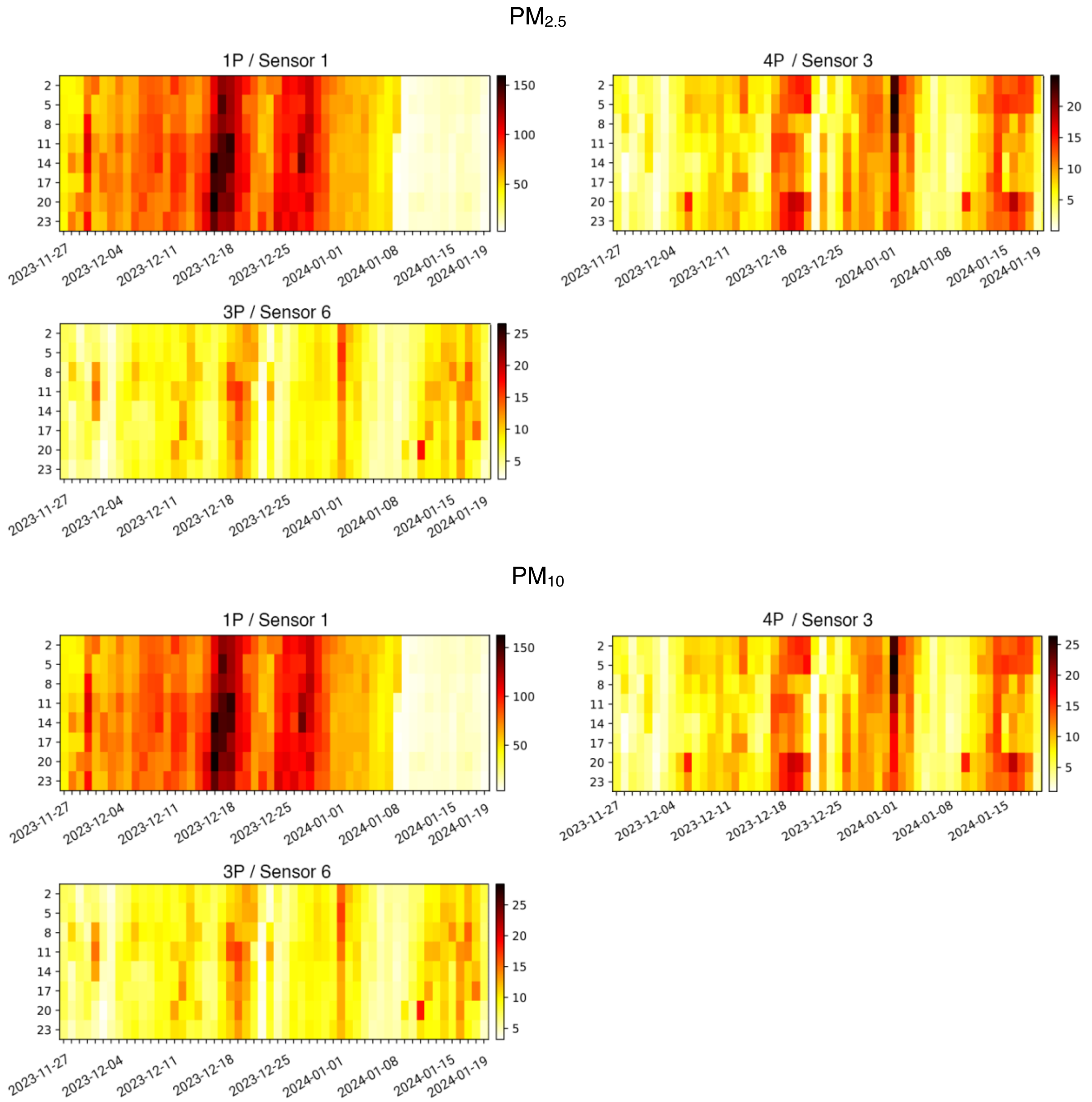

Figure 74: Expression of monitored PM_{10} concentration of Sensor 1, Sensor 3, Sensor 4 and Sensor 6 between 27.11.2023 and 19.01.2024 in the form of a heat map.

Figure 75 shows the monitored IAQ. Sensor 3, Sensor 4 and Sensor 6 measured a higher IAQ than Sensor 1.

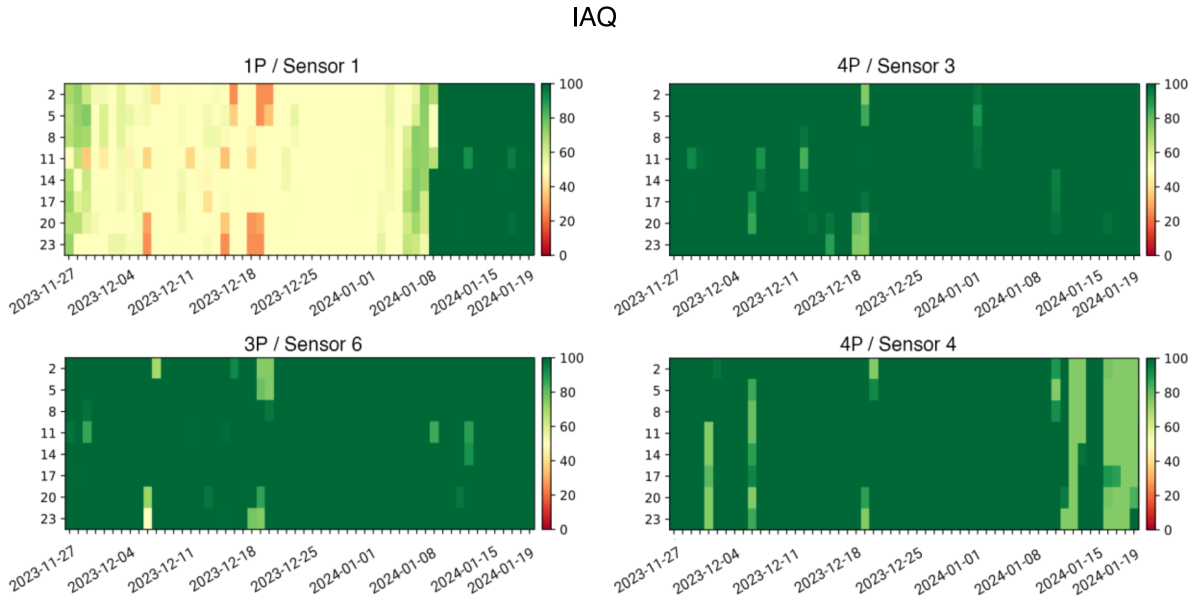

Figure 75: Expression of monitored IAQ of Sensor 1, Sensor 3, Sensor 4 and Sensor 6 between 27.11.2023 and 19.01.2024 in the form of a heat map.

No increase was observed during the Christmas holiday, SPL values increase with the use of microphones and the presence of students during classroom hours (Figure 76).

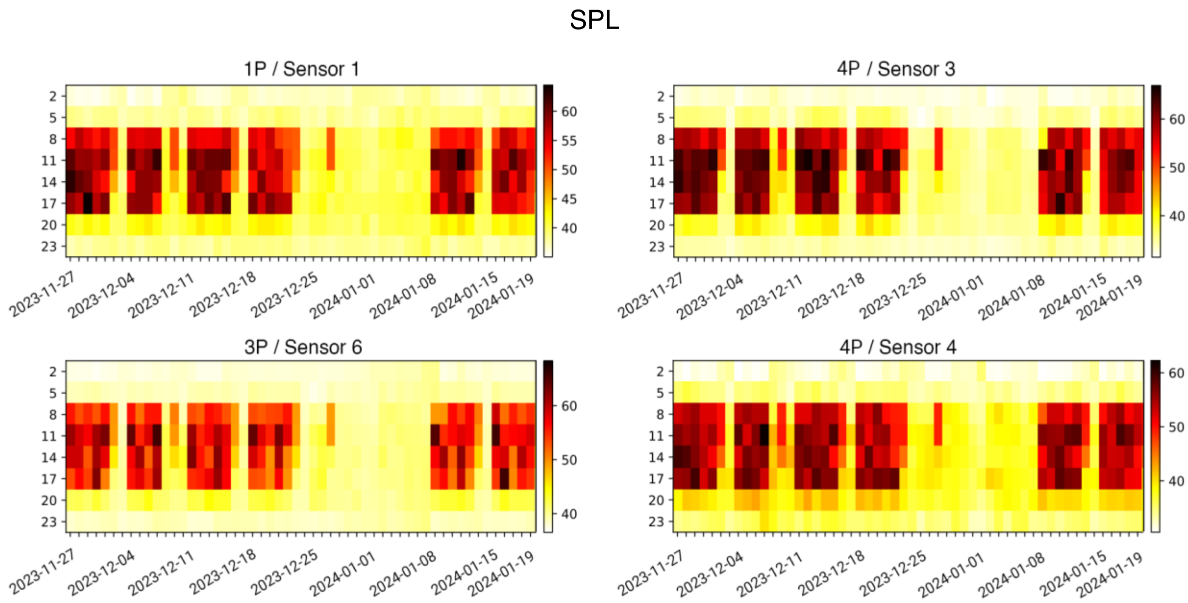

Figure 76: Expression of monitored SPL of Sensor 1, Sensor 3, Sensor 4 and Sensor 6 between 27.11.2023 and 19.01.2024 in the form of a heat map.

The illuminance value in classrooms generally increases between 11:30 and 16:00 with the presence of natural lighting (Figure 77).

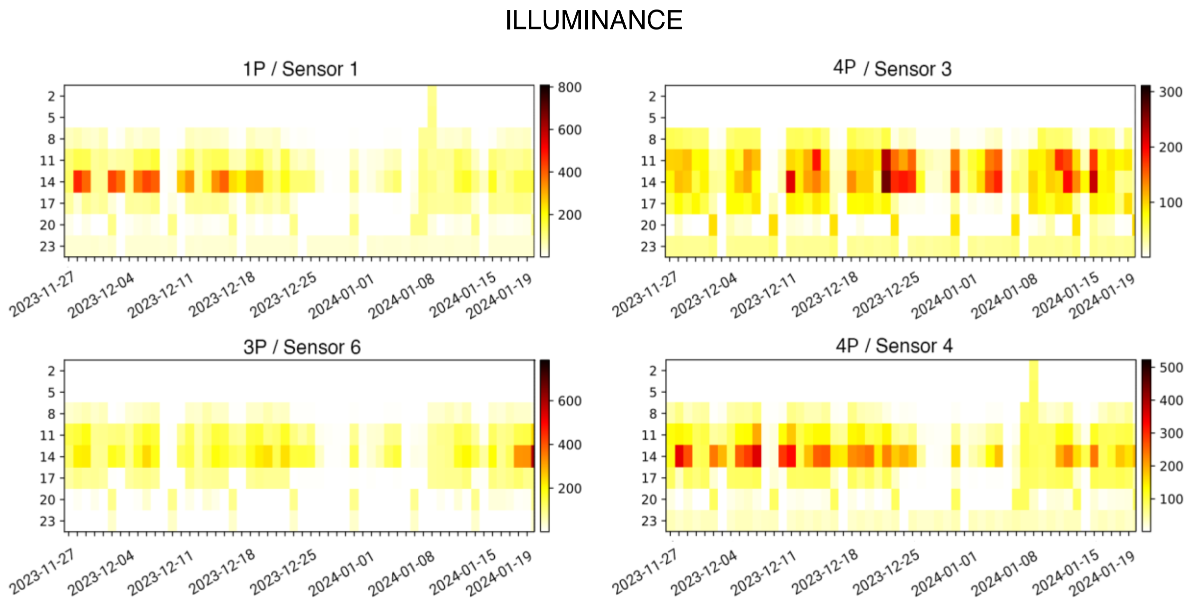

Figure 77: Expression of monitored illuminance values of Sensor 1, Sensor 3, Sensor 4 and Sensor 6 between 27.11.2023 and 19.01.2024 in the form of a heat map.

Visual quality in classrooms is often very low. Although Sensor 1 and Sensor 4 measured better values at noon with the contribution of natural lighting, very low visual quality continued (Figure 78).

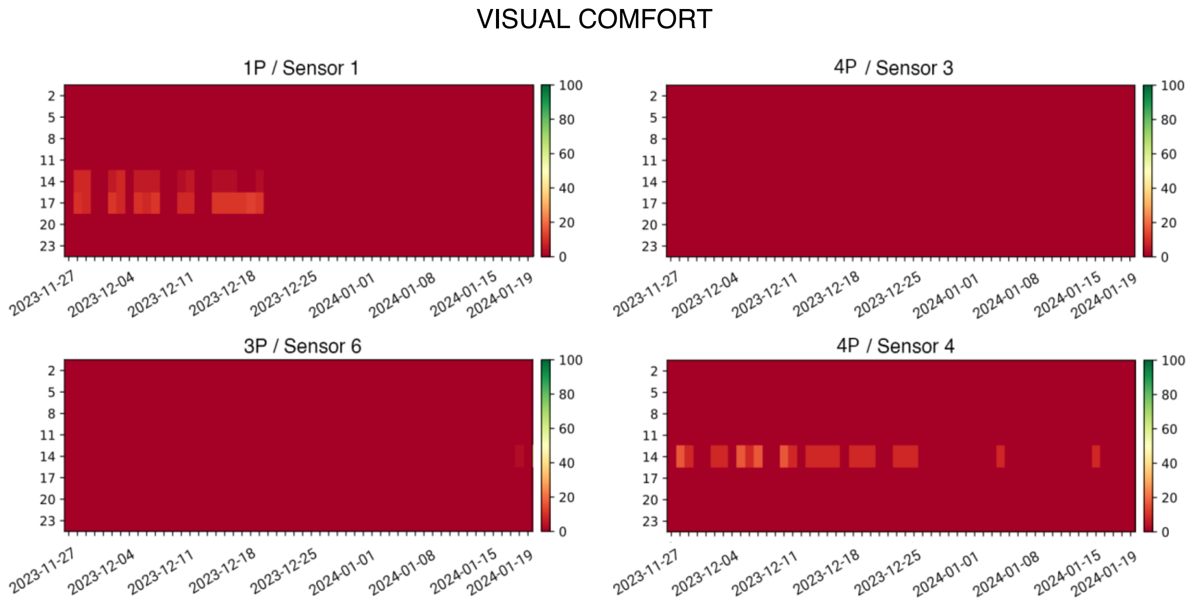

Figure 78: Expression of monitored visual comfort of Sensor 1, Sensor 3, Sensor 4 and Sensor 6 between 27.11.2023 and 19.01.2024 in the form of a heat map.

IEQ decreased during lecture hours. Sensor 1 measured lower IEQ values than other sensors. In classroom 4P, Sensor 4 measured lower values than Sensor 3 (Figure 79).

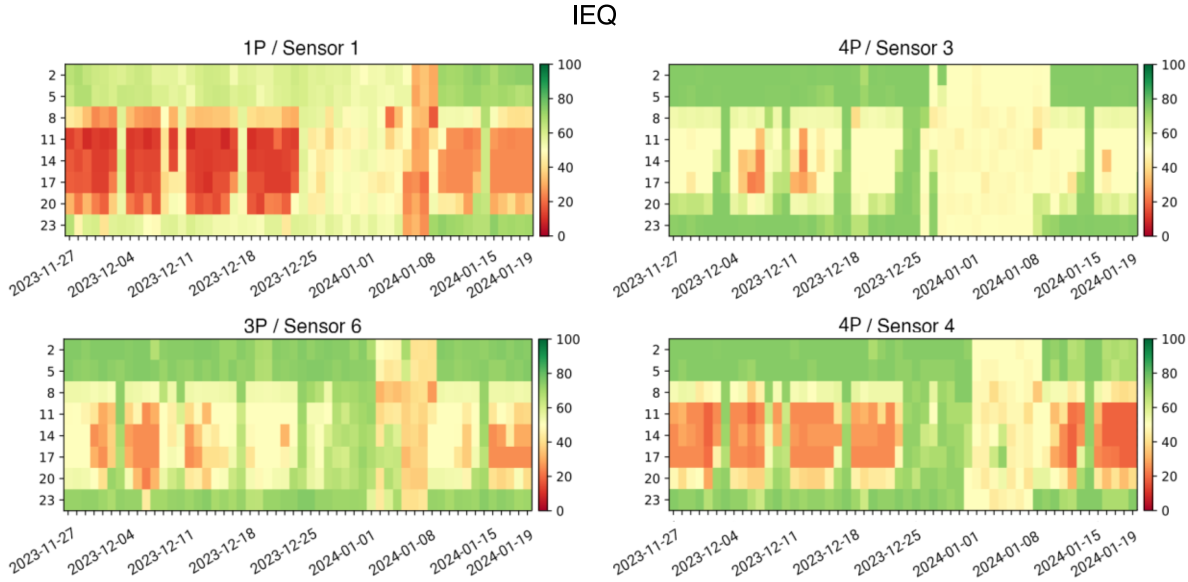

Figure 79: Expression of monitored IEQ of Sensor 1, Sensor 3, Sensor 4 and Sensor 6 between 27.11.2023 and 19.01.2024 in the form of a heat map.

4. Discussion

The aim of this thesis is to better define and evaluate students' well-being and comfort through IEQ monitoring and students' comfort assessment through questionnaires. The study was conducted to evaluate the indoor environmental conditions of four classrooms at Politecnico di Torino, selected as case studies. Classrooms are located in an independent building and are equipped with an autonomous ventilation and air conditioning system. Therefore, making changes based on the collected data will be simpler. This study aims to increase both IEQ (Indoor Environmental Quality) and IEC (Indoor Environmental Comfort) by collecting feedback from students through an anonymous questionnaire and the monitoring of the IEQ of the classrooms with a commercial multi-sensor, Aircare. A literature review has been done to analyze the state of the art on this research field and define the study methodology.

Firstly, how students perceive IEQ domains has been understood by examining studies conducted in the last six years. The IEQ domains that impact students' comfort perception were identified through the examination of questions asked to the students and the analysis of their responses. Personal and contextual factors impacting IEC were also identified through case studies. By examining and understanding the methodologies and analysis methods in the articles, it was understood how to conduct this case study.

There are 4 sensors in classrooms 1P and 4P, and 1 sensor in 2P and 3P. The sensor in 2P stopped working immediately after installation, therefore there is no monitoring data for 2P in the presented results. Contextual factors in the classrooms (i.e., on and off status of electrical lightings and microphone, open and closed status of doors and curtains-solar shadings), monitored parameters (i.e., temperature, relative humidity, SPL, illuminance, TVOC, CO_2, $PM_{2.5}$ and PM_{10}) and students' questionnaire responses were collected during the first period (30/05/2023 to 09/06/2023) and the second period (08/01/2024 to 19/01/2024), and analyzed. Statistical analysis was performed via SPSS Statistics vs. 20 to find the main correlations between contextual factors, subjective feedback and IEQ monitoring. A total of 433 responses were collected from classrooms 1P, 2P, 3P, and 4P during the winter period, and 95 responses were collected from 4P classrooms during the spring/summer period.

The majority of students are satisfied with the IEQ conditions during the winter period in 1P, 2P and 3P and during the spring/summer period in 4P. During the winter period, in 4P the majority of students are not satisfied with the IEQ conditions. The rate of students in 4P who were dissatisfied with TC during the winter period was 70.7%. For AC and VC, the number of satisfied students is more than the number of dissatisfied students. For Indoor Air Quality perception, the number of dissatisfied students is more than the number of satisfied students. The dissatisfaction with Thermal Quality (TQ) and IAQ may be attributed to the classroom having a lower T_{in} value compared to other classrooms during the same period, along with a higher TVOC value. Students in 4P who commented on the questionnaire stated that the air conditioning system gives cold air to the classroom during winter, which disturbs them, especially if they are seated at a desk close to the air conditioning system. However, according to the threshold values determined by the standards, TQ and IAQ are 100% and 95.87%, respectively. Therefore, it would be beneficial to analyze the classroom conditions more comprehensively, taking into account the feedback regarding the air conditioning system, and repeat the questionnaire for a longer period.

TQ ranges from 75.83% to 100% across classrooms, while TC varies between 47.32% and 58.59%. Although Thermal Quality complies with the standards, the students' comfort percentage is lower, therefore repeating the questionnaire with more students for a longer period would be beneficial for better analysis to understand what the reasons are. At the same time, the students' answer to the question "How do you feel now?" in winter period revealed that the students were equally distributed among 7 different answers, from cold to hot, under similar classroom conditions during the week. Therefore, it demonstrates that students' comfort perception may differ from person to person.

Acoustic Quality (AQ) in the classrooms is between 16.43% and 54.51%, while AC is between 50% and 62.5%. Students' satisfaction is higher than objective evaluation. The AQ of classrooms should be improved based on the developed algorithms for its evaluation. Some of the students stated in their questionnaire that they were dissatisfied with the mechanical sounds coming from the VAC system or microphone in the classrooms. The questionnaire should be continued after these problems are resolved. The number of answers to question regarding the evaluation of acoustic condition (i.e., "How do you find the noise in your environment now?") was low in classrooms, repeating the questionnaire with more students would be beneficial to better analyze the situation.

Among the four domains, Visual Quality (VQ) is the one that meets the standards the least (between 0.15% and 9.34%), according to the developed algorithm. The students' satisfaction percentage is between 41.67% and 62.5%. The response number to the question "How do you find visual environment now?" is quite low; to understand problems in classrooms the questionnaire should be repeated with more students. It can be assumed that when the visual quality in the classrooms is increased, the VC will also increase. However, it is understood from the students' responses to the question "How would you like your visual environment to be now?" that, despite the low illuminance in the classrooms and the failure to meet standard for VQ, some students prefer a darker classroom environment. To understand this better, comments on the questionnaire should be examined. It is revealed from the students who left comments on the questionnaire that it is difficult to associate the low visual quality in the classroom only with the darkness of the classroom. They stated that they had vision difficulties and, consequently, reading difficulties due to the lighting near the projection wall. Therefore, it should not be forgotten that the type of activity is also important to evaluate students' comfort perception.

While IAQ percentages range from 62.91% to 99.86%, students' satisfaction with air conditions varies between 45.71% and 68.75%. The comfort perception of students in 4P is lower compared to other classrooms, which can be attributed to higher TVOC levels. According to responses to the question "How do you find air velocity in your classroom now?" during the winter period in the 4P classroom, the majority of students think that the classroom is draughty. At the same time, students who left comments on the questionnaire stated that they need fresh air in this classroom. According to Pearson correlation results, it was observed that as CO_2 and TVOC values increased, students' satisfaction decreased. Despite IAQ meets standards, students' satisfaction percentages are relatively low. It would be beneficial to conduct the questionnaire over a longer period. When repeating the survey, the conditions under which students' positive and negative feedback was provided should be examined through correlation.

Monitoring results for each domain between 05.06.2023 and 09.06.2023 have been compared in classrooms 1P and 4P which have 4 sensors. Line graphs comparing the 4 sensors and mean value for every parameter and classroom were created, and parameters were analyzed throughout lecture hours. The results indicate that parameters such as temperature, TVOC, illuminance, etc., vary within the classroom and therefore, students' perceptions may also vary depending on where they sit in the classroom. This could be one of the reasons for the diversity in students' responses to the questionnaire. In analyses conducted using Pearson correlation, examining the relationship between contextual variables and monitored parameters, as well as the relationship between contextual variables and students' comfort perceptions, no significant results were obtained.

According to this study there are differences between IEQ and students' comfort perception. This attributed that due to variability of monitored parameters, contextual factors and personal factors dependent on students (e.g., physiological, psychological etc.) in the classrooms. This situation should be thoroughly investigated in future studies, and factors influencing students' comfort perceptions should be identified.

5. Conclusion

The study was conducted to evaluate the indoor environmental conditions of four classrooms at Politecnico di Torino. In the current study, the fact that students in classrooms have different perceptions under similar conditions aligns with the findings in the literature review. It has been observed that the percentages of objective evaluation and subjective evaluation may not be aligned; students satisfaction may be high when the IEQ relatively low, or IEQ may be high when student satisfaction is relatively low. Students' perceptions of IEQ can vary depending on many different personal or contextual factors. In monitoring, conducted with four sensors in 1P and 4P classrooms, it was observed that parameters vary within the same classroom. As a result, depending on contextual factors within the classroom, the IEQ perception of students sitting in different locations can change. Developing a system to determine the students location in the classroom could also be beneficial.

According to Pearson correlation analysis, no correlation was found between contextual variables and monitored parameters, as well as between contextual variables and students' comfort perceptions. In the current study actual lecture hours were used (1.5 hours). In future studies conducted in the same classrooms, slot hours should be shorter to follow changes in a shorter period. Additionally, more factors should be taken into consideration. For instance, no correlation was found between IAQ, CO_2 levels, and the frequency of doors being opened in classrooms. Considering additional factors such as wind direction, wind speed, and the operational status of the HVAC system could be beneficial in identifying these relationships. For visual comfort, to evaluate illuminance, factors such as outdoor lighting and daylight factor should be considered. In addition, the required amount of light will change depending on the activities in the classrooms. More contextual factors related to classrooms need to be included in the analyses.

Extending the monitoring and questionnaire to involve more students over a longer period would be beneficial for achieving more comprehensive results.

List of Tables

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