Edelweiss Applied Science and Technology
ISSN: 2576-8484
Vol. 7, No. 2, 164-181
2023
Publisher: Learning Gate
DOI: 10.55214/25768484.v7i2.406

Effects of the number of people, temperature, relative humidity, and CO_2 parameters on indoor air quality in higher education institution classrooms

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Abstract: This study involved the measurement of air temperature, relative humidity, and CO2 levels in both open and closed circumstances of windows and doors, both indoors and outdoors, during educational activities in a higher education institution classroom. Air temperature and relative humidity measurements were found to be within the range of 21.36 to 26.97°C and 42.94 to 55.16%, respectively. These values have been determined to be within acceptable comfort levels, according to the literature. The CO_2 concentration has been determined to increase with the number of people in the classroom and, in some cases, exceed the level of 1000 ppm, which is accepted as a general limit value, before the end of the course period. It has been determined that if the experiment is not terminated when the CO_2 level rises above 1000 ppm, the CO_2 level will reach even higher values depending on the elapsed time. The maximum level of CO_2 was measured at 1404 ppm among the CO_2 measurement data recorded before the end of the experiment. In addition, it has been determined that as the outside air intake increases, the concentration of CO_2 accumulated inside decreases. This finding suggests that ventilation is necessary in fully enclosed spaces. The number of people in the class has been determined to be 35 in order to be safe in terms of CO_2 levels in the activities carried out in the classroom where the research was carried out.
Keywords: *Carbon dioxide, Indoor air quality, Respiratory health, School, Classroom, Student.*

1. Introduction

Indoor environments where people gather have several crucial factors that need to be considered, such as the volume of the space, the condition of the structure, the number of people present, the characteristics of the ambient air, the amount of healthy and breathable air, and other influential factors. In this study, the state or the private sector can benefit from any educational and training facility. Indoor air quality becomes problematic in spaces that lack proper ventilation, particularly in fully enclosed classrooms where windows and doors cannot be opened, as this is a common situation in educational spaces. In particular, the performance of teachers and trainees has been shown to be adversely affected [1]. In a study of reading and math scores in classrooms with four different ventilation rates, students were found to perform better on exams in well-ventilated halls [2]. The negative effects of poor indoor air quality on human health can vary according to the individual's age, from primary school to higher education. Respiratory diseases and symptoms such as headache, dizziness, fatigue, malaise, numbness, fever, cough, chills, nasal problems, muscles and hearing problems, redness in the eyes due to a dirty environment, and other health problems are common in spaces without ventilation [1, 3, 4]. In a study of schools, it was determined that places such as laboratories, machinery and woodworking departments, kitchens, copying and intensive work areas, and artistic departments emit air pollution. In addition to poor indoor air quality in schools, roofs and humidity problems were also described. Although schools

History: Received: 29 August 2023; Revised: 3 November 2023; Accepted: 24 November 2023; Published: 22 December 2023
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typically have heating, ventilation, and air conditioning (HVAC) equipment, these systems are often not operated correctly, leading to increased moisture, which can promote mold and bacteria. These biologically active agents can cause severe allergic reactions, including asthma attacks. These problems, called sick building syndrome, have been observed to have an impact on the mental concentration and overall well-being of the individuals in these buildings, but the symptoms tend to disappear when the individuals leave the building. Similarly, tight-building syndrome and building-related illness are also terms used to describe building-related issues [1, 3, 5]. Therefore, indoor air quality in schools should be a priority for everyone.

Research has shown that unhealthy weather and high temperatures lead to high rates of illness, increased absenteeism, and decreased academic performance for students and adults. Deficiencies in heating, ventilation, and air conditioning systems during long periods of school should be eliminated, as shown in a study on extreme temperature and air conditioning differences at Harvard University [5]. Residents spend about 90% of their time indoors. Students have been reported to spend 23% of their academic year in school buildings and 5-10% outside. Studies have shown that indoor levels of pollutants can be 2 to 5 times higher than outdoor levels and that exposure to pollutants is higher for students due to their body weight. As time spent indoors increases, exposure to pollutants increases [6, 7]. In a 2012 study, Bulut [8] measured the amount of CO_2 in residential, office, and classroom environments and evaluated indoor air quality and ventilation. The study found that changes in CO_2 levels were related to factors such as the number of people, temperature, and relative humidity. Natural ventilation through doors and windows, regardless of the design, is insufficient in modern buildings, and filtration and ventilation must be implemented according to CO_2 concentration. According to industry standards ASHRAE Standard 62.1-2019 [9] and ASHRAE Standard 62.2-2019 [10], the term acceptable indoor air quality has been defined as the concentration of pollutants below harmful condensation levels, and at least 80% of people in the space do not feel any air-related discomfort.

In his 2015 study, Barbaroglu [11] compiled data on indoor air quality in kindergartens, primary schools, and higher education units to identify problems. Gullu [12] in another study of the same year analyzed the results of the measurement of physical, microbiological, and chemical parameters and made recommendations based on his findings. In 2011, Ozturk and Duzovali [13] measured indoor air quality for CO_2, particulate matter (PM10), humidity, and temperature in a primary school. In their 2015 study, Ugranli, et al. [14] measured parameters such as NO_2 and volatile organic compounds and evaluated the variability of these air pollutants and their effects on buildings. In their 2021 study, Vukmirovic, et al. [15] emphasized that attention should be paid to indoor air and costs, which affect the health and comfort of individuals inside buildings. In their studies conducted in 2016, Sozen and Işık [16] measured CO_2, relative humidity, and temperature in classrooms and lecturer offices of a higher education institution and evaluated their findings according to established standards. In his 2012 study, Betuz [17] measured temperature, relative humidity, CO2, and air velocity in a classroom and a design studio of a college building and identified problems with temperature, relative humidity, and CO2 accumulation due to the lack of sufficient fresh air in the winter period. In his 2014 study, Avci [18] measured the parameters of temperature, humidity, CO2, and particulate matter for the assessment of indoor air quality in college buildings, statistically evaluated the results, and recommended the necessary changes. In a 2008 study, Stranger, et al. [19] measured in-ground particulate matter in the interiors and exteriors of 27 elementary schools and found a high concentration of benzene, particularly in the lower floors. In their study in 2019, Yurdakul, et al. [20] measured CO_2, temperature, humidity, lighting, and noise levels in 86 classrooms in a higher education institution.

The mean temperature ranged from 18 ° C to 25 °C, the humidity ranged from 16.6% to 54.4 %, and the measured CO_2 concentration ranged from 629 to 3924 ppm. They explained that in all classrooms, natural ventilation was inadequate, resulting in very high CO_2 concentrations and inadequate heating problems in some units. In their 2007 study, Fromme, et al. [21] measured temperature, relative humidity, CO_2, PM10, and PM2.5 in 64 schools, 92 classrooms in the winter semester, and 75 classrooms in the summer semester. The measured CO_2 concentration was found to be 1603 ppm in winter and 405 ppm in summer. In their 2015 study, Sahin, et al. [22] measured CO_2, PM2.5, PM10, temperature, relative humidity, and noise in five primary schools with natural ventilation in Sanliurfa. The measured CO_2 concentration was above 1000 ppm in all seasons, and the measured temperature and humidity were outside the comfort range in October-December. They concluded that mechanical ventilation should be strengthened. According to ASHRAE Standard 55-2022 [23] and TS EN ISO 7730-2006 [24], factors to be considered when defining thermal comfort conditions are metabolic rate, clothing and insulation, air temperature, radiation temperature, wind speed, and humidity. These factors can vary over time. People who enter spaces that meet these standards may encounter different environmental conditions, and their sense of comfort may be different depending on the person and their activities. Therefore, thermal comfort is not easy to understand. Indoor ambient air temperatures should be between 23.5 and 28 °C in summer and 19 and 26.5 °C in winter. Uğuz, et al. [25] and Atmaca and Yiğit [26] In their study, thermal comfort was classified as an environmental and personal variable. Therefore, residential or workplace units should be built at different temperatures. In one study, measurements were made in a university building in March, May, and October-November 2017 through a specially developed intelligent sensor; CO_2, volatile organic compounds, formaldehyde, benzene, CO, $PM_{2.5}$, relative humidity, and ambient air temperature were measured. CO_2 has been found to be higher during periods of occupancy, with concentrations exceeding 2000 ppm. The results will be useful in the future for indoor air quality guidelines, ventilation design, and improving occupant satisfaction in buildings [27]. In one article, the 'modified weighted sum model', which is a multicriteria decision making method, was used as a methodology to decide on the appropriate dimensions of the option to determine the appropriate façade span of an elementary school class. The results of the analysis showed that the aperture orientation was more important than its size. The smallest aperture has been found to be better for visual, acoustic, and thermal comfort [28].

This study was carried out in a higher education class consisting of a maximum of 52 students. In this study, thermal comfort parameters such as air temperature, relative humidity, and CO_2 measurements were made in the fall semester. In the fall semester, measurements were made over 4 hours of course durations repeated twice a week for 14 weeks. The results were evaluated and compared between the measurement values, data from the literature, and the recommended health values. Such studies not only help determine the need for ventilation but also provide accurate information on the health and comfort of students in classrooms.

2. Materials and Methods

It is known that when the number of students increases, the amount of CO_2 in the same space increases, leading to a disruption in educational activities and the emergence of some health problems. This study aimed to examine this finding in a higher education institution with respect to the air temperature, humidity, and CO_2 parameters. The classroom was a computer laboratory with a capacity of 60 students. Measurements were made in the fall semester for 14 weeks. Air temperature, humidity, and CO_2 levels were measured twice a week, for 8 hours per week, during 50-minute class sessions. Measurements were taken 10 minutes after the start of class and ended 10 minutes before the end; each session lasted 30 minutes, and 300 data points were recorded, one every six seconds. The study period was chosen because it allowed for registration time and changes in class attendance. Data for the final 10 minutes of class were not collected, as many students leave the class early and the number of students remaining may not be representative of typical class occupancy. In addition, this allowed the data logger to adjust to changing occupancy levels in the room. The study focused on evaluating overall student behavior and participation without analyzing data based on gender.

Figure 1.
Data logger's computer recording screen image.

In this study, a data logger with the brand, model, and origin "HT2000 Communication Tool, TL-2000, Guangzhou, China" was used, respectively. The data logger can measure the parameters of air temperature, relative humidity, evaporation temperature, and CO_2, respectively (Figure 1). The data logger had software running on the computer, allowing for simultaneous monitoring and recording of the real-time data it was collecting. In the data logger, the year, month, day, and time parameters could be adjusted, as well as the air temperature (°C), relative humidity (% RH), dew point temperature (DP, °C), and CO_2 (ppm) parameters with the setting of the minimum and maximum values and voice warning. The technical characteristics of the device used in the measurements are as follows: Display: 3.5" (8.9 cm) liquid crystal display screen with backlight; Carbon dioxide range: 0–9999; Carbon Dioxide Accuracy: ± 50 ppm ±5% rdg (0–2000); Temperature Range: -10.0–70.0 °C (14–158 °F); Temperature Resolution: 0.1 ° C / °F; Temperature Accuracy: ±0.6 °C / ±0.9 °F (0–50 °C / 32 to 122 °F); others: ±1.2 °C; Humidity Range: 0.1–99.9%; Moisture Resolution: 0.1%; Humidity Accuracy: ±3% (10–90%); Log Memory: 40000. In the study, the audible warning level for CO_2 in the device was set at 1000 ppm. This level is generally accepted as a tolerance upper limit value with precaution. At the end of each measurement, all the data from the data logger was transferred to the computer in Excel file format. The minimum, maximum, and average values of all data exported to Excel have been calculated. Additionally, graphical images of the data were saved in an image format.

The dimensions and location of the measurement are shown in Figure 2. The height of the classroom from floor to ceiling is 2.87 m. The symbols used in the figure represent doors (d1 and d2), windows (w1, w2, and w3), the measurement point (mp), smart board (sb), white board (wb), and the trainer table (TT). The classroom was oriented at an angle of 62 degrees north and 28 degrees west, facing approximately northwest. The doors open to a corridors, and the layout of the classroom was oriented towards the southeast. The location of the measurement point, represented by mp in the measurements, was chosen as the closest location to the TT trainer table to minimize interference with the class in progress while ensuring that the measurement system's audible warning was triggered when the CO_2 level exceeded 1000 ppm. The voice prompt was turned off while the data recording continued to function. At the level of experiments, when CO_2 increased, the windows and doors of the classroom were opened, so the space was ventilated and the CO_2 level was reduced. After each measurement, the doors and windows of the classroom were opened to ventilate the environment. The classroom had 61 computers and a projection device. In experimental studies, the classroom heating system was disabled so that the temperature value of the environment was not affected and remained in its natural state. The exterior of the building was insulated, and the windows were double-glazed. There was only the heat from the computer and the number of students in the room at the time of the experiment. The activities of people in the measurement space served as the other acceptable heat source because the heating system was off at the time of measurement. There was no direct sunlight in the classroom.

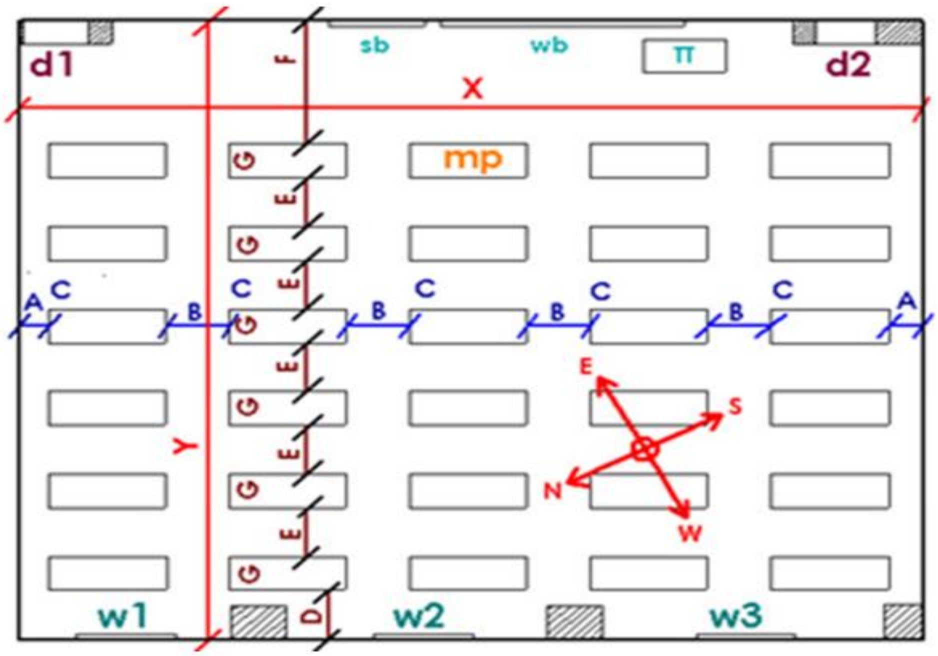

Figure 2.
Indoor dimensions.
Note: (X=13.84; Y=11; A=0.5; B=0.96; C=1.80; D=0.85; E=0.75; F=2.50; G=0.65; w1=w2=w3=1.51x1.51; d1=d2=0.92x2.15 meter).

As part of the experimental plan to obtain measurement data, all doors and windows were closed at the time of measurement, and their open/closed states were controlled according to the conditions outlined in Table 1, with doors completely closed and windows semi-open. In the study, the open/closed states of the doors and windows during the first eight measurements were used as the basic working conditions. This was because the doors, which have a larger opening than the windows, were completely closed.

Therefore, after the first eight measurements, the number of experiments was reduced. The class size on Mondays and Tuesdays was 63 and 31 students, respectively. Student participation in the course decreased during the first and fourth lesson periods. In a 4-hour class period, it was determined that the maximum number of students occurred in the second and third class periods. Therefore, when the class size was close to the full list, the second and third hours of lessons were targeted, and when the class size was smaller, experiments were carried out with a larger number of students on Monday and fewer students on Tuesday. The aim of performing an equal number of measurements on Mondays and Tuesdays was to examine the effects of a larger or smaller number of students on the measurement parameters. A total of 44 measurements were made, 22 on Mondays and 22 on Tuesdays.

Table 1.
Whether doors and windows are open or closed and the number of students' attendance.

Number of measurements	Doors		Windows			Monday (P)			Tuesday (S)		
	d1	d2	w1	w2	w3	Female	Male	Total	Female	Male	Total
1	KA	KA	AC	AC	AC	32	20	52	19	16	35
2			AC	AC	KA	26	18	44	20	6	26
3			AC	KA	KA	26	18	44	18	6	24
4			AC	KA	AC	30	20	50	18	6	24
5			KA	KA	KA	32	20	52	22	7	29
6			KA	KA	AC	28	17	45	18	6	24
7			KA	AC	KA	20	15	35	16	6	22
8			KA	AC	AC	28	17	35	20	6	26
9	KA	AC	AC	AC	KA	26	18	44	15	8	23
10			AC	KA	KA	31	16	47	22	6	28
11			KA	KA	KA	26	18	44	21	6	27
12			KA	KA	AC	26	18	44	14	5	19
13			KA	AC	KA	20	12	32	17	7	24
14			AC	KA	KA	31	16	47	22	6	28
15			AC	KA	AC	30	20	50	19	7	26
16	AC	KA	KA	KA	KA	31	16	47	22	6	28
17			KA	KA	AC	21	16	37	21	7	28
18			KA	AC	KA	22	16	38	23	7	30
19			AC	AC	AC	26	18	44	22	7	29
20	AC	AC	AC	KA	KA	22	16	38	17	7	24
21			KA	KA	KA	30	20	50	22	7	29
22			KA	AC	KA	19	12	31	17	7	24

Note: "KA" symbol's mean is window or door closed. "AC" symbol's mean is window or door open.

All measurements were completed during the fall semester on 15 measurement days at the appropriate times. Table 2 shows on which days the measurements in the measurement numbers column of Table 1 were made. The first digits appear in 5 columns labeled measurement numbers in Table 2, which indicate the number of measurements in Table 1, and the following letters indicate whether the measurement was made on Monday (P) or Tuesday (S). Between 1 and 5 experiments were performed on measurement days. This resulted in a total of 44 measurements, with 22 conducted on Monday and 22 on Tuesday. This information in Table 2 serves as a reference for the parameterized tables of measurement results.

In the space where people gather, whether doors and windows are open depends on personal needs. In the case of open or closed windows and doors given in Table 1, the evaluation of the measurements taken according to the number of people in the interior space could be carried out. The conditions of the external environment were stable and were also measured to account for the equalization effects when doors and windows were open. To conduct a measurement in the experimental study, many factors must be considered (such as the number of students, the open/closed conditions of doors and windows, and the preparation of the experimental measurement system).

To better assess thermal comfort, this study considered additional parameters beyond the experimental measurement data. These parameters are air velocity in the environment, clothing insulation, thermal sensation index, activity effects, and radiation temperature. However, no measurements were made for these parameters in this study. However, based on the experimental study environment, it can be assumed that the values of these additional parameters fall within the general assumptions given in the literature. These values are as follows: air velocity of 0.2 m/s, value related to winter clothing of 1 clo, thermal sensation index of +1 (slightly warm), activity effect of 60 W/m^2. It is significant to note that surfaces or objects with high or low temperatures in the environment can affect the radiation temperature and alter people's perceptions of comfort [26, 29].

Edelweiss Applied Science and Technology
ISSN: 2576-8484
Vol. 7, No. 2: 164-181, 2023
DOI: 10.55214/25768484.v7i2.406

Table 2.
Counterparts of measurement numbers on measurement days.

Measurement days	Number of measurements				
	1	2	3	4	5
1	5, P	-	1, P	-	-
2	5, S	19, S	21, S	-	-
3	21, P	4, P	15, P	-	-
4	22, P	13, P	-	-	-
5	7, P	-	-	-	-
6	8, P	6, P	-	-	-
7	7, S	6, S	-	-	-
8	2, P	3, P	11, P	9, P	-
9	11, S	14, S	10, S	16, S	-
10	16, P	14, P	10, P	-	-
11	4, S	3, S	8, S	2, S	-
12	18, P	20, P	-	-	-
13	9, S	13, S	20, S	22, S	-
14	12, P	19, S	17, P	1, S	12, S
15	15, S	17, S	18, S	-	-

Note: "P" symbol is Monday. "S" symbol is Tuesday.

3. Results and Discussions

3.1. Indoor Measurements

Data for the parameters of air temperature, relative humidity, and CO_2 measured indoors are given in Tables 3, 4, and 5, respectively.

Table 3.
Temperature measured indoor.

Measurement days	Averages of temperature measurements (°C)							
	1	2	3	4	5	Average	Min.	Max.
1	25.03	*	26.97	*	*	26.00	25.00	27.10
2	24.28	24.01	23.59	*	*	23.96	23.40	24.70
3	22.78	23.36	23.80	*	*	23.31	22,40	23.90
4	24.34	25.31	*	*	*	24.82	24.10	25.50
5	22.66	*	*	*	*	22.66	21.50	23.40
6	19.50	24.77	*	*	*	22.14	16.20	25.10
7	18.83	22.98	*	*	*	20.91	16.30	23.90
8	17.00	20.50	22.85	23.27	*	20.91	14.20	23.70
9	13.46	19.62	21.29	21.48	*	18.96	8.70	21.70
10	21.36	23.18	24.22	*	*	22.92	20.40	24.30
11	18.04	19.99	22.53	23.56	*	21.03	16.60	23.90
12	23.26	23.63	*	*	*	23.44	22.90	23.80
13	19.50	21.29	21.99	22.69	*	21.37	18.70	22.80
14	21.12	22.89	22.50	22.75	23.10	22.47	19.10	23.10
15	18.32	21.89	22.55	*	*	20.92	15.05	22.70

Note: Meaning of indicators (*); No experiments were conducted for their place in the table.

The 15 experimental days are shown in the first column, labeled measurement days. The data listed in cells 1–5, labeled as measurements and averages for a given day, are the arithmetic mean values of the respective measurements. Each measurement was made according to the design of the experiments. The data listed in the Average column are the arithmetic average of five measurements for a given day. The minimum and maximum data values for all data recorded by the data logger are also included in the tables

Edelweiss Applied Science and Technology
ISSN: 2576-8484
Vol. 7, No. 2: 164-181, 2023
DOI: 10.55214/25768484.v7i2.406

to observe the data change on the relevant days. For example, the minimum and maximum values for the average measurement of air temperatures in Table 3 are 17.00 °C (column 1 row day 8) and 26.97 °C (column 3 row day 1), respectively. In column Average, the minimum and maximum air temperature values are 18.96 °C (row day 9) and 26.00 °C (row day 1), respectively. The minimum and maximum air temperature values in column All data are 8.70 °C (line 9 of day) and 27.10 °C (line 1), respectively. Analysis of the average air temperature data in Table 3 with respect to the maximum and minimum values showed that the measured data are generally within the comfort range (between 19 ° C and 26.5 °C) defined in the literature [26]. Although temperature is not the only parameter that defines comfort, it is important to ensure that each comfort parameter is within the comfort range.

Table 4.
Measured humidity indoor.

Measurement days	**Averages of humidity measurements (% RH)**							
	1	**2**	**3**	**4**	**5**	**Average**	**Min.**	**Max.**
1	53.21	*	50.73	*	*	51.97	50.20	54.30
2	54.46	53.39	55.16	*	*	54.33	52.70	55.50
3	45.26	43.89	43.34	*	*	44.17	44.10	46.30
4	43.28	41.31	*	*	*	42.30	40.90	43.80
5	53.50	*	*	*	*	53.50	51.90	54.70
6	67.49	54.34	*	*	*	60.92	53.60	74.20
7	61.00	52.75	*	*	*	56.88	50.00	65.50
8	58.31	51.10	44.16	40.78	*	48.58	39.00	65.80
9	60.55	47.87	40.65	42.94	*	48.00	37.70	69.60
10	53.15	47.72	44.72	*	*	48.53	43.60	54.80
11	50.18	47.83	44.67	42.02	*	46.17	40.80	52.50
12	41.33	39.61	*	*	*	40.47	39.10	42.10
13	48.26	44.76	43.52	43.02	*	44.89	42.20	49.90
14	52.70	45.47	45.02	45.33	44.50	46.60	43.70	56.70
15	55.64	49.08	45.11	*	*	49.94	45.00	61.10

Note: Meaning of indicators (*); No experiments were conducted for their place in the table.

The minimum and maximum values for the relative humidity averages in Table 4 are 39.61% (row day 12 and column 2) and 67.49% (row day 6 and column 1), respectively. In column Average, the minimum and maximum humidity values are 40.47% (in row day 12) and 60.92% (row day 6), respectively. The minimum and maximum relative humidity values in the column All data are 37.70% (line 9 of day) and 74.20% (line 6 of day), respectively.

A comfortable environment generally has an ambient temperature of 20–22 °C and relative humidity between 40% and 50%. Some previous studies have found a relative humidity of 60% acceptable when the temperature is 24 °C. High humidity disrupts the physiological balance of the body and prevents natural sweating, which increases body temperature and leads to fever and heat stroke [26]. Furthermore, high humidity provides conditions conducive to the reproduction of mites and fungi. Low-humidity environments are known to provide suitable conditions for viruses and bacteria. Dryness in the air is a negative factor that can affect healthy individuals and, in particular, patients with respiratory illnesses [26]. When considering the relative humidity data in Table 4, the average data distribution obtained during the measurement was found to fall within the relative humidity values that are considered comfortable.

Table 5.
CO_2 data measured indoor.

Measurement days	Averages of CO_2 measurements (ppm)							
	1	2	3	4	5	Average	Min.	Max.
1	948.38	*	864.53	*	*	906.46	658.00	1039.00
2	833.69	564.74	704.55	*	*	701.00	549.00	1147.00
3	900.33	1177.45	1120.35	*	*	1066.05	873.00	1404.00
4	727.04	708.28	*	*	*	717.66	660.00	753.00
5	821.52	*	*	*	*	821.52	652.00	991.00
6	893.65	1021.28	*	*	*	957.47	785.00	1273.00
7	703.85	807.69	*	*	*	755.77	582.00	843.00
8	828.74	974.97	790.54	787.00	*	845.31	721.00	1049.00
9	614.19	657.54	641.01	827.01	*	684.94	543.00	915.00
10	918.41	768.02	755.94	*	*	814.12	629.00	1005.00
11	573.97	783.11	860.74	735.16	*	738.25	498.00	973.00
12	890.72	802.83	*	*	*	846.78	704.00	905.00
13	742.58	910.28	884.44	936.22	*	868.38	665.00	1019.00
14	809.94	643.50	637.42	722.41	671.41	696.94	561.00	883.00
15	645.91	860.50	848.11	*	*	784.84	529.00	898.00

Note: Meaning of indicators (*); No experiments were conducted for their place in the table.

In the CO_2 measurement CO_2 averages in Table 5, the minimum and maximum values are 564.74 ppm (row day 2 and column 2) and 1177.45 ppm (row day 3 and column 2), respectively. In column Average, the minimum and maximum CO_2 values are 684.94 ppm (line 9) and 1066.05 ppm (row 3), respectively. The minimum and maximum CO_2 values in all data are 498.00 ppm (line 11) and 1404.00 ppm (line 3), respectively. The increase in CO_2 levels in indoor spaces can adversely affect cognitive performance, even in healthy people. For those with previously diagnosed disorders and personal diseases, the increase in the concentration of CO_2 becomes more hazardous, and it has been explained that CO_2 levels of 800-1200 ppm should be discussed [5]. According to PrEN 15251-2006 [30] of the European Union, the acceptable upper limit may be 800 ppm higher than the outdoor CO_2 value in buildings. In most countries and in many studies, the accepted limit value is 1000 ppm below this level [20]. In the present study, 1000 ppm was accepted as a safety limit, and when this value was reached, although experiments were not stopped. When the warning was raised, the windows were opened, and the measurements were continued.

The data in Table 5 were analyzed from this perspective, and CO_2 levels as day averages were measured as data between the external environment and values greater than 1000 ppm. These measurements were made simultaneously with the measurement of outdoor CO_2 data.

3.2. Outdoor Measurements

Air temperature, relative humidity, CO_2, wind direction, wind speed, and precipitation amounts were measured in the outdoor environment (Table 6) [31, 32]. The outdoor measurement parameters for 15 experimental working days are shown in Table 6 as outdoor measurement data, and the measured values correspond to the same days and times when indoor measurements were made.

The minimum and maximum values of the air temperature averages were 4.06 °C (at day 9) and 25.70 °C (at day 4), respectively (Table 6). Outdoor temperatures represent the average values for Monday and Tuesday before and after noon, respectively. Although temperature measurements were made outdoors during the winter, they were found to exceed seasonal averages. The amount of total insolation level, wind, and precipitation on the relevant days also affected the measured values.

The minimum and maximum values of the relative humidity averages were 32.0% (on day 4) and 91.3% (on day 2), respectively (Table 6). When considering the general assumption that the relative humidity range for comfort is 40–60%, the humidity measured on 9 of the 15 measurement days was not within the comfort zone. However, this was acceptable because this was outdoor humidity and the measurement was carried out in winter. The relative humidity value of 32% (day 4) was below the lower comfort limit. Furthermore, although the current winter temperature is 25.70 °C, we determined that all measurements had a maximum temperature value.

Table 6.
Averages of outdoor measurement parameters.

Measurement days	Temperature (°C)	Relative humidity (% RH)	CO_2 (ppm)	Wind speed (m/s)	Wind direction (°)	Rainfall (kg/m²)
1	23.28	53.4	475	3.6	240	-
2	13.35	91.3	468	12.3	340	-
3	16.52	52.0	462	6.2	20	-
4	25.70	32.0	434	23.2	220	-
5	21.46	42.2	446	12.3	140	-
6	13.34	80.6	458	5.7	120	2.4
7	8.90	90.2	433	10.3	30	-
8	6.48	71.2	429	11.3	340	-
9	4.06	81.8	450	9.3	220	7.2
10	17.44	48.2	466	11.8	180	-
11	12.84	56.0	459	8.2	230	-
12	11.48	63.0	435	3.6	70	-
13	6.14	89.0	438	2.6	70	-
14	10.62	75.4	431	2.1	110	-
15	9.76	82.6	443	9.3	20	-

From the mean CO_2 values shown in Table 6, the minimum and maximum values were 429 ppm (day 8) and 475 ppm (day 1), respectively. CO_2 parameter was measured from outside the external environment, at a height of 12 m from the floor, from outside the windows. The CO_2 levels measured in the external environment are half the level of the reference limit values defined as hazardous. However, CO_2 is undesirable in the indoor environment, and its amount increases with the increase in the number of people in the environment, and exposure to it can adversely affect people's health. Therefore, outdoor CO_2 measurements are necessary to compare the amount of CO_2 generated indoors with the outdoor CO_2 concentration. We found that outdoor CO_2 concentrations were generally low, in accordance with previously published data.

The minimum and maximum measurement values of wind speed are 2.1 m/s (day 14) and 23.2 m/s), respectively (Table 6). The direction of the wind was determined based on the previous minimum and maximum wind speeds (according to the angle relative to the north direction), and it was found that it blows from 220 degrees southeast and 110 degrees northeast. Regarding the amount of rainfall, only two days of precipitation were observed, and the minimum and maximum rainfall (on day 6) were measured to be 2.4 kg/m² and (on day 9) 7.2 kg/m², respectively. The façade of the environment where the study was conducted on the outer periphery is in the north-west direction. Consequently, if one, two, or three windows are half-open, the indoor and outdoor environments will be equal. Due to strong winds, especially from the northwest direction, indoor and outdoor equilibrium states can be achieved more quickly. Consequently, when the wind directions were examined, it was determined that the winds were active at different speeds and on the façade side of the experimental environment that opens to the outside on the third, seventh, 15th, 12th, 13th, 2nd, and 8th measurement days.

3.3. Indoor measurements in Indoor and Outdoor Situations

This has an impact on the indoor air because of the variations in indoor measurements caused by open or closed doors or windows. In the cases shown in Figure 3, Figure 4, and Figure 5, three windows are always closed, and two doors are open or closed. In the cases shown in Figure 6, Figure 7, and Figure 8, two doors are always closed and three windows are half-open or closed. In all figures, the first and second vertical axes show the number of people and the variable values of one of the measured parameters (air temperature, relative humidity, CO_2). The horizontal axis shows the measurement numbers given in Table 1 and, additionally, whether the doors or windows are closed or semi-open. The first three bars from left to right show the participation numbers for Monday in the chart horizontally (P-female symbol), vertically (P male symbol), and diagonally (total symbol), respectively. The participation numbers for Tuesday are the fourth (S female symbol), the fifth (S male symbol), and the sixth (Total symbol), respectively. The symbols for indoor and outdoor measurements taken on Monday, when there are a lot of people indoors, are square and triangle, respectively. The symbols of the circle and cross, respectively, indicate the indoor and outdoor measurements taken on Tuesday when there are fewer people indoors. The numbers on the Y-axis represent the values of the indoor parameters on Monday, and those on the X-axis represent the values on Tuesday. The figures show the relationship between the number of people indoors and changes in the measured parameters.

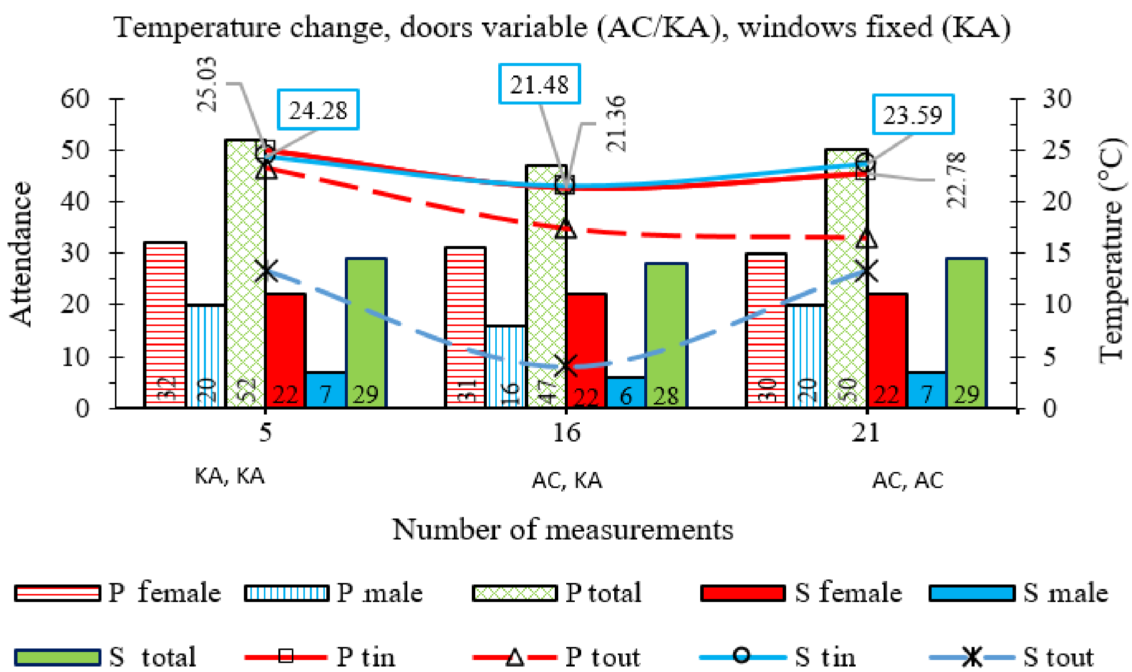

Figure 3.
Temperature measurements when windows are fully closed and doors are open or closed.

The air temperature data when the windows were completely closed but the two doors were open or closed is shown in Figure 3. Measurement numbers 5, 16, and 21 were measured on Monday and Tuesday. Maximum air temperatures were measured at 25.03 C on Monday in the class of 52 people and at 24.28 C on Tuesday in the class of 5 and in the class of 29 people in order of measurement, respectively. From the measurements, it was determined that the air temperature increased with the increase in the number of people indoors. Other measurements confirmed this upward trend. Outdoor temperatures on measurement days are lower.

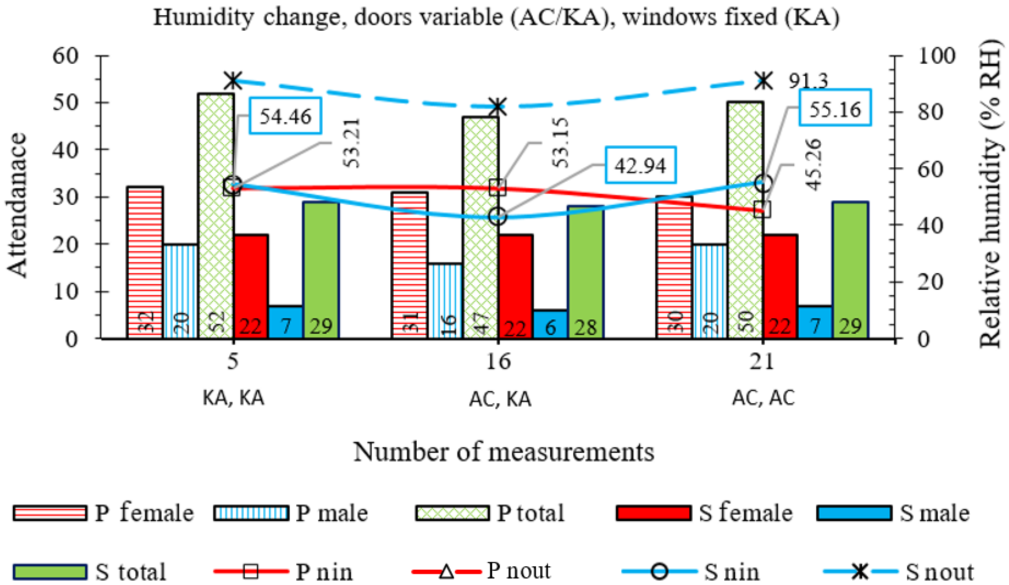

Figure 4.
Relative humidity measurements when windows are fully closed and doors are open or closed.

Relative humidity levels when the windows are completely closed and the two doors are open or closed are shown in Figure 4. Maximum humidity, measured at 5 in the number of measurements in the class of 52 people, was measured at 53.21% on Monday. On Tuesday, when 29 people were present, the maximum humidity was found to be 55.16% in 21. The external humidity measurement values on Mondays and the internal humidity measurements were close to the measured values. A large difference was obtained between the external humidity measurement values made on Tuesdays and the internal humidity measurement values. If there are parts of the interior environment that are open to the outside, a balance is formed between the humidity and temperature of the internal and external environments.

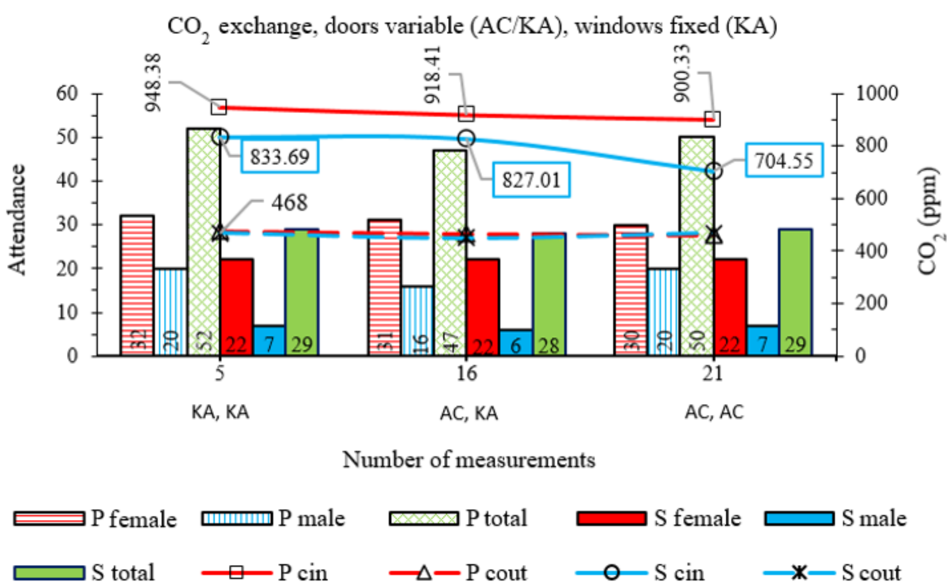

Figure 5.
CO_2 measurements when windows are fully closed and doors are open or closed.

Edelweiss Applied Science and Technology
ISSN: 2576-8484
Vol. 7, No. 2: 164-181, 2023
DOI: 10.55214/25768484.v7i2.406

The CO_2 concentration measured indoors was higher on Monday. A high CO_2 concentration was achieved in the class with a high number of participants. The CO_2 concentrations when the windows were completely closed and the two doors were open or closed are shown in Figure 5. The maximum indoor CO_2 concentration was measured at 948.38 ppm on Monday, when 52 people were present, in measurement number 5. On Tuesday, the number of people in the classroom was 29, the number of measurements was 5, and the maximum CO_2 concentration indoors was measured at 833.69 ppm. In the case of interior sections that are open to the outdoor environment, the measurement numbers are 16 and 21. Since a balance is formed in terms of parameters such as the pressure, temperature, and humidity of the indoor air, the CO_2 value of the environment has not increased with the number of people in the indoor space. For this reason, it has been seen that it is very important that the space be completely closed to the outside. In general, outdoor CO_2 concentrations measured on Monday and Tuesday are in the range of 400–500 ppm. Given the tolerable 1000 ppm limit, the number of people indoors and adequate ventilation are crucial to healthy breathing. In measurement number 5, the doors and windows are closed, and there are no thresholds under the two doors, although ventilation continues through these small intervals. When the amount of CO_2 exceeded 1000 ppm, windows and doors were opened, and the amount of CO_2 in the environment was not allowed to rise above the limit value. The measurement data show that the limit values can easily be exceeded when a large number of people are present in an unventilated environment.

In all indoor measurements, two doors were closed continuously, three windows were first completely closed (KA, KA, KA), and then one (KA, KA, AC), two (AC, AC, KA), and three (AC, AC, AC) were half open. In Table 1, the numbers 5, 6, 2, and 1 show the "order of measurement", while "Monday" and "Tuesday" show the measurement days. The air temperature, relative humidity, and CO_2 data are shown in Figures 6, 7, and 8, respectively.

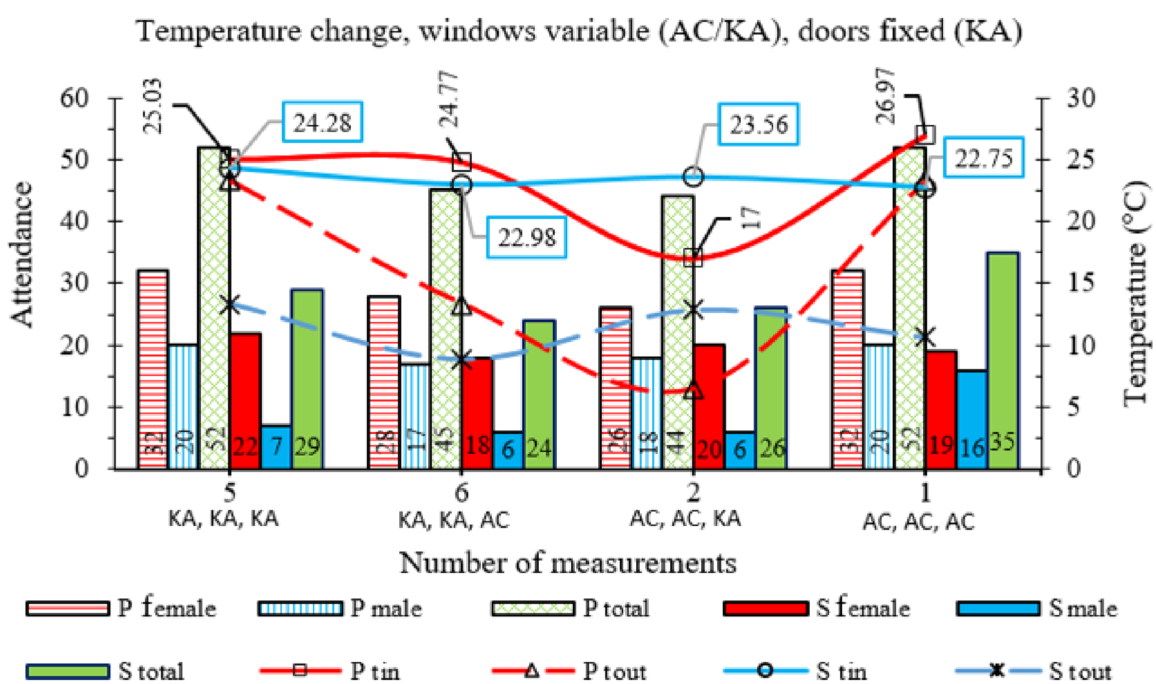

Figure 6.
Temperature measurements when doors are fully closed and windows are open or closed.

As shown in Figure 6, the air temperature on Monday, when 52 people were present indoors in measurement order 5, where all the openings to the external environment were closed, was 25.03 °C.

Furthermore, when 52 people were present indoors in measurement order 1, where all the windows were open, the maximum value of the air temperature was 26.97 °C on Monday. When the measured space was open to the external environment, the temperature of the external environment affected the measured values. The measured air temperature was lower on Tuesday due to the presence of fewer people, except for the order of measurement 2. There were 44 people indoors in Measurement Order 2. The lowest outdoor temperature on Monday was found to be 6.48 °C, and the indoor air temperature was measured at 17.00 °C due to the indoor space being open to the outdoor environment.

Figure 7 shows the relative humidity measurements when the windows are open or closed when the doors are closed. The indoor relative humidity values varied between 58.31% and 42.02% in all measurements performed on Monday and Tuesday, and this range is within the range defined as comfortable. As the amount of openness of a space to the external environment increases (such as 6, 2, and 1, for example), relative humidity affects relative humidity. On Tuesday, when the indoor space was completely closed off from the external environment, the outdoor relative humidity in measurement order 1 was 91.3%. The maximum and minimum outdoor relative humidity values on Monday were 80.6% and 53.4%, respectively.

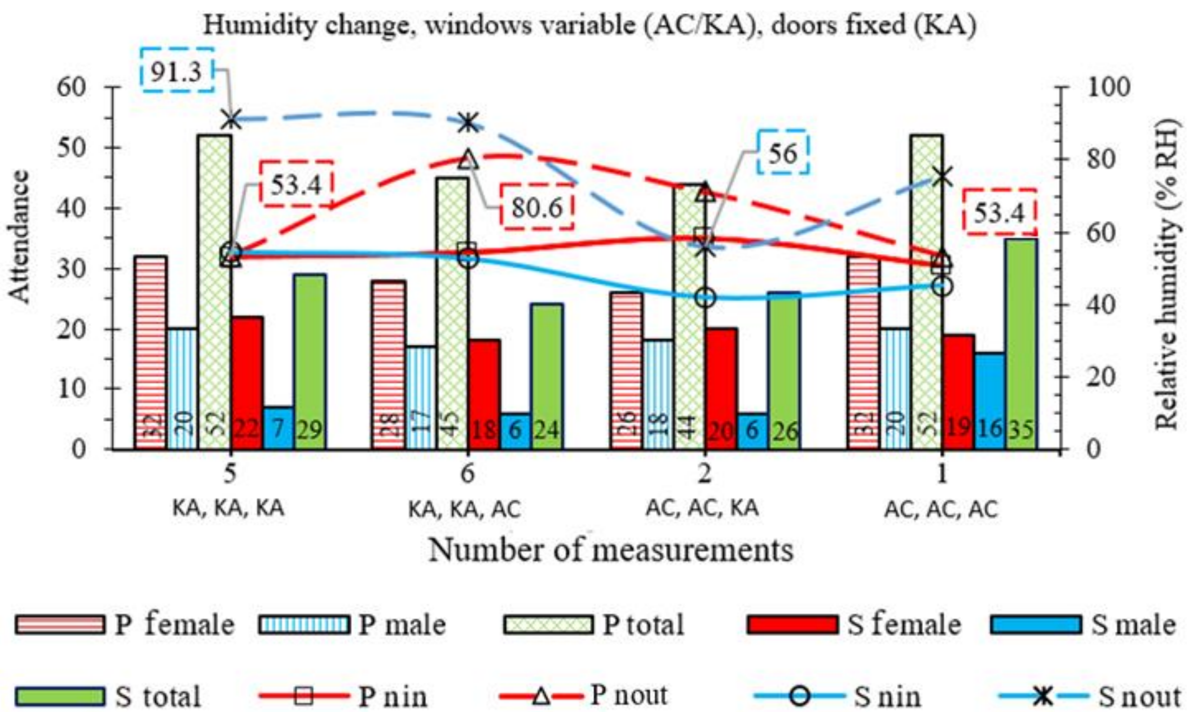

Figure 7.
Relative humidity measurements when doors are fully closed and windows are open or closed.

Figure 8 shows the results of the CO_2 measurements. The doors were completely closed, and the windows were either half open or closed. Indoor CO_2 concentrations on Monday, when there were a large number of people, were higher than those on Tuesday, when there were few people present. The concentrations in the space with a large number of people were close to the limit value.

In CO_2 concentration measurements, it was determined that 1000 ppm levels were reached in the classroom before the end of the course. Therefore, the fact that the place is completely closed to the outside and that there are students in the space for a long time is risky in terms of CO_2 concentration. In the case of open parts of the space (as seen in the measurement sequences 6, 2, and 1), it can be said that the change in the CO_2 concentration with the growth of the opening remains at lower levels due to the effort of the air in the interior to come into balance with the external environmental system. An example of this is the measured CO_2 concentration of 864.53 ppm in measurement sequence 1. In this case, since all the windows are half open even if the doors are closed, compared to measurement number 5, it can be defined as a completely closed space to the outside, despite the equal number of students in the space. Although the space is completely closed to the outside, on Tuesday, at measurement number 5, when there are 29 people in the class, the maximum CO_2 concentration was measured as 833.69 ppm.

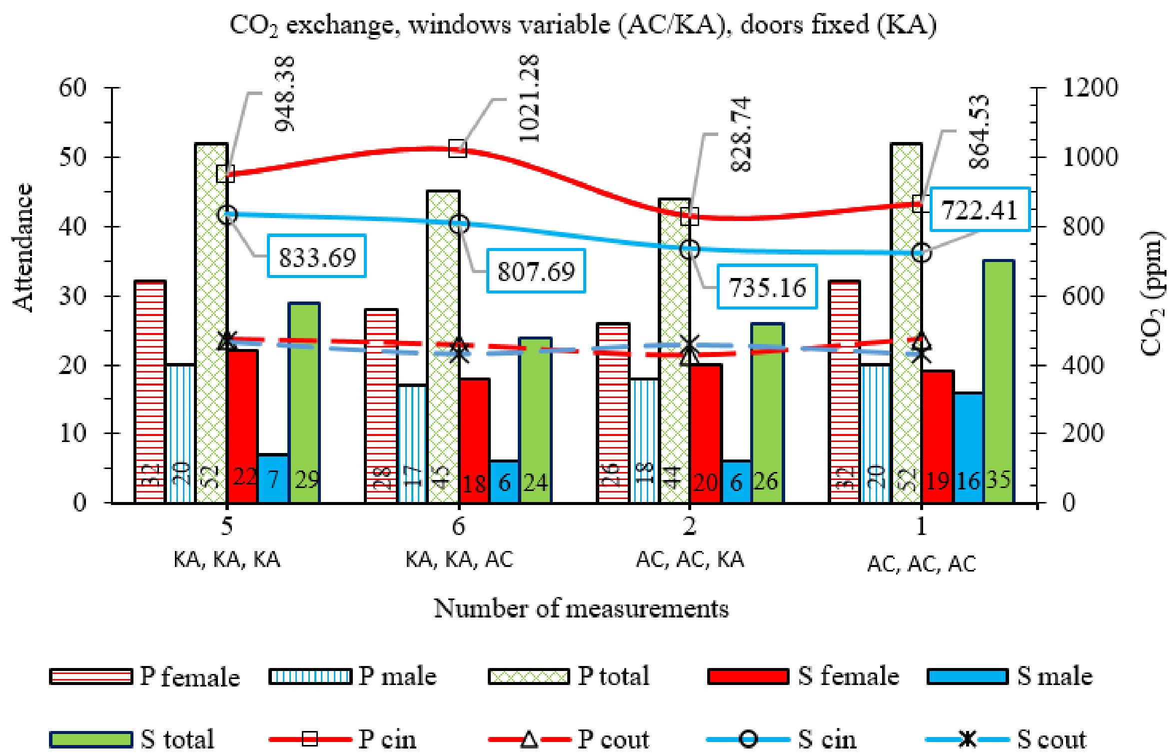

Figure 8.
CO_2 measurements when doors are fully closed and windows are open or closed.

In the measurements made on Tuesday, it was determined that if the parts of the closed area opened to the external environment increased, decreasing CO_2 values were obtained compared to the completely closed situation. In general, it was determined that the outdoor CO_2 concentration measurement values on Monday and Tuesday ranged from 429 ppm to 475 ppm.

4. Conclusions

Health issues brought on by an increase in CO_2 can disrupt education and training activities in enclosed, unventilated spaces where people reside.

As observed from the CO_2 measurements made in the study, the amount of CO_2 increases as the number of people in closed, unventilated spaces increases. In ventilated classrooms, CO_2 concentrations decrease according to the size of the ventilation opening. In Table 5, it was determined that the measurement values of the CO_2 concentration of values above 1000 ppm other than the average values were listed as 3, 6, 2, 8, 1, 13, and 10, respectively, from highest to smallest. The minimum and maximum concentrations were found to be 1404.00 and 1005.00 ppm. These values were reached at the time of measurement in the classroom, and the limit values were exceeded. In the first four of these values, even when the doors were closed as large openings and the windows were first one, then two-half-open, as small openings, the amount of opening was insufficient to obtain a lower CO_2 concentration in the class.

According to the results of the measurement of the mean CO_2 concentration (Figure 5 and Figure 8) and the findings, it is very important that respiratory health does not exceed the number of participants (35 people) in the Tuesday class when the class is completely closed.

Another reason why this number should not be exceeded is that the windows and doors are completely closed, the two doors are without thresholds, and the values are obtained with the presence of little ventilation between the classroom and the corridor section. Due to the high number of participants in the class on Monday, the CO_2 levels approached the limit value of 1000 ppm before the end of the lesson. These fully closed classrooms were determined to be unsafe for activities and needed mechanical ventilation. In indoor training, it is seen that the number of people who can be found with health inside can be determined as a result of a series of measurements, as in this study. The study can be said to be the CO_2 measurement; it will provide an understanding of the thermal comfort parameters, the presence of people in the space, and their activities, which will provide a more accurate assessment.

In this study, the measurement parameters were not independent of each other, and the classroom was completely closed. We recommend evaluating the open sections separately. In the case of a closed classroom, the temperature increases with an increasing number of people. In ventilated classrooms, air temperature and relative humidity are balanced due to heat exchange between the outdoor and indoor environments. In general, with regard to comfort parameters, the class in which the measurement is made can be controlled in accordance with the seasons, ensuring that the measurement values are within the desired ranges and that this is sustainable. In this study, the minimum and maximum values of air temperature and relative humidity on Mondays and Tuesdays ranged from 21.36 ° C to 26.97 ° C and 42.94% to 55.16%, respectively. We found that the values of air temperature and relative humidity in the classroom where measurements were taken remained within the limits determined as the comfort zone, as defined in the literature.

Issues that are out of the students' control include the circumstances in which they receive their education in schools, the suitability of the class's structural details for education, the number of students, and the instructor's method of instruction. By examining the concepts of thermal comfort and CO2 measurements, students are more likely to understand the lessons given in the classroom and obtain a more beneficial education. While this study did not examine the impact of the observed parameters on the number of men and women, it is possible to explore this relationship in a future study.

Funding:
This study did not receive specific financial support.

Institutional Review Board Statement:
Not applicable.

Transparency:
The authors confirm that the manuscript is an honest, accurate, and transparent account of the study; that no vital characteristics of the study have been omitted; and that any discrepancies from the study as planned have been explained. This study followed all ethical practices during the writing.

Competing Interests:
The authors declare that they have no competing interests.

Authors' Contributions:
Both authors contributed equally to the conception and design of the study. Both authors have read and agreed to the published version of the manuscript.

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