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Implications of indoor air temperature variation on the health and performance of Brazilian students

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Abstract

The aim of the present study was to evaluate the relationship between cognitive performance, health and environmental comfort as a function of indoor air temperature (T_a) variation. A total of 360 undergraduate students were subjected to the variation of the T_a at 20, 24 and 30 °C; their thermal responses were evaluated over three consecutive days. Performance variables measured in the study were cognitive performance, blood pressure, heart rate (HR) and comfort. The environmental variables measured were T_a, globe temperature (T_g), illumination, noise, airflow velocity and air quality. The variation in HR was influenced by the variables, relative air humidity and mean radiant temperature (T_{rm}) during the three days of observation, where HR was higher than 100 bpm when T_g was greater than T_a. T_{rm} increased proportionally to the increase in T_g, thus characterising heat exchange by radiation. The number of correct answers and test response time were also positively influenced by T_{rm} when T_a was 20 °C. Teaching environments (TEs) with increased heat load due to the individual body heat of students, increased outdoor T_a and urban morphology associated with the building of the TEs result in increasing in T_{rm} due to the T_g being higher than the air temperature, with possible impacts on health and performance variables.

Keywords

Environmental health, Performance, Cognitive test, Thermal comfort, Indoor air temperature

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Introduction

Humans are constantly subjected to actions from their environment. To maintain full functionality and to protect physiological functions, the body employs mechanisms that regulate its equilibrium. Hence, environmental variables, such as temperature, humidity, illumination, noise, airflow velocity and air quality, are considered conditioning factors of homeostasis, well-being, safety and consequently, the quality of the activities performed by individuals.[1]

The main objective of buildings in general is to provide healthy and comfortable environments for their occupants. People are estimated to spend an average of 90% of their time inside buildings, whether inside their homes, their place of work, school, stores, transport vehicles or other locations.[2,3] Therefore, the

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quality of the indoor environment – as the complex combination of variables such as thermal, visual and acoustic conditions, indoor air quality, electromagnetic fields, static electricity and vibration – is an important factor to ensure the health and well-being and quality of life of its users.

In the case of offices, the cost of human comfort is 100 times higher than the energy cost of buildings, which makes worker's job performance significantly important for the improvement of organisational productivity. Environmental conditions can have a greater influence on worker productivity than job dissatisfaction and stress levels, which justifies investments due to the advantageous and quantifiable cost–benefit ratio. Low air quality and high air temperature levels negatively affect performance in work environments.[4–7] Poor thermal conditions and indoor air quality could affect performance in office and school work.[8]

Special attention should be paid to the fact that external factors (aspects of urban morphology as the factor of vision of the sky; climate change) also could affect health and performance in both indoor and outdoor work environments. The mean temperature throughout Brazil is expected to be at least 3 to 6 °C higher in 2100 than at the end of the 21st century.[9] Temperature increases in areas of Brazilian regions due to climate change, combined with increased indoor heat load in the work environment due to the use of new technologies and the urban morphology of the Brazilian capital, generate the need to investigate to what extent changes in the air temperature of work environment could compromise performance and health. Furthermore, in regard to learning environments, positive teacher–student outcomes may be associated with cognitive factors and the satisfactory conditions of the teaching environment (TE).[10] Therefore, physical variables must be controlled to facilitate student well-being and good performance.

The regions of Brazil vary extensively in their thermal characteristics. The north region and the interior of the northeast region have mean annual temperatures higher than 25 °C, whereas the south and part of the southeast region of the country have mean annual temperatures lower than 20 °C. However, if Brazil experiences a temperature increase of 3 to 6 °C by 2100, such increases are expected to compromise the performance and health of individuals, such as students who perform their activities in climatized or non-climatized environments.[9]

In the context of student health factors, heart rate (HR) was considered of crucial importance for this study, given that HR is a physiological parameter that should be considered in workload assessments because it has a direct relationship with metabolic expenditure and heat load, as it reflects the vasodilatation and vasoconstriction processes. Because these processes are neural mechanisms that control changes in the circulatory system, they are important for core temperature control and the activity of the sympathetic and parasympathetic systems.[11–14] Thus, HR measurement is a promising tool for verifying the effect of the stress caused by adrenergic activation.[15–17] Furthermore, during the performance of a cognitive activity, HR also changes, being determined by the motivation to perform the task, anxiety and the task's degree of difficulty.[18]

Therefore, considering the changes occurring in work environments with the use of new technologies, the time spent by people in these environments, the growing urbanisation of cities and climatic changes, all of these aspects could compromise human health and performance throughout the workday.[19] Therefore, this study evaluates the relationship between performance and environmental comfort factors that influence the health of students from different regions of Brazil in TEs with video display terminals (VDTs) and subjected to changes in air temperature.

Productivity and thermal comfort

Chakraborty and Harper[20] emphasised the importance of measuring the impact of socioeconomic and environmental factors not only on the performance of teachers and students but also on school efficiency. Environmental variables such as thermal variables have been found to be important for the health and performance of individuals during activities in climatized environments.[21,22]

Niemela et al.[4] investigated the effect of high temperature in summer on the work productivity of two call centres. One of these centres had its temperature reduced with the installation of a cooling system. The productivity was monitored prior to and after the intervention. The study indicated a decrease in productivity for temperatures higher than 25 °C, at a reduction rate of 2.4% per °C.

There is a consistent decrease in human performance in typical office tasks with temperatures above 24–26 °C.[23] Lan et al.[13] analysed the consequences of thermal discomfort on performance in replicated office tasks, such as typing, addition and multiplication and in neuro-behavioural tests, while participants were subjected to two thermal sensations: neutral (22 °C) and hot (30 °C). The study presented a decrease in performance when individuals were subjected to 30 °C.[13]

Lee et al.[24] measured the relationship between indoor environmental quality (thermal comfort, air quality, illumination and noise) of university teaching rooms and the learning performance of engineering students. The study concluded that the environmental variables were correlated with complaints about learning performance. Out of 312 students interviewed, 261 demonstrated acceptance to the thermal environment, with 88% of the comfort votes ranging from –1 to 1 (from slightly cold to slightly hot).[24]

Tham and Willem[25] investigated the relationship between thermal parameters and the mental alertness of individuals through perceptual and physiological responses. The experiment was performed at three temperature conditions, 20 °C (moderately cool), 23 °C (neutral) and 26 °C (moderately warm), with each session lasting 4 h, where participants were subjected to a series of mental performance tests (arousal/alertness, concentration, creativity and reasoning). The highest thermal comfort levels were observed in the environment at the temperature of 23 °C. Under moderately warm conditions (26 °C), the participants exhibited lower alertness and performed better on speed and accuracy. The relationship derived from the participant's subjective perception votes on thermal comfort indicated the highest satisfaction at a temperature of 24.2 °C.[25]

Bakó Biró et al.[26] investigated the relationship between student health, well-being, performance and air quality in primary schools in Southern England. The study indicated a significant impact of the ventilation rate on school work performance, as performance levels on addition and subtraction increased by 5.1% and 5.8%, respectively, under improved ventilation, reaching up to 7% for students with higher mathematical skills.[26]

Warm climate and health

Changes in cities have led to reflections about urbanisation and the quality of life of the population. Urbanisation causes changes in meteorological variables with thermal influences on the human body and tends to aggravate the effect of heat waves. Climate changes could contribute considerably to these problems and are therefore expected to affect functionality in daily routine and health, which should be considered from an integrated and multifactorial perspective, relating it to physical, mental and social well-being, along with the cultural, economic and political dimensions that may favour the creation of a health-promoting environment.[5,27,28]

Constant growth in cities could generate future problems associated with cardiovascular and respiratory problems during the hottest times of the year. Harmful impacts could also affect behaviour, work performance and sports performance.[28]

The physiological foundation of the effect of heat on humans is well known. However, the pathophysiology of heat exhaustion and heat stroke still requires further clarification. When the internal body temperature exceeds 37 °C, the risk of heat disorders increases. Internal temperatures higher than 38–39 °C could lead to heat stroke and failure of the central thermoregulatory system. The temperature increase causes an increase in HR, peripheral blood flow and sweating. Its consequences to health can be mild, such as dehydration, headache, cramps and rashes, or more severely, such as reduced performance and work capacity, cataract, cardiovascular and respiratory diseases, renal failure, immune system weakness, heat shock and death.[27–31]

In addition to changes caused by heat, the body can experience stress due to different factors, such as performing physical or cognitive activities. This stress induces physiological reactions that prepare the body for fight-or-flight situations, which are cardiovascular, hormonal, neurological, metabolic and muscular changes due to activation of the sympathetic system and reduction of parasympathetic control (Figure 1). Chronic exposure to stressors can lead to overload and exhaustion of the physiological systems.[15,32] Specifically concerning the cardiovascular system, chronic exposure to

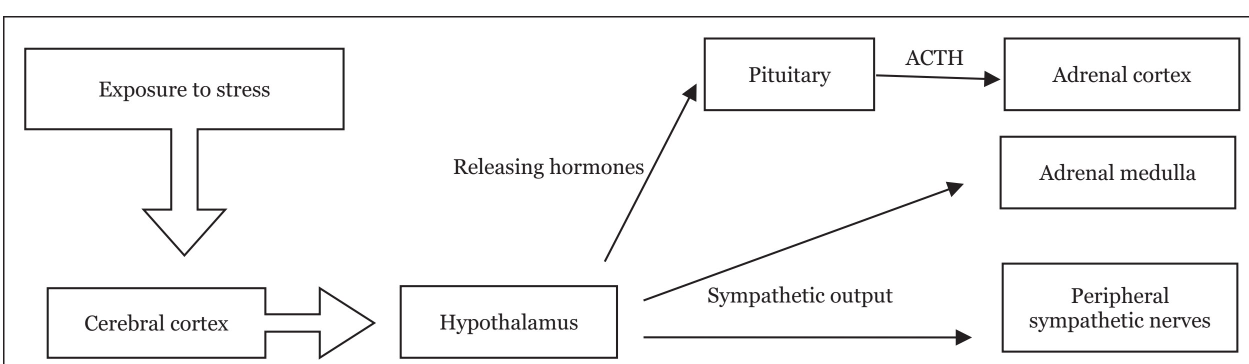

Figure 1. Responses to physiological stress.[34]
ACTH: adrenocorticotropic hormone

stress can cause heart diseases such as coronary disease, hypertension, myocardial ischaemia, arrhythmia, cardiomyopathy and myocardial infarction.[33]

The perception of stress stimulates the hypothalamus, which, through the anterior pituitary gland, promotes the secretion of adrenocorticotropic hormone. This hormone acts on the adrenal cortex (kidneys), initiating the synthesis and release of glucocorticoid hormones, promoting the mobilisation of stored energy. The perception of stress also activates preganglionic sympathetic neurons in the spinal cord, which project to pre- or paravertebral ganglia, which in turn project to the target organs, including the heart and the adrenal medulla.

These physiological changes are influenced by the type of activity performed. The physiological state has a direct impact on the autonomous nervous system, thus affecting cardiac control.[32] Solving mental tasks could affect many psychophysiological variables, particularly those related to the beta-adrenergic system, such as the pre-ejection period and systolic blood pressure. Moreover, mental tasks evoke additional heart activity and increased HR, especially in difficult tasks when compared with easy or impossible tasks.[18]

The effects of exposure to air temperature on the cardiovascular system have drawn much attention from researchers, as there is a relationship between cardiovascular diseases and environmental conditions (temperature and air quality).[31] During heat stress, there is an increase in the demands of the cardiovascular system, as due to peripheral vasodilatation and fluid loss, the central blood volume is reduced. This volume decrease is compensated by an increase in the HR to maintain cardiac output. These changes can decrease physical work capacity and affect cognitive performance.[29,30]

Environmental factors include heat, which is promoted by the outdoor and indoor conditions of the work environment. Increase in the intensity of this factor along with other aspects of the workplace could have implications on worker's health. Low vascularisation areas, such as the eyes and temples, are at a greater risk of being damaged by the heat. The eyes are considered very critical organs in the context of the effect of non-ionising radiation, being highly susceptible to the effect of heat. Relatively small amounts of electromagnetic energy could increase the temperature of the eye lenses because they do not contain adequate vascular systems for heat exchange, which in turn reduces their heat dissipation capacity. Thus, the possibility of eye damage is a very serious aspect of microwave and radiofrequency radiations. Consequently, high temperatures associated with large heat loads in TEs containing VDTs can promote a greater heat intensity in the environment, which could affect the health and performance of students.[19]

Methods

The study was performed in TEs with VDTs in the northern, northeastern, central-western, southeastern and southern regions of Brazil, to ensure the homogeneity of variables that could affect the sensation of comfort of individuals, such as age group, weight, height, diet, metabolic rate and clothing type. This study was performed in university classrooms, each with approximately 20 students. In total, 18 TEs were evaluated during 2014 and 2015, in the winter and summer.

Sample

In total, 360 engineering students aged 18 to 30 were evaluated. The participants were mostly male (70%), self-reported good overall health status and a signed free and informed consent form. Students who could not correctly fill out the required information, those who were not present during the three days of study and those who had blood pressures higher than 150 mm Hg on some days of the study were excluded.

The students who participated in this study were from different regions of Brazil, where the respective climates are: (1) wet equatorial, which includes the Amazon; (2) alternating wet and dry tropical, comprising a large part of the central area of the country and the mid-north coast; (3) tropical, tending to be dry due to irregular air masses, comprising the northeastern hinterlands and middle valley of the São Francisco river; (4) coastal wet climate, exposed to maritime tropical masses and encompassing a narrow strip of the eastern and northeastern coast and (5) wet subtropical climate of the eastern and subtropical coasts, widely dominated by maritime tropical masses, encompassing the south region of Brazil.

Variables and indicators

Because the experiment was performed in climatized TEs, physiological parameters, environmental comfort variables and cognitive performance variables were selected for analysis. Table 1 presents the studied variables and their respective indicators.

Personal variables

Blood pressure and HR were assessed prior to and after the cognitive tests with an OMRON HEM-7220 (manufactured by OMRON HEALTHCARE INC, has a pressure measurement range of 0 to 299 mmHg and a measurement error of 3 mmHg) automatic arm blood pressure meter, validated according to the international protocol of the European Society of Hypertension (60). In addition to the blood pressure meter, a POLAR FT7 (manufactured by the company POLAR, has a

Table 1. Study variables and indicators.

	Variables	Indicators
Comfort parameters	Personal	Age (years old), gender, heart rate (bpm), blood pressure (mmHg)
	Environmental	Air temperature, Ta, (°C); Mean radiant temperature, T_{rm} (°C); Relative air humidity, RH (%);
Subjective parameters	Thermal sensation Thermal evaluation	7-Point scale of perception and preferences of ISO 10551/1995 standard
Performance	Reasoning	Number of correct answers and response time (BPR-5)

measurement range of 30 to 199 bpm and a measurement error of 1 bpm) heart rate monitor was used to monitor the HR of students during the cognitive test prepared based on the Battery of Reasoning Tests 5 (BPR-5).

Students' weights were measured using a digital weight meter G. tech BALGL10 model (manufactured by ZHONGSHAN CAMRY ELETRONIC CO., LTD) with a Visor LCD, 150-kg capacity and a 100-g variation. Students' heights were measured using a Sanny standard stadiometer for height measurement. Their body mass indexes (BMIs) were calculated using the two previous measurements.

Regarding the determination of the equivalent thermal resistance of the clothing indicated by each student during the test, the calculation was based on the thermal insulation table from the International Organization for Standardization.[35] The metabolic rate was standardised at 70 W/m^2 according to the type of activity.[36,37]

The HR measured by the heart rate monitor was recorded in the device and transferred via software to an electronic spreadsheet. Before starting the cognitive test, the heart rate monitor was placed on the student. The chest strap was placed below the nipples and adjusted with an elastic band so that the contact areas located on the back were in direct contact with the skin of the person and would not come loose during the measurement. The heart rate monitor was activated at the start of the test.

The maximum HR and mean HR recorded during the measurement period were calculated. These data were directly transferred to the computer using the Polar Web Sync program (supplied by the company POLAR, as software before the blood pressure meter POLAR FT7). Thus, the initial and final HRs (HR_{rest} and HR_{final}) measured by the blood pressure meter were considered, along with the maximum and mean HRs ($HR_{maximum}$ and HR_{mean}) recorded by the heart rate monitor.

Environmental variables

The measurements of the environmental variables air temperature (T_a), wet-bulb temperature (T_{bu}), globe temperature (T_g), mean radiant temperature (T_{rm}) and airflow velocity (Va) were collected using a TGD300 heat stress meter (manufactured by Instrutherm, has a measuring range of –5 to 40 °C and accuracy of 0.5 °C) and a BABUC microclimate station, which recorded data by creating a local file. The equipment met the requirements of standard[38] and was properly calibrated by reference certified agencies, in this case the National Institute for Space Research at Rio Grande do Norte (Instituto Nacional de Pesquisas Espaciais – INPE-RN).

The TGD300 heat stress meter and the BABUC microclimate station were set up in the middle of the experiment room, 60 cm from the ground (floor).[38] Individual measures were taken for each day and class, and the mean of data recorded during the experimental period was calculated. The equipment was programmed to record measurements every 1 min, from the moment when students entered the classroom.

Lighting was measured using a Phywe lux meter (manufactured by Phywe, has a measurement range of 0 to 300,000 lux and an accuracy measurement of 3%).[39] The environmental noise level was measured using a Bruel & Kjaer 2250-L manual sound analyser (manufactured by Bruel & Kjaer, has a measuring range of 16.4 to 140 dB and accuracy of 0.2 dB), following the principles of the Jorge Duprat Figueiredo Foundation for Safety and Occupational Medicine.[40] The air quality was measured using a Fluke 983 air particle counter (manufactured by Fluke) according to the principles of the Brazilian Association of Technical Standards.[41]

Subjective parameters

The subjective parameters, such as the thermal sensation and thermal preference of students, were obtained with the application of a questionnaire based on 7-point scales of thermal perception and preferences,[42] described in Table 2. In addition to this questionnaire, the students also answered questions related to their lifestyle, clothing and overall health conditions.

Table 2. Scale of thermal perception and preferences.

Scale	Description
–3	Hot
–2	Warm
–1	Slightly warm
0	Neutral
1	Slightly cool
2	Cool
3	Cold

Cognitive performance

To test the cognitive performance of students, an adapted version of the Reasoning Test Battery 5 (BPR-5)[43] with the same difficulty level was applied. The BPR-5 is an instrument that tests general cognitive function and is used by experts to assist, for instance, in psychodiagnostics, in the selection of professionals or in school evaluations.[43] The skills evaluated by these five tests that compose the instrument are abstract reasoning (AR), verbal reasoning (VR), spatial reasoning (SR), numerical reasoning (NR) and mechanical reasoning (MR). The questions were randomly distributed for application over three days to avoid repeating the questions on the other days. At the end of the experiment, the response time and number of correct answers were calculated for these tests on each measurement day. The tests were randomly distributed so that each student completed one test every day; at the end of the study period, all three tests were completed.

Ethical aspects

The study was registered in the Brazil Platform (Plataforma Brasil),[44] evaluated and approved by the Research Ethics Committee of the Federal University of Paraíba (Universidade Federal da Paraíba – UFPB), CAAE no. 57844916.9.0000.5188. The students who participated in the experiment were individually informed about the scope of the study and formalised their participation by signing the Free and informed Consent form, based on resolutions 196/96 and 466/2012 of the National Health Council.

Experimental procedure

In a previous session, students were informed about the aim of the study and types of questionnaires they would complete. The nature of the reasoning test questions was explained, and any questions about the study methodology were addressed. Those who agreed to participate in the study were instructed to arrive on a pre-determined day and time in the Laboratory of Informatics of the institution.

The experiment was performed over three consecutive days, during which the air temperature was adjusted to 20, 24 and 30 °C, according to the International Organization for Standardization[45] and American Society of Heating, Refrigerating and Air-Conditioning Engineers.[46]

During the first day of the experiment, students signed the free and informed consent form, and data such as weight and height were collected.

Before starting the cognitive test, students spent some time acclimatizing the room environment (20 min), and their blood pressure and HR were then measured. The heart rate monitors were placed at the height of the xiphoid process, and the watch was placed on the left arm. After the device was placed, the students were instructed to activate the recording on the POLAR FT7 device and to start answering the online questionnaire. At the end of the questionnaire, the participants deactivated the device, and new blood pressure and HR measurements were taken. The procedure was repeated on two subsequent days.

To answer the online questionnaires, students used desktop computers. The test battery was accessed online, with the link for each test day available only at the time of the testing, preventing participants from learning the questions prior to taking the test. At the end of the cognitive test battery (BPR-5), the participants answered questions related to their diet, environmental comfort and life habits.

Data analysis

After the data were collected, they were organised in tables in Microsoft Excel and prepared to be used in R software, where graphs were plotted, the probability distribution and correlations were analysed, and mathematical models were developed.

To explain the relationship between the variables, the Generalized Linear Model (GLM) class was used, given that this class of model synthesises and expands the possibility of modelling the response variable.[47] The class of model allows the explanatory variables to be both metric and non-metric, and the dependent variable should belong to the exponential family of distributions. The GLM structure was built with the independent variables y_i (personal and performance variables). The probability distribution function of the exponential family of each y_i is formalised by equation (1)[48]

$$f(y_i, \theta_i) = \prod \exp\left[y_i b(\theta_i) + c(\theta_i) + d(y_i)\right] \quad (1)$$

where $b(\theta_i), c(\theta_i), d(y_i)$ are natural parameters of the f distribution and θ_i is the parameter of this. Hence, the model was built with the monotone link function

$g[E(y_i)] = X_{iT}\beta$, where X_i is a vector whose components are the explanatory variables (environmental variables). The g function is the expected relationship between y_i and X_i, which could be represented by the linear and nonlinear link functions, and this difference depends on the probability distribution of each y_i.

Results and discussion

This study evaluates how environmental comfort variables, determined by perceptions, are related to the performance and the health of students (the percentage of male subjects was 68.59% and of female subjects was 31.41%) in TEs with VDTs during the performance of cognitive tasks, where the air temperature was set at 20, 24 or 30°C, over three consecutive days, according to the International Organization for Standardization[45] and American Society of Heating.[46]

Some peculiar aspects during the experiments resulted in some observations. The air in the TEs with VDTs did not contain pollutants in harmful concentrations for health, as particulate matter PM_{10} did not exceed 50 μg/m^3, which was considered satisfactory by more than 80% of students, thus corroborating the principles of Standards.[49] The recorded noise levels were approximately 50 dB(A); only two environments presented noise levels of 52 dB(A), which is satisfactory according to the Brazilian Association of Technical Standards.[49] The relative airflow velocity was approximately 0.10 m/s and, therefore, constant.

In turn, the T_g of most environments was higher than the air temperature, and in some environments, this difference was greater than 2 °C. This increase could be associated with different factors, such as the following. (1) Characteristics of the urban morphology of certain Brazilian cities: Some of the TEs were located in neighbourhoods considered as heat islands, which contributes to the increase in the indoor heat load of built environments.[50] (2) Use of new technologies in TEs: These environments contain equipment that increase the indoor heat load, such as VDTs, desktop computers, laptop computers, wireless systems, air conditioning systems, lighting systems, printers and video projectors, in addition to heat load from students. (3) Outdoor temperature increase: Some Brazilian cities, especially during the summer, have temperatures of approximately 40 °C. In the city of Teresina, for instance, located in the interior of the northeast region, during the data collection period, the outdoor humidity and wind speed were low, causing a thermal sensation of four to five degrees above the actual temperature, i.e. 45 °C, according to the city's Office for the Environment. Therefore, these factors are likely to contribute to the increase in the indoor heat load. Hence, the mean radiant temperature (T_{rm}) variable, which represents the effect of thermal radiation, was adopted as an important thermal variable in this study because it can be used to evaluate the effect of the cooling or heating of the TE.

Due to the characteristics of the activity performed by students during experiments using VDTs, which demands visual comfort, visual effort and visual safety, the illumination variable is very important in this study. However, the illumination was found to be within the acceptable range, between 200 and 500 lux.[39] During the experiments, even in the winter, many regions of Brazil recorded high temperatures, with the relative air humidity ranging from 21% to 30%, which is concerning, considering that the ideal level according to the World Health Organization (WHO) is higher than 60%. Because experiments were performed in different seasons, when the humidity was higher in some cities and lower in others, the variable relative air humidity was very important in this study.

Considering this information, the variables T_{rm} and relative air humidity (RH) could be related to (1) the variables response time (RT) and number of correct answers (NC) in the test taken by students during the experiments and to the (2) maximum heart rate (HR_m) of students during the cognitive tests in the TEs with thermal changes.

The relationships presented must be evaluated statistically to verify whether they are susceptible to investigation. Hence, the likelihood-ratio test was performed, and the results are presented in Table 3.

According to Table 3, the NC variable was related to the RH and T_{rm} variables ($p < 0.05$) when the air temperature of the TE was 20°C. At this temperature, the RT variable was related to T_{rm} ($p < 0.05$), and HR_m was related to the variable RH and T_{rm} ($p < 0.05$). According to the Guidelines of the Brazilian Cardiology Society on the Analysis and Issuance of Electrocardiographic Reports,[51] the normal HR range is between 50 and 100 bpm (beats per minute). During the reasoning tests, some students presented HR values higher than 100 bpm. Thus, the variable that could contribute to the increase in HR was investigated, along with the air temperature range where this increase would occur. Moreover, Table 3 indicates that at 24°C, the NC variable was related to RH ($p < 0.05$) and the HR_m to RH and T_{rm} ($p < 0.05$). Finally, when the air temperature was 30°C, only HR_m was related to the variables RH and T_{rm} ($p < 0.05$).

At first glance, the analysis of Table 3 from a statistical perspective, indicates that HR_m has a significant relationship with variables T_{rm} and RH ($p < 0.05$) during the three days of experiments when the air temperatures in the TE were 20, 24 or 30°C. Therefore, mathematical models are presented next, which provide the evidence of the dependence relationship as

Table 3. P-values of the likelihood-ratio test.

Intervening variable Air temperature	Independent variable	Dependent variable NC	RT	HR_m
20 °C	RH	8.68×10^{-7}***	0.2967	0.00013***
	T_{rm}	0.00057***	0.00000000352***	0.00000318***
24 °C	RH	0.005071***	0.8328	0.00036***
	T_{rm}	0.07413	0.8378	0.001833**
30 °C	RH	0.379	0.588	0.000118***
	T_{rm}	0.983	0.911	0.02256*

*p < 0.05; **p < 0.01; ***p < 0.001.

described, emphasising that the parameters of the variables in the models were significant at the 5% significance level, corroborated by the Wald test, which compared the estimated maximum likelihood of each parameter with its estimated standard error, where $p < 0.05$.

Analysis of the relationship between variables in 20°C TEs

Equation (2) of Model 1 relates the NC to the T_{rm}. There is a 4.9% NC increasing if T_{rm} increases by 1°C. If there is a 2°C increase in the T_{rm}, this probability would increase to 9.6%. This result is justified because the performance of cognitive tasks in low-temperature environments – implying conditions of thermal discomfort because of the need for heat – could prevent satisfactory results. Therefore, an increase in the T_{rm} can generate comfort conditions in the environment, indirectly favouring body heating. Warming of the environment was requested by most students, whether they were from regions with mild climates or not.

$$NC = 4.075(1.049)^{Trm} \quad (2)$$

Equation (3) of Model 2 relates the NC to the RH. By increasing the RH by 1%, the NC is likely to increase by 0.91% (with a 10% increase in RH the NC increases by 9%). As previously discussed, during the winter and summer, low outdoor RH was observed, according to meteorologists. However, the indoor RH was within the normal standards for the type of activity performed by students.[52] Hence, maintaining the RH at the ideal level for the human body, between 40% and 70%, helps to better balance the body temperature control mechanism exerted by transpiration, with effects on student comfort and performance.

$$NC = 7.621(1.0091)^{RH} \quad (3)$$

Equation (4) of Model 3 relates the RT of the cognitive test to the T_{rm}. Different from the two previously mentioned models, this model presents identity and non-logarithmic link functions, thus representing a linear model. The model suggests that for each 1°C increase in T_{rm}, the time to finish the test, RT, tends to decrease by 97.88 s. This linear trend is justified because, according to the analysis of the thermal perception of students, when the environment was at 20°C, they preferred a warmer environment, with a predicted mean vote (PMV) closer to 1. Hence, if the environment was at a lower temperature (20°C), thermal discomfort tended to increase, with a negative impact on the processing speed. Consequently, an increase in T_{rm} could possibly promote a 'double' contribution to the student because, in addition to obtaining a better performance accuracy, it also improves the processing speed, causing the individual to be more functional, i.e. the cognitive function could be put to better use. Resolution 9 of the National Health Surveillance Agency (Agência Nacional de Vigilância Sanitária – Anvisa)[53] recommends an ideal air temperature between 23°C and 26°C for operational activities in indoor environments, especially during the summer. By keeping the air temperature between 21 and 25°C in call centre environments or teaching facilities, Maula et al.[54] found that the performance was not greatly affected. That is, the performance was negatively affected by slightly warm temperature in the N-back working memory task. Temperature had no effect on performance in other tasks focusing on psychomotor, working memory, attention or long-term memory capabilities. Temperature had no effect on perceived performance. However, slightly warm temperature would cause concentration difficulties.

$$RT = 3018.71 - 97.88.Trm \quad (4)$$

Equation (5) of Model 4 presents the relationship between T_{rm} and HR_m. Each increase in T_{rm} of 1 °C increases the chance of HR_m above 100 bpm. Heart beats are affected by the thermoregulatory system

(TS) and psychological reasons. In hot environments, the TS commands the peripheral vasodilatation to increase the flow rate, and the heart increases its rate to guarantee the flow rate.[54] When the environmental air temperature is 20°C, there is no vasodilatation; therefore, the increase in HR should be proportionally higher for a student in the environment at 20°C in relation to students in environments with higher temperatures, given that students at higher temperatures are already experiencing vasodilatation.

$$ChanceP(HR_{\max} \geq 100) = 0.0000003(1.822)^{Trm} \quad (5)$$

Finally, the relationship between maximum heart rate (HR_{max}) above 100 bpm and RH is represented by equation (6) of Model 5. The model indicates that for each 1% increase in the RH, there is a 5.89% increase in the chance of HR_{max} over 100 bpm. This result is expected because the indoor RH was within the normal range for the type of activity performed by students, between 40 and 70%.[55] Within this range, there is a better balance of the body temperature control mechanism performed by transpiration. With this balance and in the environment at 20°C, a relatively low temperature, the students' blood vessels are constricted, a response promoted by the nervous system. Because the vasodilatation process is not started, the increase in the HR_{max} is likely not very large for each 1% increase in RH.

$$ChanceP(HR_{\max} \geq 100) = 0.0166(1.0589)^{RH} \quad (6)$$

Analysis of the relationships between variables in the 24°C TEs

According to equation (7) of Model 6, a 1% increase in RH tends to increase the NC by 0.7%. A 10% increase would increase the NC by approximately 7%. This result highlights that with RH under control, between 40 and 70%, it would only be necessary to better maintain the equilibrium of the body temperature control mechanism performed by transpiration to ensure a more satisfactory performance.

$$NC = 7.621(1.007)^{RH} \quad (7)$$

Equation (8) of Model 7 describes the relationship between T_{rm} and HR_{max}. Therefore, for each increase in T_{rm} of 1°C, there is a 66.2% increase in the chance of HR_{max} over 100 bpm. Moreover, by increasing the air temperature in the classroom from 20 to 24°C, the students start to experience vasodilatation. With a warmer environment, the human body will promote peripheral vasodilatation to allow for a better heat exchange between the body and the environment.

$$ChanceP(HR_{\max} \geq 100) = 0.000002(1.662)^{Trm} \quad (8)$$

Equation (9) of Model 8 represents the effect of RH on HR_{max}. The model suggests that for each increase in RH of 1%, the chance that the heart rate will exceed 100 bpm is increased by approximately 7.66% (since the odds ratio associated with the variable is 1.0766). Additionally, the RH in the TEs was approximately 40 to 75%,[51] in workplaces where activities that require intellectual effort and constant attention, the RH should not be lower than 40%. Therefore, with the RH under control and the environment at 24°C, few students will likely have HR_{max} above 100 bpm.

$$chanceP(HR_{\max} \geq 100) = 0.008(1.0766)^{RH} \quad (9)$$

Analysis of the relationships between variables in the 30°C TEs

Equation (10) of Model 9 describes the relationship between RH and the HR_{max}. According to the model, for each 1% increase in RH, there is a 6.18% increase in the chance of HR_{max} exceeding 100 bpm (since the odds ratio associated with the variable is 1.0618). The student was already experiencing vasodilatation, as the cognitive tasks were being performed in high temperature environments (30°C), where heart rates above 100 bpm are expected. According to measurements and students' perception, the RH is satisfactory. Thus, increasing RH by 1% in the range between 40 and 75% will not increase the HR_{max} greatly.

$$chanceP(HR_{\max} \geq 100) = 0.0136(1.0618)^{RH} \quad (10)$$

Equation (11) of Model 10 describes the relationship between HR_{max} and T_{rm}. The model indicates that for every 1°C increase in T_{rm}, there is a 14.4% increase in the chance of HR_{max} exceeding 100 bpm. The heat exposure causes vasodilatation, which decreases blood pressure and leads to external heat loss. If the student's activity is prolonged, the blood pressure is likely to decrease, resulting in an increase in heart rate.

$$ChanceP(HR_{\max} \geq 100) = 0.0138(1.144)^{Trm} \quad (11)$$

Conclusions

Many studies highlight the influence of air temperature on comfort, somatic symptoms and performance.

Therefore, in accordance with results and discussions and considering the relationship between the comfort, performance and health of 360 engineering students from different universities of Brazil who performed cognitive tasks in a TE with changes in air temperature, the following conclusions are drawn (all these conclusions are based on results of the likelihood ratio tests, whose results are shown in Table 3):

1. If there is an increase in the heat load in the TE due to the body heat of each student, the use of new technologies in the TE, increases in outdoor temperature and the urban morphology associated with the TE building, the T_g is expected to be higher than the air temperature, and therefore, the T_{rm} of the TE is expected to rise.
2. The performance of students in cognitive tasks will only be satisfactory in the TE with an air temperature of approximately 20°C if the indoor temperature is increased because the students would be out of their thermal comfort zone, causing them to achieve better results on the cognitive test.
3. If the TE is warmed by 1°C increase in T_{rm} when the air temperature is 20°C and the RH ranges from 40 to 70%, there is a 4.8% increase in the scores, and there should also be a reduction of approximately 1.63 min in the RT of the cognitive test performed by students.
4. If the air temperature in the TE is 24°C, with the RH ranging from 40 to 70%, the TE will be comfortable, which was confirmed by students of the participant institutions from different regions of Brazil.
5. Even under controlled RH between 40 and 70% in a TE with an air temperature of 30°C, for each 1°C increase in T_{rm}, there is an approximate 13.5% increase in the likelihood of student HRs exceeding 100 bpm.

In conclusion, for the temperature of 30°C, if the relative air humidity in the teaching environment is between 40 and 70%, each increase of 1°C in T_{rm} represents an approximate 13.5% increase in the probability of the students' heart rate exceeding 100 bpm. This phenomenon occurs mainly in institutions where the given external air temperature oscillates between 35 and 42°C, which is a feature of the northern and northeastern regions of Brazil.

Authors' contribution

All authors contributed equally in the research study/project.

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