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Indoor Air and Light Quality Assessment in a University Campus Classroom

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# Indoor Air and Light Quality Assessment in a University Campus Classroom

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## Abstract

Educational buildings should provide a secure, healthy, and comfortable indoor environment for students since they spend a noteworthy part of their time inside. The present study aims to identify and assess the key indicators related to the light and air quality of a campus classroom, which contributes to the health of students. The indicators are chosen from an existing green rating tool, the WELL Building Standard (WBS). The research methodology consists of three main phases; indicator selection, impact assessment, and validation process. The engagement of stakeholders was taken into the account in the entire research framework. The research findings showed that there is a considerable gap among the acceptable range of indoor air and the light quality of the classroom. This led to verifying various health issues among the students, including dryness and irritation of the skin and eyes, and consequently increased their dissatisfaction rate. The study provides some significant insights based on the obtained results, highlighting the importance of incorporating student health and wellness into educational building design and operations, including visual comfort and indoor air quality conditions, which are often worse than the stipulations in standards.

**Keywords:** educational buildings, indoor air and light quality, WELL building standard (WBS), health issues.

## Introduction

Studies on the health and wellness of occupants have received much attention in recent years among scholars. The health-centered approach regarding occupants is at the heart of two Sustainable Development Goals (SDGs) of 3 *"Ensure healthy lives and promote well-being for all at all ages"* and 4 *"Ensure inclusively and quality education for all and promote lifelong learning opportunities for all"* (Azizibabani & Dehghani, 2017; Bortolini & Forcada, 2021; Costanza et al., 2016; Lynch, 2016).

As stated by the National Institute for Occupational Safety and Health (NIOSH), Indoor Environmental Quality (IEQ) refers to the environmental quality of the buildings, in relation to the health and wellness of occupants (H. Abdulaali et al., 2020; *CDC - Indoor Environmental Quality - NIOSH Workplace Safety and Health Topic*, 2019; Liang et al., 2014; Torabi & Mahdavinejad, 2021). The IEQ is determined by a range of environmental factors, such as thermal comfort, lighting, acoustic quality, and indoor air quality (H. Abdulaali et al., 2020; Arif et al., 2016; Liang et al., 2014; Sarbu & Sebarchievici, 2013).

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It is well accepted that indoor air and light quality issues have negative impacts on human health (Lee & Lee, 2019; Marchetti et al., 2019; Pacitto et al., 2020). Particularly, students are considered more vulnerable to the poor IEQ since they spend a noteworthy part of their time in the scholastic environment (Arcega-Cabrera et al., 2018; Ferguson & Solo-Gabriele, 2016; Iglesias-González et al., 2020; Ma et al., 2019; Turunen et al., 2014). Therefore, the educational buildings should provide a secure, healthy, and comfortable indoor environment for students (Bortolini & Forcada, 2021; Zhu et al., 2021; Zinzi et al., 2021). This study is motivated by the main concern of poor IEQ in the campus buildings, which can lead to health issues, high virus transmission rates, and reductions in learning performance in the long term (Annesi-Maesano et al., 2013; Daisey et al., 2003; Turunen et al., 2014; Veenhoven, 1989; Zhu et al., 2021).

To date, many studies have conducted research about the IEQ influences on the health and wellness of students in educational buildings (Badeche & Bouchahm, 2021; Jamaludin et al., 2016; Tahsildoost & Zomorodian, 2018). These studies have focused on the IEQ assessment concept in campuses and its relationship with the satisfaction level of students, employing different quantitative and qualitative methodologies (e.g., measurements, surveys) (Jamaludin et al., 2016; Tahsildoost & Zomorodian, 2018; Turunen et al., n.d., 2014). A recent study has introduced a 'green' building as a building that reduces the negative impacts on the environment during its lifecycle. Moreover, it focused on assessing green buildings through the Environmental Building Rating Systems (Shamseldin, 2021). Another study conducted a comprehensive literature review regarding the impact of IEQ on the health and wellbeing of occupants (H. S. Abdulaali et al., 2020). This study introduces Malaysia's Green Building Index (GBI) and highlights the IEQ as a fundamental criterion of the green building rating system to be considered while designing, constructing, and operating a building (either residential or non-residential) (H. S. Abdulaali et al., 2020). Moreover, the evaluation of IEQ and student satisfaction levels regarding a campus building has been conducted by Mohd Amri Sulaiman et al. (Sulaiman et al., 2013), based on four main IEQ parameters—thermal comfort, auroral comfort, indoor air quality, and lighting through on-site measurements and a questionnaire survey (Sulaiman et al., 2013). Similarly, another study has investigated the use of quantitative and qualitative methods (i.e., measurements of IEQ parameters and post-occupancy evaluation) to explore the performance level of the building and user satisfaction, according to the GBI (Khamidi et al., 2013).

The above-mentioned studies have measured different IEQ parameters, such as temperature, and humidity, for their specific case study in order to assess the sustainability level of the building. In addition, they analyzed the satisfaction level of users of the place by utilizing questionnaire surveys. However, none of the previous studies has selected key indicators relying on a green rating tool and measured the impact of IEQ parameters in relation to the students' health. In detail, they have not specifically focused on the measured-based process and have not compared their indicators assessment results with the targets of a rating system and standard.

Due to the complexity of this research field, this paper aims to identify and assess the key indicators related to the light and air quality of a campus classroom, which contributes to the health of students. It, therefore, addresses the following research questions: *"What are the key indicators related to the light and air quality which contribute to the health of students? And how these indicators can be selected and assessed?"*. This study selects a specific measure-based tool and its relative indicators to realistically measure the most important factors of IEQ in the campus buildings influencing student health and wellness.

At present, the green school concept is of great importance and efforts are being made to raise awareness of sustainable development (Meiboudi et al., 2018; Zhao et al., 2015). In 2018, a comprehensive review on six green school rating systems which have been distributed worldwide was conducted (Meiboudi et al., 2018). These global rating systems were developed in various countries, including the Building Research Establishment Environmental Assessment Method (BREEAM) in the United Kingdom, Leadership in Energy and Environmental Design (LEED) in the United States, Foundation for Environmental Education (FEE) for ECO-Schools in Europe, Green Star Education in Australia, Comprehensive Assessment System for Building Environmental Efficiency (CASBEE) in Japan, and China Society for Urban Studies (CSUS) in China (Meiboudi et al., 2018). Moreover, the University of Indonesia (UI) Green Metric World University Ranking has been introduced as an international rating system to assess the situation of green campuses (UWI, 2016). In 2016, the WELL Building Standard (WBS) for educational facilities in the United States was launched, to work beside LEED and other global green systems, with the intent to monitor the features of the built environment and address issues related to human health (*Educational Facilities Pilot Addenda | WELL V1*, n.d.; *The WELL Building Standard-V1*, 2016). WBS is a well-known green building assessment system that assesses educational sustainability performance and certifies health and wellbeing in the built environment (Heath et al., 2018; *The WELL Building Standard-V1*, 2016). The WBS assesses the IEQ on human health through the set of various indicators of air, light, and comfort. Particularly, the WBS indicators are based on a human-centered orientation approach (*Educational Facilities Pilot Addenda | WELL V1*, n.d.; *The WELL Building Standard-V1*, 2016).

All the existing sustainability and green rating tools differ in their structural features, such as the weighting schemes and the assessment ranking (Ali & Al Nsairat, 2009). Moreover, they take into consideration the various environmental issues and intend to promote environmental health, as well as human health and wellbeing (Meiboudi et al., 2018). In this research, the WBS is chosen due to its multidisciplinary performance and its suitability to deal with health and wellness aspects.

## Methodology

The methodological framework proposed for this study consists of three major Phases: indicator selection (Phase I), impact assessment (Phase II), and validation process (Phase III).

The aim of **Phase I**, indicator selection, was to reduce the number of non-practical and inefficient indicators and to maintain those which are most adequate to perform a concrete IEQ assessment. Although a vast number of indicators exist for the assessment of IEQ performance, it is not helpful to have more and more indicators (J.-J. Wang et al., 2009). On the contrary, fewer indicators may sometimes be more advantageous for evaluating the relative issues. Generally, the selection of indicators requires consideration of those which are SMART; that is, Specific, Measurable, Achievable, Relevant, and Time-bound (Ho et al., 2021; Ishak et al., 2019).

This phase was divided into three steps: pre-selection, filtration, and final selection. The procedure starts from the comprehensive review of WBS indicators to preselect them. Regarding the filtration process, stakeholders' opinions have been taken into account.

The IEQ assessment at the sustainable campus requires the comprehensive vision of different expertise in various sectors (Yusoff & Sulaiman, 2014). Hence, multiple stakeholders in the selection of indicators should be involved who can influence or will be influenced by the recognition of objectives (Dente, 2014). To this end, this study first has performed the stakeholders' analysis employing the power-interest grid in order to identify the relevant experts in light and air sectors. Afterward, a specific questionnaire was designed to select the most important indicators according to the stakeholders' opinions. The questionnaire proposed a voting scale for the experts in relation to their preferred indicators. In the questionnaire, the authors avoided expressing any personal preferences and played only the role of analysts (Løken, 2007). At this stage, in order to select the final set of indicators, the availability of data was taken into account since they should be measurable, achievable, straightforward, and cost-effective (Ishak et al., 2019).

In **Phase II**, the impact of the selected indicators was assessed. The impact assessment procedure was performed based on the literature review, technical documents investigation, focus groups with stakeholders, data measurements, elaboration of geometric data, and in-situ analysis (Torabi Moghadam et al., 2018).

The purpose was to measure the indicators in quantitative and qualitative ways to verify if they meet the targets defined by WBS. According to the WBS, if the evaluated indicators do not meet those targets, various health issues among the users might happen (*The WELL Building Standard-V1*, 2016).

Into this, in **Phase III** (validation process) a further survey has been launched to validate the primary research findings from phase II. The survey intends to engage the students to verify which health issues are common among the students during their presence at the location considering their perceptions. Moreover, their satisfaction level is evaluated through the questionnaire. Furthermore, the study involved specialized doctors to verify the stated health issues by the students and identify the factors that affect their health. This is because it should consider the specialized doctors' assessments rather than only the students' responses to a questionnaire.

Table 1 shows the schematic overview of the research methodology, as described above.

Table 1

Research methodology overview

| Phases | Steps | Methods | Outputs |
|---|---|---|---|
| I. Indicator selection | Pre-selection | Protocol review | Consider all WBS indicators |
| | Filtration | Stakeholders' analysis employing the power-interest grid | Select the most important indicators according to the stakeholders' opinions |
| | | Launch of questionnaire | |
| | Final selection | Data analysis | Select those indicators where the data is available and measurable |
| II. Impact assessment | Data collection | Literature review | Measure the value of each indicator if they meet the targets defined by WBS |
| | | Technical documents investigation | |
| | | Focus groups with stakeholders | |
| | | data measurements | |
| | | Elaboration of geometric data | |
| | | In-situ analysis | |
| III-Validation process | Students' survey and specialized doctors' engagement | Questionnaire and Diagnosis | Involve the specialized doctors to verify the stated health issues by the students and identify the factors that affect their health |
| | | | Verify the health issues among students and satisfaction level during their presence hours |

## Case study

The Polytechnic University of Turin (Polito) is located in the city of Turin in Italy, and it has a continental temperate climate. A large size classroom, ''classroom 1'', located at the main campus of the Polito, built-in 1958, was chosen as a case study to implement and test the proposed methodology. The ease of accessibility to the classroom to perform different in-situ analyses, the presence of sensors, and the availability of data were the main reasons to select ''classroom 1''. The classroom area is about 318.11 m2 and its volume is almost 1460 $m^3$ possessing 408 seats. The air conditioning of the classroom is supplied by an Air Handling Unit (AHU) (Noussan et al., 2017).

The Heating, ventilation, and air conditioning (HVAC) system of the classroom consists of a compressor, a condenser, an expansion valve, and an evaporator. HVAC systems follow a thermodynamic process to remove heat from one place, replace it with cold air, and expel the hot air to the outside atmosphere (Talei et al., 2021). They take the most power consumption to carry out the indoor environmental comfort (Hamidi et al., 2021). The classroom HVAC system has been working since 1991 and the operation hours are 8:00 am to 7:00 pm from Monday to Friday and from 8:00 am to 2:00 pm on Saturday. The commercial building management system for HVAC (Desigo™) developed by Siemens is the basis of the control system for the classroom (Noussan et al., 2017). In the building renovation process in 2015, new automatic windows were installed. However, the window operations are not controlled by the Desigo™ software. The data related to the air quality (e.g., temperature, relative humidity, and CO2) has been measured by the HVAC system of the classroom from 2011 up to now. Fig. 1 shows an interior picture of the classroom.

Fig. 1

Polito, Campus in Corso Duca degli Abruzzi, Classroom 1. Source: Photo by Polito Data Lab, October 2019

## Results

This section reports the results of each phase, and it discusses the significance of the findings. The outcomes obtained from the application of the methodology in the case study (classroom 1) are outlined below;

### Phase I — Indicator selection

The pre-selection started from 94 indicators, which were the total indicators of WBS classified into seven categories: Air, Water, Nourishment, Light, Fitness, Comfort, and Mind. As the case study was a classroom which is an interior part of the building, the indicators that did not have any impact on IEQ were discarded, i.e., Water, Nourishment, Mind, and Fitness. At this point, the number of indicators was reduced to 50.

The filtration started with the design of the specific online questionnaire to select the final set of indicators. Initially, the stakeholders were identified among academic experts in the field of energy and through the interests-power grid were mapped. Afterward, the online questionnaire was launched among those 80 selected stakeholders.

The goal of the voting process was to identify the most significant indicators relative to the indoor air and light quality of the classroom, which can affect the health of students. By considering the opinion of all the experts in the field, it was possible to carry out a pre-selection of indicators and rate the importance of the different issues for IEQ assessment.

The experts were asked to answer the questions based on an ordinal scale of 0 to 4 (0 = not important to 4 = very important and DK (Does not know)), in order to express their preferences. In particular, the experts rated each indicator according to three main criteria—(i) understandability, (ii) measurability, and (iii) relevancy.

Based on the experts' answers, the indicators were first ranked from the most preferred to the fewer ones. Then, formula (1) was employed to select the limited number of indicators (Rasali et al., 2016). The average rate (X) of indicators was calculated by summing the total rates of all indicators (Q) and dividing it by the total number of indicators (Z). By this method, the indicators which had the total rate (Y) more than the average rate (X) in each category were selected.

$$Q/Z = X \quad if \quad Y \geq X \rightarrow Select\ the\ indicator \qquad (1)$$

The results of the questionnaire highlighted the 12 most important indicators categorized into Comfort, Air, and Light. They highly voted those indicators that affected the IEQ issues, in terms of student health and, hence, the less important indicators were ranked at the bottom of the list. The data availability and measurability were also considered to select the final set of indicators. In this phase, the comfort category was eliminated, as the data related to its indicators were not available to be assessed. Therefore, the final selection led to selecting 7 indicators. The data relating to the selected indicators were collected from the existing databases (i.e., Data lab and Building Area) of the Polito campus. Table 2 shows the list of the final seven indicators and explains their objective and unit.

Table 2

The final set of indicators, source WBS (*The WELL Building Standard-V1*, 2016)

| Category | Code | Indicator | Objective | Unit |
|---|---|---|---|---|
| Air | A1 | Humidity Control; Relative Humidity | To provide adequate humidity levels by limiting the growth of pathogens, reducing exhaust gases, and preserving thermal comfort. | % |
| | A2 | Smoking ban; Indoor smoking ban | To avoid smoking, reduce air pollution, and decrease the exposure of non-smokers to smoke. | – |
| | A3 | Air filtration; Particle filtration | To eliminate indoor and outdoor air pollution through air filtration. | % |
| Light | L1 | Daylighting fenestration; Window sizes for working and learning spaces | To reduce excessive radiation and make the exposure of the occupants to daylight better by increasing fenestration parameters. | % |
| | L2 | Daylighting fenestration; Window Transmittance in Working and Learning Areas | To reduce excessive radiation and make the exposure of the occupant to daylight better by increasing fenestration parameters. | nm |
| | L3 | Right to light; Window access for working & learning spaces | To increase occupant exposure to daylight and increase outside view by reducing the distance of workstations or desks to a window or atrium. | m |
| | L4 | Solar glare control; Daylight management | To avoid sun glare by obstructing or mirroring direct sunlight from occupants. | – |

### Phase II — Impact assessment

Within Phase II, the impact of the final seven selected indicators was assessed for classroom 1 to explore the indoor air and light quality, and consequently, their impact on student health. Table 3 summarizes how each indicator was evaluated illustrating the assessment methods (the description of how the indicator can be measured), type (quantitative vs. qualitative), and data sources (a list of resources that were used in developing the assessment of the indicators).

## Table 3

Summarization of overall assessment of indicators, source (Gorini et al., 2008; Gualano et al., 2014; *The WELL Building Standard-V1*, 2016; Valente et al., 2007)

| Code | Unit | Assessment method | Type | Data source |
|---|---|---|---|---|
| A1 | % | Calculations/Measurement | Quantitative | Data measured by Data Lab at Polito campus |
| A2 | - | Policy Document/ Visual inspection | Qualitative | Literature Review |
| A3 | % | Calculations/Measurement | Quantitative | Regional Agency for Environmental Protection (ARPA) Piemonte, Italy |
| L1 | % | Architectural Drawing/ Visual Inspection | Quantitative/ Qualitative | Architectural drawing documents created by Building Area at Polito Campus |
| L2 | nm | Architectural Drawing/ Architect | Qualitative | Technical office at Polito Campus |
| L3 | m | Architectural Drawing/ Visual Inspection | Quantitative/ Qualitative | Architectural drawing documents created by Building Area at Polito Campus |
| L4 | - | Architectural Drawing/ Visual Inspection | Quantitative/ Qualitative | Architectural drawing documents created by Building Area at Polito Campus |

The upcoming part is dedicated to the assessment of indicators, which was thoroughly examined in the case study. In this part, the WBS requirements for each indicator, their assessment procedure, and evaluation results are fully described.

_ *Indicator A1. Humidity Control; Relative Humidity (RH)*

*Requirements of WBS:*

According to WBS, at least one of the following is required:

a An air conditioning system capable of maintaining the relative humidity between 30% and 50% during all presence hours, by reducing or increasing the humidity to the air.

b The humidity level modeled in the location for at least 95% of all the working hours of the year is within 30–50%. Buildings that are in humid areas are recommended to follow this feature (*The WELL Building Standard-V1*, 2016).

*Assessment process:*

This indicator was assessed through specific measurements obtained from different networks of probes, sensors, data logs, and software. The data acquisition was achieved, at a time resolution of 15 minutes, for the whole year of 2019. The data was collected by the Living Lab of the Polito campus, written partly in the Perl script and partly in the R language, and was based on a Microsoft SQL Server database for long-term storage. The data points related to every minute were exported into a text document and, after that, were imported into an MS SQL Server 2012 relational database and aggregated to a 15-minute basis. Fig. 2 indicates the arrangement of RH, Temperature (T) values, and their correlation in 2019.

According to Figure 2, the trend of changes in RH values experienced an enormous escalation from June/July/August to February/March. Looking at more details, RH began at 85 % on 9/6/2019, which was the highest humidity in 2019. Despite the highest value in June, the amount of RH then declined significantly and fell to the lowest rates of 10 % and 0 % on the $13^{th}$, and $20^{th}$ of January and $13^{th}$ of September, respectively. Considering the measurements, of 11,845 RH base detections every 15 minutes, only 2833 RH detected points were within 30–50% during presence times in the year 2019 (8:00 am to 7:00 pm from Monday to Friday; 8:00 am to 2:00 pm on Saturday).

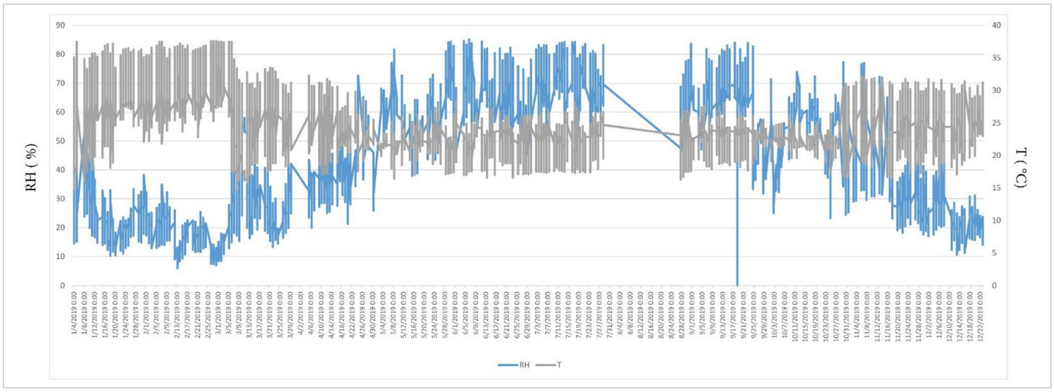



Fig. 2

RH and T measurements at classroom 1 for 2019, source: Living Lab Polito

In addition to the RH, the air temperature was also measured by the HVAC system. Despite having reached a peak of 35 °C in January/February 2019, the changes in the Temperature value had a period of stability from May to October (with an average of 23°C). What stands out in Figure 2 is that the trend then escalated slowly from October to December 2019.

The figure also illustrates the correlation between the changes of T and RH amount in 2019. With respect to the information given by the graph, the humidity values experienced a significant rise in RH from March to May 2019 with a peak of 83 % on 8/5/2019, while the Temperature showed an enormous decline during that period and remained stable from 4/5/2019 to 31/10/2019. The RH then saw a significant reduction and fell to 7 % on 22/12/2019. Despite fluctuating heavily between 4/1/2019 and 18/4/2019, the trend of T changed, then remained steady at 50 %.

To conclude, the T values were quite stable during the period and did not change with high fluctuations, while the RH values changed rapidly. The reason for this is that the Air Handling Unit (AHU) of the classroom measures the RH without controlling it, and the ventilation system of the classroom is obsolete; whereas the temperature of the classroom is controlled by the HVAC system and the above measurement confirm the stable variations in the T values.

*Evaluation result:*

According to the measurements, not all of the RH values were in the required range (30–50%), and only a few days and hours matched with the WBS requirements.

_ *Indicator A2. Smoking ban; Indoor smoking ban*

*Requirements of WBS:*

The following building policy is required:

a Smoking and e-cigarettes are prohibited indoors (*The WELL Building Standard-V1*, 2016).

*Assessment process:*

Since 10 January 2005, the anti-smoking law banned smoking in all public indoor spaces in Italy (Gorini et al., 2008; Gualano et al., 2014; Valente et al., 2007). Awareness of the building policy and an in-situ visualization has outlined that smoking is forbidden inside the Polito campus building and classrooms.

*Evaluation result:*

The smoking ban indicator for classroom 1 met the WBS requirements.

_ *Indicator A3. Air filtration; Particle filtration*

*Requirements of WBS:*

At least one of the following requirements should be encountered in the buildings:

a The filters with MERV13 (or higher) are used in the air conditioning system to filter outdoor air.

b The $PM_{10}$ and $PM_{2.5}$ levels of the outdoor air measured within 1.6 km of the building for 95% of yearly hours are less than the limits indicated in the WELL Air Quality Standards feature (*The WELL Building Standard-V1*, 2016).

*Assessment process:*

This indicator was assessed by an energy simulation software, which checks all the filters located in the ventilation system of the classroom to determine the Minimum Efficiency Rate Value (MERV). The calculation process was carried out considering the particle size range [nm], Average minimum Particle Size Efficiency (PSE) designator (%), and fractional efficiency (%). Table 4 demonstrates the results of the fractional efficiency MERV calculations for the filters.

Table 4

Fractional Efficiency MERV calculations

| Particle size range[nm] | | | Fine filter #1 | | Fine filter #2 | | Fine filters #3 & #4 | |
|---|---|---|---|---|---|---|---|---|
| Lower limit | Upper limit | Geometric mean | Fractional efficiency [%] | Average minimum PSE [%] | Fractional efficiency [%] | Average minimum PSE designator [%] | Fractional efficiency [%] | Average minimum PSE designator [%] |
| 300 | 400 | 346.41 | 78.73 | 87.85 | 80.25 | 89 | 78.18 | 87.06 |
| 400 | 550 | 469.04 | 86.36 | | 87.72 | | 85.79 | |
| 550 | 700 | 620.48 | 90.89 | | 92.49 | | 90.51 | |
| 700 | 1000 | 836.66 | 95.4 | | 95.54 | | 93.75 | |
| 1000 | 1300 | 1140.18 | 99.6 | 97.69 | 97.18 | 98.22 | 96.43 | 97.10 |
| 1300 | 1600 | 1442.22 | 99.6 | | 97.83 | | 96.42 | |
| 1600 | 2200 | 1876.17 | 98.32 | | 98.72 | | 97.18 | |
| 2200 | 3000 | 2569.05 | 99.40 | | 99.13 | | 98.35 | |
| 3000 | 4000 | 3464.10 | 99.60 | 99.83 | 99.30 | 99.60 | 98.60 | 99.20 |
| 4000 | 5500 | 4690.42 | 99.80 | | 99.50 | | 99.00 | |
| 5500 | 7000 | 6204.84 | 99.90 | | 99.70 | | 99.40 | |
| 7000 | 10000 | 8366.60 | 100 | | 99.90 | | 99.80 | |
| Minimum Efficiency Reporting Value (MERV) | | | MERV 15 | | MERV 15 | | MERV 15 | |

*Evaluation result:*

From the measurements, it was outlined that all the filters placed inside the AHU of the classroom correspond to MERV 15 and the filtration system was better than the minimum required.

_ *Indicator L1. Daylighting fenestration; Window sizes for working and learning spaces*

*Requirements of WBS:*

The following conditions should be observed in facades with regularly occupied spaces:

a On the external facades, the window–wall ratio should be between 20% and 60%. If the ratio is over 40%, it requires exterior shading or tunable glazing, which is able to control unwanted heat gain and glare.

b If the ratio is between 40% and 60%, the windows should be located at least 2.1 m above the floor (*The WELL Building Standard-V1*, 2016).

*Assessment process:*

This indicator was assessed in three steps. In the first step, architectural drawings (DWGs) of the classroom (e.g., section, plan, and view) were utilized to measure the window and wall areas. The window–wall ratio calculations followed Formula (2):

$$(Windows\ area/walls\ area) \times 100\ \% = \text{Ratio}, \quad If \sum Ratio > 40\% \rightarrow windows\ need\ external\ shadings. \tag{2}$$

The classroom had a total of three exterior walls (2 walls A + 1 wall B) and 13 windows that varied in size (5 windows on each wall A + 3 windows on wall B). The results of the measurements were as follows:

$$Wall\ A{:}(\ Windows\ area/Walls\ area) \times 100\%,$$
$$[(208\times150)+(224\times150)+(240\times150)+(257\times150)+(270\times150)]\div13166.28=13\%$$
$$Wall\ B{:}(\ Windows\ area/Walls\ area) \times 100\%,$$
$$[(240\times165)+(240\times165)+(283\times165)]\div646697=19\%,$$
$$\sum Ratio = (\ 2\ Ratio\ wall\ A) + Ratio\ wall\ B,$$
$$(2\times13\%)+19\%=45\%.$$

According to these calculations, the total window-wall ratio was about 45%. In the second step, the distances of walls and windows were measured, using the DWGs. The measurements outlined that all the windows were located 3.5 m above the floor. At the third step, an in-situ survey was implemented, which confirmed the presence of exterior blinds attached to the windows of the classroom. Figure 1 shows an interior picture of the classroom, with the exterior blinds on the windows.

*Evaluation result:*

According to the measurements, the window-wall ratio in classroom 1 was more than 40% and the distance of windows from the floor is more than 2.1 m. Moreover, the windows had exterior shadings, and the indicator fulfilled the WBS target.

_ *Indicator L2. Daylighting fenestration; Window Transmittance in Working and Learning Areas*

*Requirements of WBS:*

The following Visible Transmission (VT) conditions should be met for all non-decorative glazing:

a All glazing located 2.1 m above the floor should have a VT of 60% or more.

b All glazing (excluding skylights) located equal to or less than 2.1 m from the floor should have a VT of 50% or more (*The WELL Building Standard-V1*, 2016).

*Assessment process:*

To assess this indicator, the distances between all windows and the floor were measured using the architectural drawings, and it was determined that all the windows were located 3.5 m above the floor. Moreover, the technical office of the Polito campus (the relevant experts) confirmed that all the glazing used in the campus building had a Visible Transmission (VT) of 60%.

*Evaluation result:*

The indicator met the WBS requirements regarding the glazing VT conditions.

_ *Indicator L3. Right to light; Window access for working and learning spaces*

*Requirements of WBS:*

The following conditions should be met in the buildings:

a The distance between 75% of workstations or desks from an atrium or a window that has e the possibility to see the outside should be 7.5 m.

b The distance between 95% of all workstations from an atrium or a window that has the possibility to see the outside should be 12.5 m (*The WELL Building Standard-V1*, 2016).

*Assessment process:*

This indicator was assessed using architectural drawings (DWGs) of the classroom to measure the distance between students' chairs and desks from the windows. The measurements showed that 84% of desks had a 7.5 m distance from windows without views to the exterior, as the windows of the classroom were located 3.5 m above the floor and students were unable to see the outside. Figure 1 shows the location of windows in the classroom.

*Evaluation result:*

The indicator did not meet the WBS requirements since the windows only had the function of providing light, and there was no visual view to the outside.

_ *Indicator L4. Solar glare control; Daylight management*

*Requirements of WBS:*

In regularly occupied spaces (excluding lobbies), if the distance between all the glazing and the floor is more than 2.1 m, at least one of the following is required:

a Automatic or manually controllable interior window shading, or blinds preventing excessive radiation.

b Automatic exterior shading systems to block excessive sunlight.

c Interior light shelves to reflect sunlight onto the ceiling.

d A window glazing system with a micro-mirror film that reflects sunlight upwards.

e A variable transparency glazing, such as electrochromic glass, can decrease the light and heat transfer by 90% or more (*The WELL Building Standard-V1*, 2016).

*Indicator assessment:*

To assess this indicator, an onsite visualization of the classroom was implemented. In addition, the distances between windows and floors were measured, utilizing the architectural drawings (DWGs) of the classroom. The DWGs measurements indicated that windows were located 3.5 m above the floor. Furthermore, an onsite survey outlined the interior blinds attached to the glazing. The blinds were controllable through an electrical component. Figure 1 shows the presence of interior blinds on the windows.

*Evaluation result:*

The indicator met the WBS target since the presence of blinds which were controllable through an electrical component that manually control the excessive radiation.

Table 5 summarizes the WBS requirements and the results of the impact assessment. Over the seven indicators, five (A2, A3, L1, L2, and L4) totally met the requirements of the WBS, while the indicators A1 and L3 did not.

The results obtained from the impact assessment of indicator A1 showed that the ventilation system was not working appropriately. Moreover, the RH level was not between 30–50% in all of the presence hours. According to the WBS, a low level of humidity may cause health symptoms, such as skin dryness and irritation of the skin, eyes, throat, and mucous membranes. However, a high humidity level can lead to respiratory symptoms, especially in sensitive persons (*The WELL Building Standard-V1*, 2016). Regarding indicators A2 and A3, no incompatible situation was observed in the evaluation process. As indicated previously, smoking was forbidden in the entire campus and the filtration system was in a good condition. Therefore, they will probably not cause

Table 5

Data verification results for indicators

| Category | Indicator Code | WBS requirement (*The WELL Building Standard-V1*, 2016) | Data Verified |
|---|---|---|---|
| Air | A1 | The RH was between 30- 50% at all presence hours | X |
| | A2 | Indoor smoking was forbidden in the classroom | ✓ |
| | A3 | Filters had MERV 13 or higher | ✓ |
| Light | L1 | If window–wall ratio was between 40-60%, the external shadings were required | ✓ |
| | L2 | All glazing has a VT of more than 60% | ✓ |
| | L3 | The distance between 75% of students' desks from a window which could see the outside was 7.5 m | X |
| | L4 | The distance between all the glazing and the floor was more than 2.1 m and the windows had blinds | ✓ |

any health issues among the students relying on the WBS target. Moreover, the window sizes and, consequently, the window–wall ratio (indicator L1) and their transmittance rate (indicator L2) were in the acceptable range. Regarding indicator L3, the location of windows 3.5 m above the floor (and, thus, obviously above the heads of students) led to a lack of view to the exterior. As indicated in the WBS, having no views to the outside may cause some psychological issues for students, such as depression and distraction during the time (Shamseldin, 2021; *The WELL Building Standard-V1*, 2016). In contrast with this issue, all the windows had exterior and interior blinds (indicator L4), which were able to control the unwanted heat and light gain to the classroom. Thus, this may not cause exhaustion and discomfort among students.

The primary research achievements and comparing them with WBS needed to be validated and verified whether the indicated health issues were really felt by students. Into this, Phase III, as a validation process was designed.

### Phase III — Validation process

A second online survey was launched to verify the results obtained in phase II to validate the primary research findings, regarding the health symptoms experienced by students. This survey was designed in order to compare the health issues indicated by the WBS and the real symptoms felt by students.

As anticipated, the health issues indicated by the WBS due to poor air and light quality of the classroom were dryness and irritation of the skin and/or eyes, throat, mucous membranes, respiratory irritation and allergies, depression, and distraction.

To this end, the questionnaire comprised four main close-ended questions, starting with a general question asking their gender as a socio-demographic variable (Q1) (Numata et al., 2021). The main body of the questionnaire was designed according to consider the health of students. Q2 was related to the health symptoms due to the poor air quality of the classroom, while Q3 asked for details of the problems caused by poor light quality. In addition, Q4 evaluated the general health and satisfaction rate of the students of the classroom (Prozuments et al., 2020). Moreover, an open-ended question, Q5, was added, which asked whether the students have any suggestions for the future improvements of indoor air and light quality of the classroom. The questionnaire is shown in Table 6.

Table 6

Student health questionnaire

Dear students,

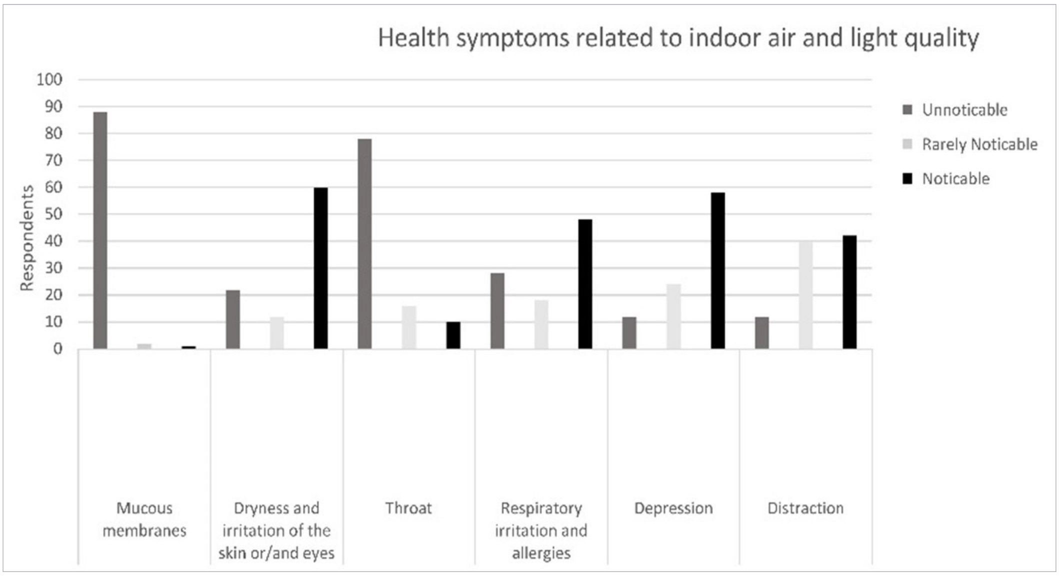
This questionnaire was designed to evaluate your health and satisfaction rate about the indoor air and light quality of classroom 1 on the main campus during your presence. Please answer the following questions considering your real feelings and perceptions.

| Questions | Responses | | | |
|---|---|---|---|---|
| 1. Please indicate your gender? | Female | Male | Prefer not to say | |
| 2. Did you have any of the following health symptoms in the past 6 months? | Noticeable | Unnoticeable | Rarely noticeable | |
| Dryness and irritation of the skin or/and eyes | | | | |
| Throat | | | | |
| Mucous membranes | | | | |
| Respiratory irritation and allergies | | | | |
| 3. Did you have any of the following psychological and neurological disorders in the past 6 months? | Noticeable | Unnoticeable | Rarely noticeable | |
| Depression | | | | |
| Distraction | | | | |
| 4. Are you satisfied with | Very dissatisfied | Dissatisfied | Satisfied | Very satisfied |
| Lighting in the classroom? | | | | |
| The ventilation system of the classroom? | | | | |
| Please indicate your motivation... | | | | |
| 5. Do you have any suggestions for the future indoor air and light quality improvement of the campus? If yes, please write here. | | | | |

The questionnaire was launched in December 2019, the same year of the data collection. Even if the capacity of the classroom was 408 seats, during the research period (2019), only 120 students were present, and 91 students have filled in the online questionnaire. The precipitated students were composed of 35 males, 38 females, and 18 of them preferred not to say about their gender. Afterward, the data was accurately analyzed and elaborated. According to the questionnaire responses, some health symptoms were almost unnoticeable among the students in the classroom, such as mucous membranes and throat, with 88 and 78 unnoticeable responses, respectively, given by the students (**see Fig. 3**). However, dryness and irritation of the skin and eyes were reported, with 60 noticeable responses. In addition, about 58 students felt depression and only 12 students did not have any issue with distraction, while 42 of them were always distracted and 40 students were rarely distracted. **Fig. 3** shows the health symptoms of respondents, related to the indoor air and light quality of the classroom.

Fig. 3

Health symptoms related to indoor air and light quality




Based on 76 satisfied responses over 91, the feedback highlighted that almost all the students were satisfied with the lighting situation in the classroom, while they were not satisfied with the ventilation system (60 dissatisfaction responses). The high rate of satisfaction with the lighting system of the classroom confirmed that it was in good condition, while only 24% of students were satisfied with the ventilation system, accounting for the least number of students. Fig. 4 illustrates the satisfaction rate of students related to the indoor air and light quality of the classroom.

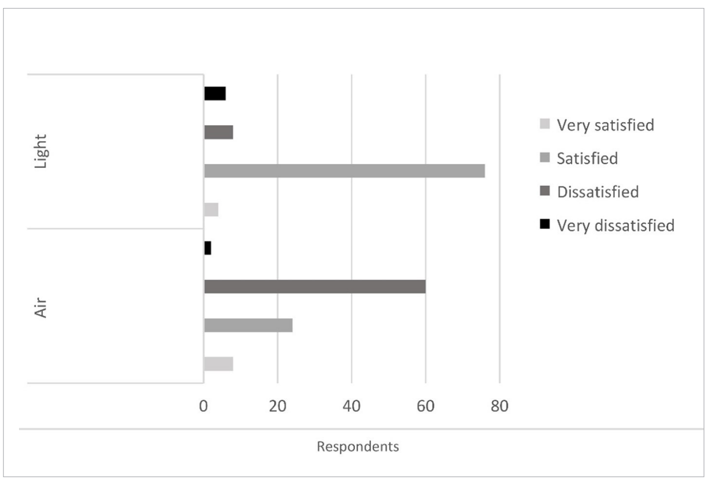
Some of the students also provided their motivations for their dissatisfaction. They stated that "*the air seems very dense, and we cannot breathe well, the windows are never open*" and "*we would like a slightly brighter light, the air in the class does not seem fresh, It's too hot and humid*".

Some students suggested installing better air conditioners and also air cleaning, which will be helpful for having fresh air in the classroom.

Notably, students' answers are often subjective and can be influenced by a plethora of external factors unrelated to the air and light issues. Moreover, due to the fact that the life and activity of students take place inside and outside the university campus, their health is also being influenced by external factors that must be taken into account. Hence, also the specialized doctors' assessments have been considered rather than only the students' responses to a questionnaire.

Fig. 4

Satisfaction rate related to indoor air and light quality of the classroom




According to the analysis, the health symptoms felt by students, such as irritation and allergies, were due to inappropriate levels of RH in the classroom, as was seen in the impact assessment result for indicator A1. Besides, the lack of external and natural light caused depression and distraction among a major part of students, confirming the validity of the assessment results for Indicator L3.

## Discussion and Future Insights

The research results showed that it is important to consider and integrate all the three above-mentioned phases engaging the relevant stakeholders to measure accurately the air and light quality in an educational building. A set of indicators have been identified as the most important ones that contribute significantly to the health of students in the classroom. The impact assessment came up with two main issues, which were lastly verified by the specialized doctors. A poor level of humidity and an inappropriate position of windows in the classroom has led to the students' health issues such as irritation and allergies, depression, and distraction. The use of assessment tools helped in defining the targets to be met and standardizing the procedure.

Hence, three significant insights are provided based on the key findings of the present study and interviews with experts. By doing this, the study intends to promote a high level of indoor air and light quality, in order to improve the health of students. The given insights take into account social, environmental, and economic aspects intending to aid designers to make better decisions in the design phases of the project by linking to the different SDGs, to better reflect the idea behind it.

- **Adapting the HVAC system of the classroom:** The design of HVAC systems is a challenging engineering task that requires experienced decision-making (Calero-Pastor et al., 2017). Moreover, the properties of HVAC systems are very important for health purposes, and their adaption can help to reduce the risk of various infectious diseases which are transmittable by the ventilation system (Chirico et al., 2020; Mohammadi Nafchi et al., 2021). The indoor temperature and humidity are high in a building; the virus transmission reduces. However, it is important to change the indoor air with fresh outdoor air (Chipalkatti et al., 2021; Haque & Rahman, 2020; J. Wang et al., 2020). The simulation results and relevant experts' advice demonstrated that the HVAC system of the classroom has no device to control the RH; thereby, the RH is not at an appropriate level at all during the presence hours. Considering the present case study, it is quite probable that the infection risk of viruses, such as the novel coronavirus causing COVID-19, could be increased during the present time, due to the inappropriate ventilation rate and RH level, especially when the RH is low. Therefore, adapting the HVAC system of the classroom is a vital point to improve the indoor air quality and advance the health of students. (Link with SDGs 3, 4, 7, 13, 16, 11).
- **Using Photocatalytic oxidation technology in the central ventilation system:** Photocatalytic oxidation technology plays an important role in human health, by purifying the indoor air. This technology has been used in various places, such as buildings materials, ventilation systems, and furniture (Yu & Brouwers, 2009). Therefore, according to the expert opinions, using this technology in the central ventilation system of the classroom may help to remediate indoor air pollution and help to decrease possible health issues among the students. (Link with SDGs 3, 4, 7, 11, 13).
- **Using active shading systems:** Active shading systems fall into three categories: Integrated renewable energy shading, kinetic shading, and smart glazing (Al Dakheel & Tabet Aoul, 2017). Dynamic shading systems minimize building energy consumption, balance IEQ, and improve occupant visual and thermal comfort (Al Dakheel & Tabet Aoul, 2017; Shamseldin, 2021). These systems fold, slide, expand, shrink, and transform in the shading devices if exposed to mechanical, chemical, or electrical drivers (Al Dakheel & Tabet Aoul, 2017). In the studied classroom, the glazing shadings were not automatic, but are manually controllable by the students through an electrical component. Therefore, in the classroom, daylight could have undesirable side effects, such as unwanted heat gains and glare. In this regard, installing automatic shading devices and light sensors is vital to reduce excess heat gain and glare, thus improving the indoor light quality of the classroom, as well as student health. (Link with SDGs 3,4, 7,13).

## Conclusions

The present study addressed the need for the selection of the indicators from the green rating tool which assesses the indoor air and light quality of a campus classroom, which contributes significantly to the health of students. In this route, among various campus green rating tools, the WBS was selected due to its suitability to deal with health and wellness aspects. The set of seven indicators was selected through the comprehensive review of WBS protocol, stakeholder engagement, and data analysis. Afterward, the value of each selected indicator was measured employing different assessment methods to verify if those values meet the WBS targets in terms of wellness and health of students. Additionally, the health issues among students and their satisfaction level during their presence hours, have been analyzed by specialized doctors. The authors point out some of the most relevant findings of the present study which cover three points:

**It is crucial to engage the expert stakeholders in the process of the indicator's selection:** in fact, engaging the stakeholders led to considering different technical aspects. Hence, a specific questionnaire was developed and filled out by relevant experts in the field, with the aim of selecting the most relevant indicators that mainly contribute to indoor air and light quality and, consequently, student health and wellness.

**The indicators need to be measured by collecting real data:** after selecting the indicators, the necessary data was collected through the indicated methods shown in Table 2 to assess the impacts of indicators in the specific case study. It is notable to say that there is a need to preprocess the data in order to prepare accurate, reusable, and elaborated information.

**The social aspects such as students' perception should be integrated into the process:** this study emphasized the importance of integrating the social aspects into the technical ones engaging the students. Into this, the specific questionnaire has been distributed among the students, and consequently, their responses showed that two health symptoms were the most widespread; (i) dryness and irritation of the skin about 66%, and (ii) eye and respiratory irritation and allergies about 52 %. The students' answers were well aligned with the out-of-range indoor air and light quality in the classroom.

The used methodology is capable of being easily generalized and replicable in different similar contexts collecting the specific data and information. Indeed, this flexible approach leads to a wider contribution that has been brought to the current state of the art.

As a preliminary theoretical framework proposed by this study, the outcome helps designers to consider the indoor air and light quality issues from the early phase of the project with specific attention to social, institutional, and technical aspects. Finally, the theoretical framework represents a substantial step towards sustainable development in the context of campus buildings.

The main limitation of the present study was related to a lack of appropriate data for assessing a higher number of indicators. Therefore, the indicators will need to be extended and revised through the use of specialized tools in the future with specific attention to the COVID-19 situation.

### Author Contributions

Formal analysis, investigation, methodology, computational analysis, original draft preparation writing, graphic material elaboration, and scenario formulation: F.A.; formal analysis, investigation, computational analysis, original draft preparation, reviewing, and supervision: S.T.M.; methodology, reviewing and supervision: P.L. All authors have read and agreed to the published version of the manuscript.

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## Conflicts of Interest

The authors declare no conflict of interest.

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