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Article

Exploring classroom temperature and humidity on students’ emotions through IoT and image processing

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Abstract: The quality of indoor classroom conditions influences the well-being of its occupants, students and teachers. Especially the temperature, outside acceptable limits, can increase the risk of discomfort, illness, stress behaviors and cognitive processes. Assuming the importance of this, in this quantitative observational study, we investigated the relationship between two environmental variables, temperature and humidity, and students’ basic emotions. Data were collected over four weeks in a secondary school in Spain, with environmental variables recorded every 10 minutes using a monitoring kit installed in the classroom, and students’ emotions categorized using Emotion Recognition Technology (ERT). The results suggest that high recorded temperatures and humidity levels are associated with emotional responses among students. While linear regression models indicate that temperature and humidity may influence students’ emotional experiences in the classroom, the explanatory power of these models may be limited, suggesting that other factors could contribute to the observed variability in emotions. The implications and limitations of these findings for classroom conditions and student emotional well-being are discussed. Recognizing the influence of environmental conditions and monitoring them is a step toward establishing smart classrooms.

Keywords: indoor environmental quality; temperature; humidity; students’ emotions; well-being; academic performance; smart classroom; Py-Feat

1. Introduction

Environmental factors can have a significant impact on students’ academic background (Abbas et al., 2023), which can influence students’ educational development, positively or negatively, and their future academic performance. Indeed, special emphasis is placed on the environmental conditions, since it is detected that they are influential in the teaching-learning processes and represent a relevant path for innovation in the classroom (Mogas-Recalde, 2021).

Many factors can influence students’ academic performance (Frontczak, 2011) but the indoor environmental quality (IEQ) of classrooms, including thermal, acoustic, and lighting conditions, can positively influence teaching and learning (Lee, 2010) and is linked to higher student satisfaction and perceived learning (Choi, 2014). Wang (2020) further supports these findings, indicating that a positive classroom climate is associated with improved academic and psychological outcomes for students. In this study we will focus on temperature and humidity, among other environmental parameters and its relationship with students’ emotions. The interest in studying the temperature and thermal comfort levels of educational facilities aims to improve the conditions of the indoor spaces in which both teachers and students spend a large part of their day (Chatzidiakou et al., 2012; Chen et al., 2018; Wargocki, 2019).

Beyond achievement, students' emotional experiences can be considered as relevant outcome variables in themselves, constituting important factors of student well-being (e.g., Goetz et al., 2003; Salovey et al., 2000). This is why understanding how temperature influences students' emotions is essential to promote their well-being, and knowing the relationship between temperature and emotions can help optimize the learning environment.

In the Brink's (2020) systematic review, postulated that although several standardized tests exist to measure short-term cognitive performance, just few methods were identified to measure the effect of IEQ on emotional response, as well as long-term physical health and academic performance; for that new methods should be developed to reveal the influence of actual and experienced IEQ on emotion, among other factors, in students and teachers. A different interdisciplinary approach such as ours, in which we explore the influence of temperature/humidity on emotions, using technologies such as IoT and image processing, could be the start to answer these knowledge gaps.

Beyond that, it may account for the importance of integrating technologies in learning environments, bringing us closer to a smart classroom in our context, in which all three levels work: environmental conditions (architecture, furniture, and environmental indoor factors), pedagogical process (contents, process of teaching and learning, systems support), and technology (hardware, devices, software, AI, IoT…) (Palau and Mogas, 2019). A tangible example is the implementation of Burunkaya and Duraklar (2022) for the measurement and control of environmental variables, using a smart classroom incubator (SCI). According to Moreno and Palau (2023) recommendations for the design and use of classrooms are formulated so that the agents involved in the creation, construction and shaping of these spaces are aware of the number of factors on which they can act to make these spaces stimulating, versatile, flexible, safe, comfortable and sustainable.

The influence of temperature/humidity on emotions and well-being

The study of classroom temperature and its consequences on well-being and performance was already present since the last century (see work by Earthman (2002), as well as other variables. For example, in 1931, the New York Commission on Ventilation established that when classroom temperature was not maintained between 19.4 ℃ and 22.8 ℃, more cases of illness were reported in students than when the environment was controlled.

Most authors agree that the thermal comfort of classrooms is reached when the temperature range oscillates between 20 ℃ and 26 ℃ (Muñoz, 2018). These data roughly correspond to the limits that Reza and Kojima (2020) propose for the comfortable and acceptable value (22–25.6 ℃). This coincides with the European Standard EN 15251 which places the temperature between 20 ℃ and 26 ℃ for a class II type building with a normal level of expectations, which would be an ordinary school.

The temperatures recommended by ASHRAE (American Society of Heating, Refrigerating and Air-Conditioning Engineers) assuming slow air movement (less than 12 m per minute) and an indoor relative humidity of 50%, range from 20.8 ℃ to

23.9 °C in winter and from 23.9 °C to 26.9 °C in summer. The difference in temperature ranges between seasons is largely due to clothing selection. ASHRAE also recommends that indoor relative humidity be maintained at or below 65% with no prescribed lower humidity limit (ANSI/ASHRAE, 2017).

Wang et al. (2016) insist on the idea that the environmental conditions of spaces determine their healthiness and comfort, being the temperature out of acceptable limits can increase the risk of discomfort and diseases, such as irritated eyes, tiredness, flu symptoms, or increased heat-related health symptoms in students (Bidassey-Manilal, 2016).

When students perceive thermal discomfort can lead to stress behaviours that affect their learning (Amasuomo, 2016). Both Wang (2017) and Kim (2017) highlighted the importance of a comfortable thermal environment for students, with Wang identifying appropriate design parameters for heating systems and Kim emphasizing students' preference for cooler temperatures and the use of air conditioning.

Experts agree that increased temperature has a negative impact on health, especially fatigue (Fujii et al., 2015). Temperature above what is recommended impairs learning by slowing down the pace of students in activities, who become more tired (Aparicio-Ruiz et al., 2021). Work performance is significantly affected by temperatures above 26 °C and low relative humidity levels, specifically below 40% (Gupta et al., 2018). Such as high temperatures, associated with high levels of relative humidity in the air, have been associated with increased fatigue in healthy people (González-Hidalgo et al., 2011), being fatigue, an important bio-alarm for health that contributes to the deterioration of the quality of teaching and generates sick leave among teachers (Leme and Maia, 2015). Similarly, Noelke et al. (2016), found in adults that temperatures above 21 °C reduce positive emotions (e.g., joy, happiness), increase negative emotions (e.g., stress, anger), and increase fatigue. Long-term exposure to high ambient temperatures in urban areas has been found by Younan et al. (2018) to be correlated with aggressive behaviours in children and adolescents.

For other hand, Uzelac et al. (2015) indicate that lower temperature and humidity enhance concentration, while Cui et al. (2013) relate temperature to motivation and performance.

The temperature continues to affect students indirectly, through teachers' perceptions. Evidence suggesting that thermal conditions in the classroom can negatively affect the mood and fatigue of teachers, which can influence the quality of teaching and cause a negative perception of the behaviour of students, who end up losing interest in class, asking to leave to drink water or go to the playground before the period established for it (Biondi et al., 2015). Similarly, Boix-Vilella (2021) found that indoor temperature and humidity, as well as the difference between outdoor and indoor temperature, can influence teachers' mood and worse perceptions of student behaviour.

2. Materials and methods

2.1. Participants

A total of 76 secondary school students from 6 different classrooms in an urban area in northeast Spain participated in this study. The average number of students participating per classroom was 24 with a range of 12 to 32 students per class. The students' age ranged between 12 and 16. Classes were approximately equally mixed by gender.

2.2. Data collection

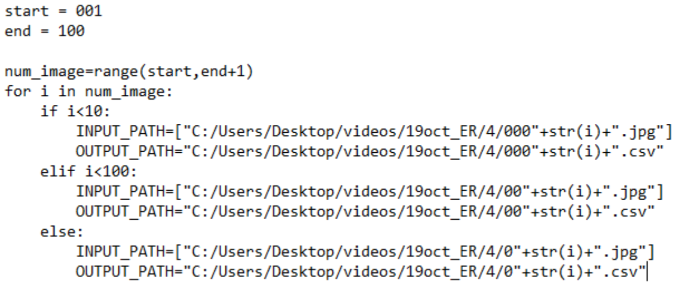
This study employed an exploratory observational design to collect environmental data, such as temperature and humidity, and to monitor the emotions of secondary school students across six different class groups over a four-week period. The experiment was conducted during the first term of the school year (September and October). Students of all classes were attending Technology subject or another subject related to technology, as SDG project (Sustainable Development Goals—Green project).

2.3. Ethics statement

The present study was conducted in accordance with ethical standards provided by the Ethics Committee of the Rovira i Virgili University (URV), with reference number: CEIPSA-2021-TD-0019. Prior to students' participation in the study, they read an informed consent in which the purpose, duration, and procedure of the research were explained. They were informed that their participation was voluntary. Moreover, data collection and analyses were done on anonymous data. Researchers gathered data during regular classroom hours. So, because this experiment involved contact with humans and before data collection, parents of all students in the school sign, as every course year, a consent form in favor or against their children being photographed or recorded.

2.4. Emotion recognition (ER)

Face detection, identification, and analysis of facial expressions were achieved using a sophisticated camera system and custom-developed software. The code was written in Python, a programming environment well-suited for handling image acquisition and processing tasks. Py-Feat, a high-quality and functional library, was selected for emotion detection in students attending the class. A custom script, incorporating various Py-Feat libraries, was crafted to evaluate student well-being through image analysis. As illustrated in **Figure 1**, this programmed code enables the video acquisition system to accurately identify basic emotions such as fear, anger, disgust, sadness, happiness, surprise, and neutral.



```
# parameter
start = 001
end = 100

num_image=range(start,end+1)
for i in num_image:
    if i<10:
        INPUT_PATH=["C:/Users/Desktop/videos/19oct_ER/4/000"+str(i)+".jpg"]
        OUTPUT_PATH="C:/Users/Desktop/videos/19oct_ER/4/000"+str(i)+".csv"
    elif i<100:
        INPUT_PATH=["C:/Users/Desktop/videos/19oct_ER/4/00"+str(i)+".jpg"]
        OUTPUT_PATH="C:/Users/Desktop/videos/19oct_ER/4/00"+str(i)+".csv"
    else:
        INPUT_PATH=["C:/Users/Desktop/videos/19oct_ER/4/0"+str(i)+".jpg"]
        OUTPUT_PATH="C:/Users/Desktop/videos/19oct_ER/4/0"+str(i)+".csv"
```

Figure 1. Sample code.

Before the experiment, the effectiveness and reliability of the Py-Feat library were evaluated through facial and Emotion Recognition (ER) tests administered to students in a classroom setting. The first day served as a trial during which the students were asked to modify their facial expressions to test the functionality of the code.

During various lessons, students were recorded by the laptop camera for data acquisition, with each session lasting from 50 minutes to one hour. The recordings were saved in MP4 format. The camera was strategically positioned to clearly capture both the front and the back of the class, maximizing the effectiveness of this imaging tool. All students within the webcam's field of view were included in the video. These videos were then uploaded to a Google Drive account. Subsequently, the videos were segmented into consecutive frames every 10 seconds, a process facilitated by specific coding that converted the frames into PNG files for further data analysis. Finally, a CSV file was generated containing all the emotions identified in each image, after which all images could be deleted.

2.5. Environmental kit

The environmental device used for this study is called ACTUA-041 kit and belongs to ACTUA project from the University Rovira i Virgili (URV), which started during the COVID-19 pandemic, in May 2021. The main goal of the project, which applies technology and data analysis, was to investigate the transmission of SARS-CoV-2 in school classrooms. Taking advantage of this background and technological tool, our objective is different and aims to provide the creation of a monitoring tool for contextual variables, and the creation of a data analysis infrastructure.

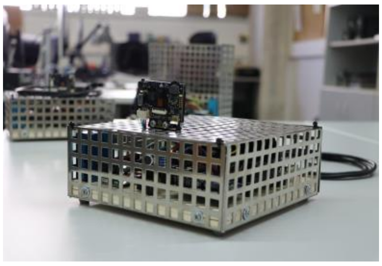


Figure 2. Monitoring kit.

The kit is a box of 20 × 20 × 10 cm, with a base made of wood and recovered by a perforated plate or aluminum mesh (**Figure 2**). The sensor kit contains a single board computer, called Raspberry Pi. Despite their small size, these boards can operate as a traditional computer, although they have a lower computing capacity. So, the kit contains a set of sensors that capture the contextual variables of the study: temperature and relative humidity. All these sensors are connected to the Raspberry Pi through cables inside the kit itself (Batista et al., 2023).

The kit was installed in the classroom, in a strategic point to control the parameters as efficiently as possible, and near the entrance door to provide the information about whether it is open or not. Continuously, every 10 min, the kit measures some variables, such as temperature and relative humidity, in order to monitor the conditions inside the classroom. The monitoring kit includes a thermometer that measures the temperature and the relative humidity with the hygrometer (**Table 1**).

Table 1. Kit features and precision.

Parameter	**Unit**	**Precision**
Temperature	℃	+/−1 ℃
Humidity	%	+/−3%

To measure classroom conditions, the project has developed a platform for monitoring contextual variables based on IoT, which facilitates the achievement and deployment of sensory systems with network connectivity capabilities, in addition to including physical characteristics of the classroom and its occupants (**Table 2**).

Table 2. Classroom environment variables.

Environmental parameters	**Characteristics**
Temperature	m^2
Humidity	height
Pressure	#doors
CO_2	#windows
Aerosols	heater
Ventilation	orientation
Sound	#students
UV light	
Mobility	

#May differ.

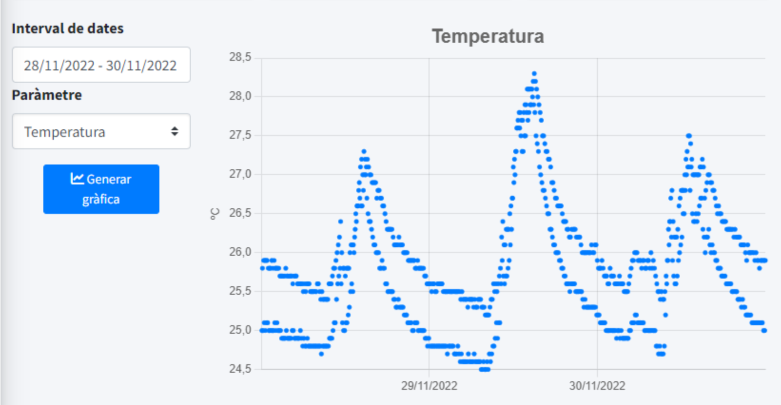

Interval de dates
28/11/2022 - 30/11/2022
Paràmetre
Temperatura

Figure 3. Graphic of the temperature variable.

This device sends the collected data every 8 h to the server through the Internet. All the information is stored in one database on the server, which also provides a web application to manage and visualize the system’s data (**Figure 3**).

3. Results and discussion

The descriptive results of the variables and inferential results are presented below. An initial correlation analysis was conducted to explore the relationships between the variables of interest. Subsequently, a regression analysis was conducted to examine in more detail the predictive influence of environmental, variables, temperature and humidity, on student emotions.

Temperature ranges between 27.5 ℃ and 30.6 ℃, with the median and mean coinciding at 29.8 ℃. Humidity ranged from 36.3% to 51.3%, with the median being 42.23 ℃ and the mean 43.04 ℃ (**Table 3**).

Table 3. Descriptive statistics of temperature and humidity.

Temperature		**Humidity**
Valid	16845	16845
Missing	0	0
Median	29.000	422.300
Mean	29.8471	430.440
S.E. Mean	0.0066	0.0277
S.D.	0.8592	35.914
Range	4.1300	147.100
Minimum	27.4900	366.100
Maximum	31.6200	513.200

Regarding the students' basic emotions, the presence of each of them is small, the most abundant being neutral emotion. The least present emotions are disgust, followed by anger; the rest of the emotions appear to a greater degree. All emotions follow a distribution of asymmetry to the right, meaning that many emotion scores are presented with no intensity or anything, while fewer emotions appear intensely. The descriptives table and graph can be visualized below (**Table 4** and **Figure 4**).

Table 4. Table of the values of emotions.

Descriptive statistics							
	fear	**ang**	**dis**	**hap**	**sad**	**sur**	**neu**
Valid	16,845	16,829	16,845	16,845	16,845	16,845	16,845
Missing	0	16	0	0	0	0	0
Mode	0.0061[a]	0.0011[a]	0.0007[a]	0.0122[a]	0.0076[a]	0.0023[a]	0.0127[a]
Median	0.1210	0.0096	0.0025	0.0557	0.1323	0.1624	0.1991
Mean	0.1440	0.1005	0.0160	0.1144	0.1703	0.2244	0.2305
S.D	0.1178	0.2056	0.0592	0.1522	0.1468	0.2062	0.1764
Skewness	15.169	26.516	83.400	25.140	13.559	10.881	10.993
S.E. Skewness	0.0189	0.0189	0.0189	0.0189	0.0189	0.0189	0.0189
Kurtosis	36.436	64.247	863.882	70.401	20.875	0.5368	12.320
S.E. Kurtosis	0.0377	0.0378	0.0377	0.0377	0.0377	0.0377	0.0377
Range	0.9897	0.9983	0.9621	0.9913	0.9429	0.9836	0.9831
Minimum	0.0001	0.0000	0.0000	0.0000	0.0001	0.0001	0.0002
Maximum	0.9898	0.9983	0.9621	0.9913	0.9430	0.9837	0.9833

[a] The mode is computed assuming that variables are discreet.

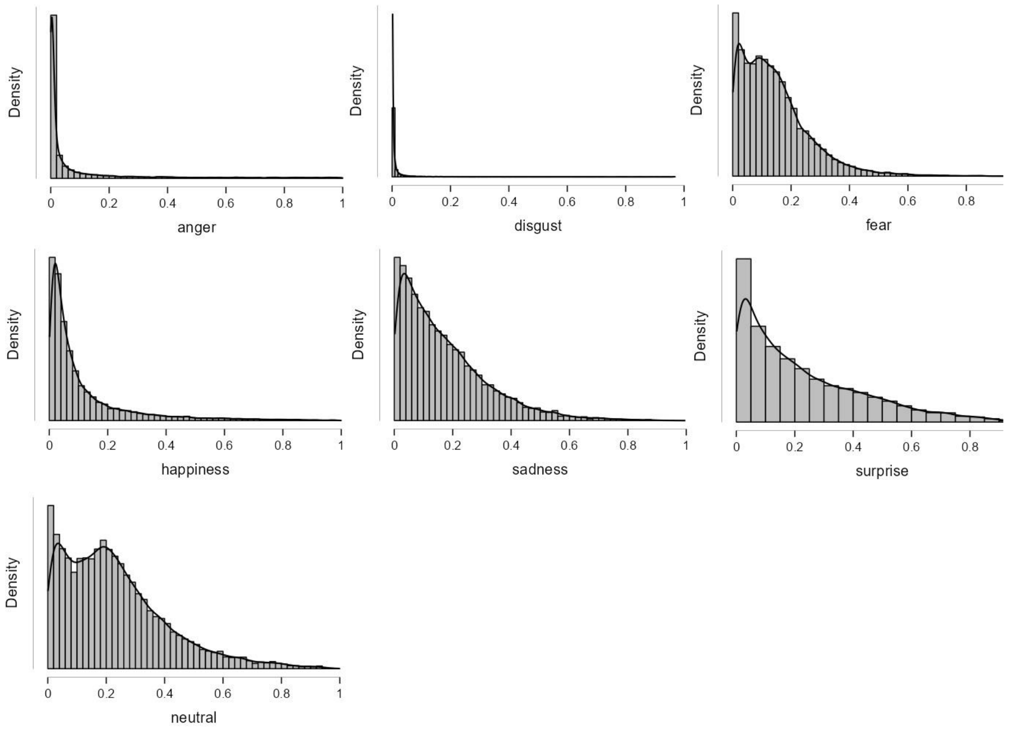


Figure 4. Distributions of emotions.

To determine whether there is a relationship between emotions and environmental variables, Spearman’s test was applied (**Table 5**). This non-parametric test was chosen because the emotion variables do not follow a normal distribution. For the purpose of clarity, we present the result of the significant correlations of the two variables, temperature and humidity with the emotions considered negative (fear, anger, disgust and sadness), and the positive emotions (happiness and surprise) with each other.

Temperature correlated significantly and positively with fear (0.0962, < 0.001) and sadness (0.069, $p < 0.001$), while negatively with anger (−0.1169, < 0.001) and happiness (−0.0312, < 0.001). Disgust does not correlate with temperature (0.0029, $p = 0.71$). Humidity correlates significantly and positively with anger ($r = 0.3005$, $p < 0.001$) and with disgust (0.0892, $p < 0.001$), and negatively with fear (−0.1876, $p < 0.0001$), sadness ($r = -0.2051$, $p < 0.001$) and surprise (−0.1033, $p < 0.001$). Meanwhile, neutral emotion correlated positively with temperature (0.0809, $p < 0.001$), and negatively with humidity (−0.1345, $p < 0.001$).

These significant correlations imply that the relationship between emotions and the two variables are unlikely to be due to chance. However, the strength of the relationship is small.

Table 5. Correlations among temperature/humidity and emotions.

Spearman's correlations									
Variable	**TEMP**	**HUM**	**Fear**	**Anger**	**Disgust**	**Sadness**	**Happiness**	**Surprise**	**Neutral**
TEMP									
HUM	−0.7496***								
	< 0.001								
Fear	0.0962***	−0.1876***							
	< 0.001	< 0.001							
Anger	−0.1169***	0.3005***	−0.3379***						
	<0.001	<0.001	<0.001						
Disgust	0.0029	0.0892***	0.0551***	0.5150***					
	0.7100	< 0.001	< 0.001	< 0.001					
Sadness	0.0690***	−0.2051***	0.4039***	−0.3103***	0.0021				
	< 0.001	< 0.001	< 0.001	< 0.001	0.7811				
Happiness	−0.0312***	0.0752***	−0.0390***	0.0420***	0.2120***	−0.1122***			
	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001			
Surprise	0.0217**	−0.1033***	0.0162*	−0.4544***	−0.3035***	−0.1758***	0.0294***		
	0.0048	< 0.001	0.0350	< 0.001	< 0.001	< 0.001	< 0.001		
Neutral	0.0809***	−0.1345***	0.0982***	−0.1814***	−0.2223***	0.1285***	−0.2449***	−0.0825***	
	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

Table 6. Summary of regression models for emotions.

Emotion	R^2	**RMSE**	***F*-statistic (ANOVA)**	***p*-value (ANOVA)**	**Covariates**	**Coefficient**	***T* value**	***p*-value**
Fear	0.016	0.117	139.574	<0.001	Temp Hum	−0.007 −0.005	−3.856 −12,398	<0.001 <0.001
Anger	0.063	0.199	564.123	<0.001	Temp Hum	0.028 0.019	9.577 27.166	<0.001 <0.001
Disgust	0.014	0.059	118.593	<0.001	Temp Hum	0.009 0.003	10.524 15.190	<0.001 <0.001
Sadness	0.034	0.144	299.588	<0.001	Temp Hum	−0.025 −0.011	−11.873 −22.434	<0.001 <0.001
Happiness	0.012	0.151	105.563	<0.001	Temp Hum	0.019 0.017	8.292 13.835	<0.001 <0.001
Surprise	0.011	0.205	89.501	<0.001	Temp Hum	−0.029 −0.010	−9.556 −13.279	<0.001 <0.001
Neutral	0.008	0.176	64.082	<0.001	Temp Hum	0.005 −0.003	2.016 −5.166	<0.001 <0.001

Below we briefly describe the results of the linear regression (**Table 6**). It is important to consider in the application of linear regression may be subject to certain methodological limitations that could influence the results interpretation. The regression model revealed that 1.6% of the variability in the emotion of fear was explained by the regression model ($F = 139.574$, p < 0.001). The model indicated a 6.3% explanation of the variability in the emotion of anger ($F = 564.123$, $p < 0.001$).

The variability in the emotion of disgust was explained by 1.4% by the regression model (F = 118.593, $p < 0.001$). The regression model could explain 3.4% of the variability in the emotion of sadness (F = 299.588, $p < 0.001$). The variability in the emotion of happiness was explained by 1.2% by the regression model (F = 105.563, $p < 0.001$). The 1.1% of the variability in the emotion of surprise was explained by the regression model (F = 89.501, $p < 0.001$). Finally, 0.8% of the variability in the neutral emotion was explained by the regression model (F = 64.082, $p < 0.001$). We highlight that temperature and humidity had statistically significant effects on the emotional responses of the students ($p < 0.001$), although in a limited way.

4. Discussion

The temperatures recorded in the classroom range from 27.5 ℃ to 30.6 ℃, considering that the measurement was taken in the beginning of autumn, and are not appropriate for an educational space. Exceeds the limits recommended by the European Standard EN 15251, the American Standard ASHRAE, and authors.

At this level, the consequences are negative for the occupants of the classroom. Students would present more discomfort and illnesses (Bidassey-Manilal, 2016; Wang, 2016), stress behaviors (Amasuomo, 2016), more aggressive behavior (Younan et al., 2018), fatigue (Aparicio-Ruiz et al., 2021; Fujii et al., 2015), also in teachers (González-Hidalgo et al., 2011; Leme and Maia, 2015), who would also perceive their students’ behavior worse (Biondi et al., 2015; Boix-Vilella, 2021).

Regarding humidity, between 36.3% and 51.3%, therefore, depending on the moment, it would not be comfortable when it is beyond 40%. Acceptable indoor conditions cannot be achieved without considering air quality, thermal comfort, acoustical comfort, and visual comfort holistically. Any alterations in these measures result in discomfort and reduced productivity in classrooms (Dorizas et al., 2015).

Regarding the significant and weak relationship between the emotions and the two variables studied, as well as the predictor variables have a relatively low weight in the explanation of variability in emotions, there are other variables that may be influencing on emotions. Temperature, which is high, correlated with fear and sadness, although they are considered negative emotions, we did not find in the literature information that studies precisely these emotions. Although there was no positive correlation between anger and temperature, we found anger to be the emotion that is most influenced by the two environmental variables examined, something that is consistent with Noelke et al. (2016) and Younan et al. (2018). On the other hand, humidity did correlate with anger and disgust, suggesting that humidity would have an influence than temperature on the emergence of these emotions. However, it behaved in the opposite way with fear and sadness, also with surprise, which would be a positive emotion in an educational environment.

Some of the results, could be explained because the association between weather and psychological changes usually have produced mixed results. For example, there are two factors than moderated the on the weather’s psychological effects, such the season and time spent outside (Keller et al., 2005); or some studies found a link between hot temperatures and cold emotions (Hsiang et al., 2013), while others did not (Hong and Sun, 2012). Relatedly, the underlying mechanism of the interaction between physical warmth/coldness and emotional warmth/coldness remains unclear (Huang et al., 2014).

Taking into account the infrastructure, the classroom studied, there is no air conditioning, as it usually is in the schools in the country. According to Muñoz (2017), in classrooms lacking temperature regulation systems, students may struggle to focus on their academic tasks due to extreme temperature changes in certain periods. This situation of high temperature in the classroom, on a constant basis, would require, among other things, adequate ventilation and air conditioning (Cohen et al., 2009).

Technology not only allows improvement of environmental conditions, but also enables transitions from traditional classrooms to smart classrooms. To achieve this, authors (Mogas et al., 2020; Mogas and Palau, 2021) encourage for research collaboration among educational centers, universities, and technology companies, along with increased involvement of the administration and technology partners in solution development, starting from considering the advantages of the smart classroom. Moreover, the figure of the teacher is crucial, since in a smart classroom he/she would receive real-time information about the environment and the students' variables, which need to be understood in order to make decisions to improve teaching and learning conditions (Unciti and Palau, 2023).

The importance of the study of thermal comfort is related to the relationship between occupant satisfaction in the built environment, but also, from another perspective, with building performance, and energy consumption (Zomorodian et al., 2016). This should consider for decision making by school management and educational administrations, especially with climate change.

As limitations of the study, we have focused on temperature and humidity, when in fact indoor conditions include CO_2, particles, lighting or noise. Related to this, a future line of research is to consider environmental variables holistically in the classroom for their influence on emotions, as well as to consider academic performance. Another limitation lies in the frequency of recording environmental variables, which is every 10 min. Although this time interval provides an overview of environmental conditions, it may not capture subtle variations or transient events that could have a significant impact on the learning environment. Therefore, a future line of research could focus on exploring more frequent recording time intervals. While our linear regression analysis provides valuable insights into the relationship between environmental variables and basic emotions, it's essential to acknowledge the limitations. Finally, linear regression assumes certain data distribution and linear relationship between variables, which may not be fully met in our data, potentially affecting the accuracy of our estimates. Additionally, linear regression can be sensitive to outliers or model misspecification, influencing result interpretation. Future research is encouraged to use complementary or alternative analysis methods, such as multivariate analysis or machine learning methods, to enhance our findings.

About the contributions, we explored the relationship between emotions and indoor environmental variables, in this case temperature and humidity, usually the studies are more oriented to academic performance. Another contribution is our approach involves developing and implementing a smart classroom technology through systematic observation in a natural setting, rather than relying on student perceptions or experimental setups. These aspects have covered lacks or suggestions from previous studies (Brink, 2020).

Finally, even though classrooms have not yet reached optimal environmental conditions, the fact of recognizing their influence on emotional well-being and implementing devices to measure and analyze them signifies the first step towards establishing smart classrooms.

Author contributions: Conceptualization, RP; methodology, GF; software, CL; validation, CL; formal analysis, GF; investigation, GF and CL; resources, CL; data curation, GF; writing—original draft preparation, CL and GF; writing—review and editing, GF, CL and RP; visualization, GF; supervision, RP; project administration, RP. All authors have read and agreed to the published version of the manuscript.

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