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Thermal comfort evaluation in an educational building with air conditioning located in the warm tropical climate of Colombia.

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Abstract. The objective of this work is to evaluate the perception of thermal comfort that students have in building 10 of the Universidad de la Costa located in the city of Barranquilla. For the investigation the methods for the thermal comfort evaluation are analyzed, selecting the Steady-State methodology of Fanger according to the ASHRAE 55 Standard. With the application of the surveys, the thermal sensation that the students had in the building was evaluated, which was preferably fresh and thermal acceptability where 87% responded satisfactorily to indoor climate conditions in classrooms. It was also obtained that the perception of inner thermal comfort is between 21.1 ° C and 23 ° C of temperature. With the results obtained, recommendations are issued to ensure that students feel thermal comfort and the proper regulation of air conditioning systems.

1. Introduction

Thermal comfort is constituted as the person's mental perception of the thermal environment [1]. Therefore, when evaluating the perception of the occupants, the thermal comfort state of a place can be determined. It is also defined as a neutral sensation of the person with respect to a certain thermal environment without the need to sweat or develop their activities without disturbance [2–4]. The expectations of thermal comfort depend on the place where the person is and the climatic conditions inside and outside the enclosure [5–8]. The psychophysiological variability of the human being makes it impossible to get everyone to feel comfortable with the thermal environment, whatever the reference conditions. According [9], the discomfort related to the sensation of cold or heat has a negative effect on the well-being of the participants however, the welfare decreases to a greater extent when the environments are colder.

Due to the size and dynamic environment of buildings, reducing energy while providing the desired comfort for users is a challenge. The cost of energy is based on the non-linear cost relation with the energy consumed, which is modeled consecutively in terms of the specific heat load of the building [10]. A study carried out in Chile showed that the state of a building depends to a large extent on the functionality of the air conditioning systems; therefore, insufficient thermal comfort and high energy consumption are the result of inefficient construction. Correcting these deficiencies, means great benefits, it is possible to raise the standard, increase the thermal comfort inside and lower the expenses in air conditioning [11–14]. In a study conducted at the University of Bordeaux in France, it was determined that among the factors that influence the variability of energy consumption, are the climatic factors and the thermal comfort sensation of the users [15], [16]. As well, [17] evaluated the thermal comfort and its behavior from the energy point of view in a teaching educational center in Valencia - Spain.

The studies listed above indicate thermal discomfort may be due to misuse, design errors and inadequate operation of air conditioning systems, hence the importance of studying the thermal comfort state of a building and its causes. The greater the amplitude and the greater adaptation to the outside temperature of the comfort zone, the less active air conditioning systems must be activated and, therefore, there will be less energy consumption [18].

The study of thermal comfort has been applied in several universities and schools with the purpose of achieving a balance between the energy efficiency of the building and the thermal comfort of the students in the classrooms. In Taiwan, an experiment was carried out to measure thermal comfort in the classrooms of seven Universities and the result was to acquire the ideal range of thermal acceptability and climate adaptation for students [19]. An evaluation on thermal comfort was also carried out in a building of the National University of San Juan in Argentina; that allowed identifying opportunities for improvement in the building [20]. Another study was conducted in Universities of Zulia in Venezuela [21]. Research on the importance of thermal comfort in the performance of learning have also been carried out in schools and universities by different authors [9], [22–24].

Considering that the behavior of the conditions that are generated in buildings to ensure thermal comfort, may be significantly affected by parameters associated with climate and energy technologies that are used, this work aims to assess the perception of thermal comfort they have students in block 10 of the Universidad de la Costa. With the results obtained, recommendations are issued to ensure that students feel thermal comfort and the proper regulation of air conditioning systems.

2. Methodology

2.1. Selection of the thermal comfort measurement model.

For the development of the project, a search was made of the thermal comfort measurement methodologies and their characteristics, in addition to the measurement variables used for a climate-controlled thermal environment that allowed knowing the degree of influence of comfort on the welfare of building occupants. The most used methodologies were compared and the standard model Steady-State of Fanger was chosen for its practical value, based on the ASHRAE 55: 2013 standard. This methodology is ideal for measuring thermal comfort in closed environments, where people are exposed to long working or academic hours, allowing knowledge of the thermal state of the place to propose alternatives for improvement [25], [26].

2.2. Selection of the reference building for the study of perception of thermal comfort and calculation of the sample of students for the application of the survey.

It is selected for the study and application of the survey, building 10 of the Universidad de la Costa, of figure 1, located in the city of Barranquilla, which has an area of 480 m², 26 classrooms that measure on average 43.16 m² and maximum capacity of 40 students. And a laboratory with an area of 41.99 m² and capacity for 15 students

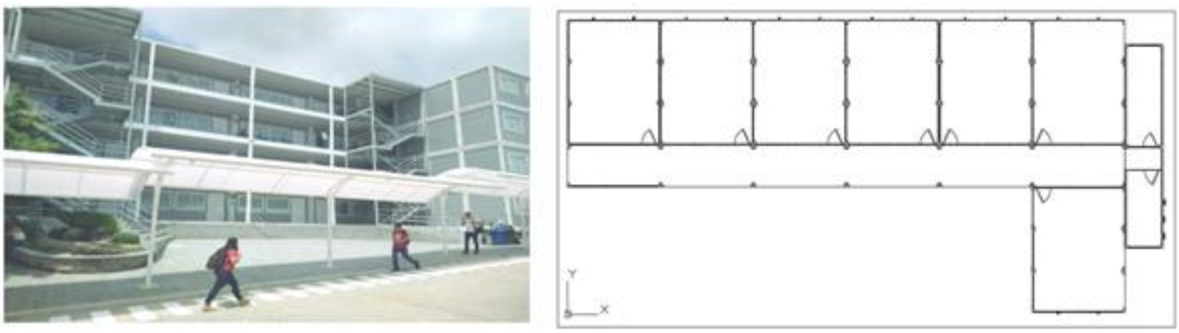

Fig 1. Building 10 of the Universidad de la Costa.

To determine the number of students to be surveyed, the sample size was determined with a confidence level of 95%, applying equation (1):

$$n = \frac{Z\alpha^2 \cdot N \cdot (p \cdot q)}{e^2 \cdot (N-1) + Z\alpha^2 \cdot (p \cdot q)} \quad (1)$$

Where, n-Population size of 1080 corresponding to the maximum capacity allowed by the building,$Z\alpha^2$- Designated value of 1.96, α-Confidence interval of 0.95, e-Acceptable error limit of 0.05, p.q-Standard deviation of 0.5

The sample size calculated was 283 students, and 584 students were surveyed. The number of students surveyed in each floor was 133 on the first floor, 125 on the second floor, 181 on the third floor and 140 on the fourth floor. On average, 22 students were surveyed per classroom. And of the total number of respondents, 303 were male and 281 were female.

2.3. Development of the survey for the measurement of the thermal perception of the occupants of building 10, of the University of the Coast.

The survey was designed to evaluate psychological, physiological and physical aspects of the user regarding the environment in which the users were and the measure corresponded to a scale of value suggested in the standard. The questions asked mainly considered the location of the occupant in the classroom, the level of insulation of the clothes, level of activity in the last instance of sitting time and the criterion of sensation and thermal acceptability. The process of evaluation of surveys was taken into account the following conditions: The surveys were applied in all classrooms of building 10 of the Universidad de la Costa, only students with a minimum time of 15 minutes in the classroom as indicated by the ASHRAE 55: 2013 Standard.

Studies carried out by different researchers have shown that one of the main factors influencing thermal comfort are the environmental conditions present in the city where the building is located his is due to the direct proportionality that exists between the external climate and the interior climate of the building, for the case of Barranquilla, which is characterized by having a hot-humid climate, especially during the summer, and average temperatures that range from 28ºC to 33ºC, with a higher incidence at midday. Therefore, measurements of temperature and relative humidity were made in each classroom at the time of the surveys.

3. Results

The main factors analyzed in the project to determine the perception of thermal comfort by students in building 10, are: the external climate, the indoor climate (air conditioning system), the amount and type of clothes, the location of the person and activity level of the students within the classroom.

3.1. Analysis of the general characteristics of the students and their location in the classrooms.

The survey was conducted in the months of July to September 2018, from 10:30 am to 12:30 p.m. The distribution of students in the classrooms was identified considering the location of the air conditioning, windows and doors of each room, where it was identified that criteria of sensation and thermal acceptability were different depending on the location. The average height of the students surveyed was 1.70 meters. The clothes most used by the respondents, was light of characteristic use for the type of climate, with a low Clo value.

The metabolic rate of the occupants is estimated based on the data provided by the ASHRAE 55 standard, for a variety of common activities, such as sitting, standing, walking, office activities and leisure activities, among others. The standard allows averaging the metabolic rate of the occupants, when the level of activity developed is common. For the study, the metabolic rate of the students was estimated for the activity of sitting and writing, as shown in table 1.

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Table 1. Metabolic table according to activity carried out

Activity	Metabolic rate W/m²
Sitting (office, home, school, laboratory)	60
To write	60

3.2. Analysis of the thermal sensation identified in the students in building 10.

Figure 2 shows the results obtained when the analysis was performed to assess the thermal sensation that the students had in building 10, where it was possible to identify that 34% felt the environment cool, although there was a minimum percentage of 12% that had a feeling of heat inside the classroom. In general, a cool thermal sensation predominates in the building.

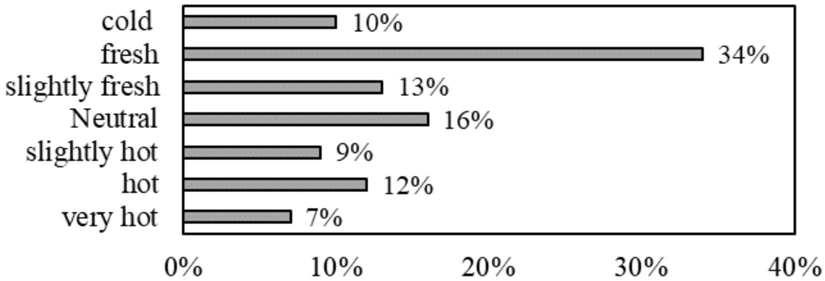

Fig 2. Thermal sensation of the students in the building.

When each floor is analyzed, represented in Figure 3, it is observed that the highest percentage of students agree that their thermal sensation is cool in all the floors, being the floor 2 identified as the hottest and the 1st floor the coldest for the most critical conditions of thermal sensation evaluated.

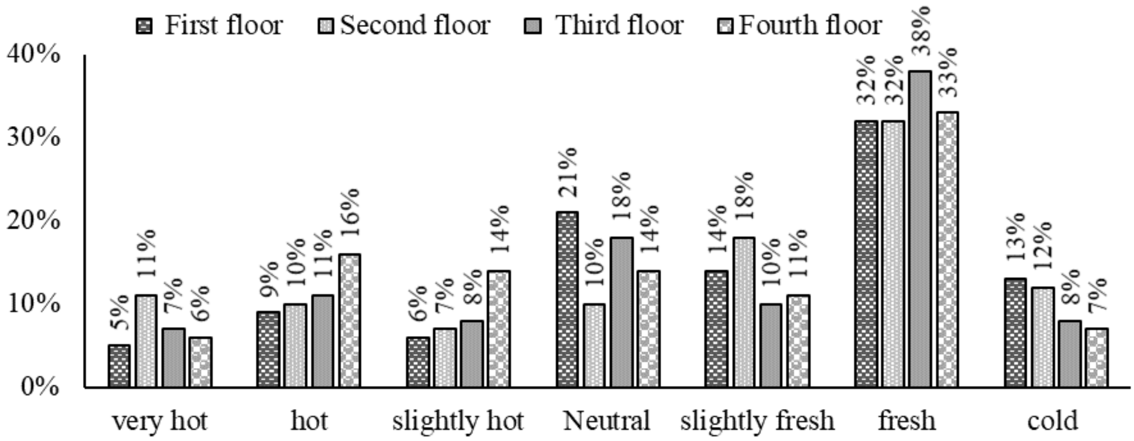

Fig 3. Thermal sensation of the students on each floor of the building

The results for each classroom were found that the two hottest rooms in the building were on the second floor and the coldest room was located on the first floor. This, product of the technical condition and temperature selection in the air conditioners.

3.3. Analysis of thermal acceptance identified in students in building 10

The thermal acceptability was also analyzed, as shown in Figure 4, obtaining as a result that the students in the highest percentage found in the range of acceptable thermal comfort in building 10. The unacceptability had a very low percentage of only 14%.

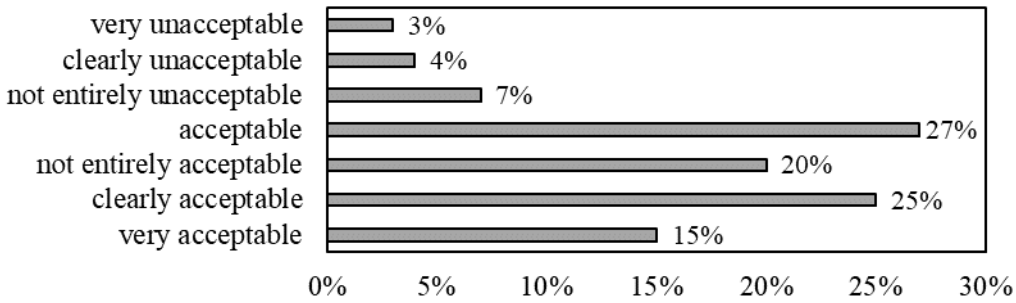

Fig 4. Thermal acceptability of the students in the building.

Figure 5 shows the results of thermal acceptability on each floor of building 10. It can be seen that the second floor obtained the best percentages in acceptability and the fourth floor was the one with the least acceptability on the part of the students. Regarding the classrooms analyzed, the opinion of clearly acceptable and acceptable predominates in most of the classrooms surveyed in all the floors.

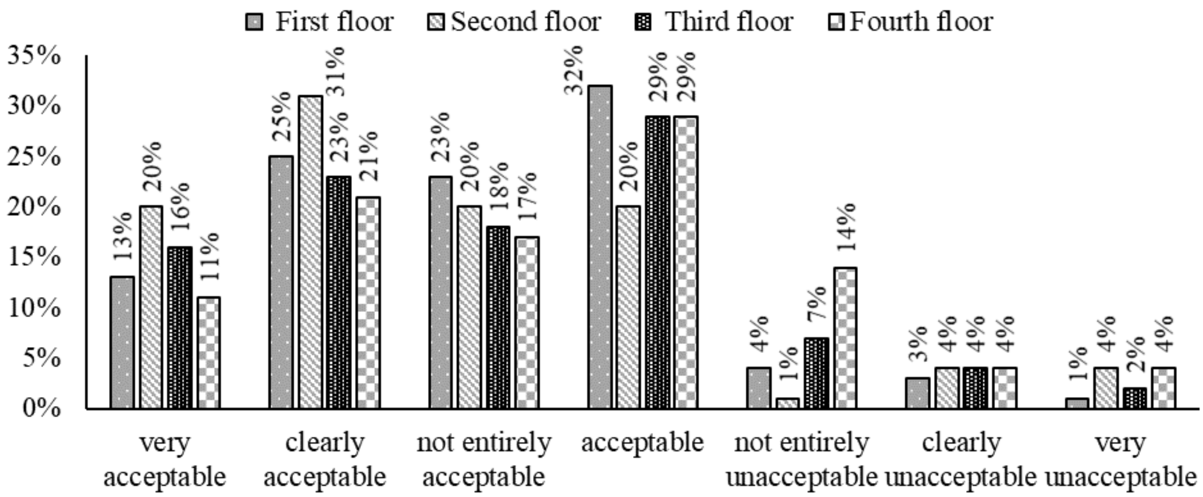

Fig 5. Thermal acceptability of students on each floor of the building.

3.4. Analysis of the thermal sensitivity according to the temperature inside the classroom.

At the time of the survey, the temperature and relative humidity were measured outside and inside the classrooms, observing, in Figure 6, that there is a thermal sensation of coolness that predominates.

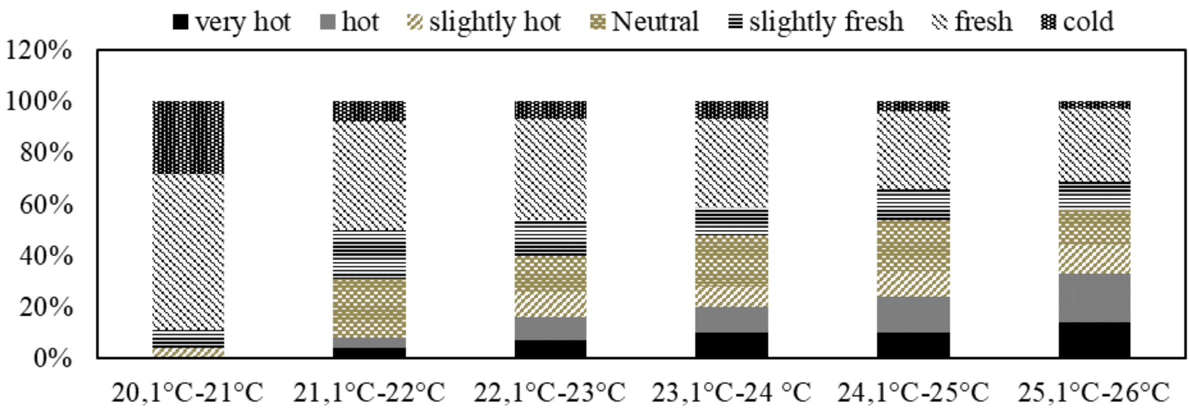

Fig 6. Thermal sensation of the students according to the interior temperature of the classroom.

From Figure 6, it is concluded that, although in the range of 20.1 to 21 ° C the sensation of cold increases and from 25.1 to 26 ° C that of heat, the temperature range of 21.1 to 23 ° is preferred by students. C. Therefore, it can be considered to establish set point temperatures of 22 ° C in the air conditioners of each room of the building.

Studies have shown that neutral thermal sensations are not always the ideal or preferred thermal state for people, demonstrating adaptive behavior in air-conditioned classrooms [27]. This is reflected in the students' preference for low temperatures, where they express cool to cold thermal sensation, but they show acceptability to the indoor climate in classrooms and, therefore, perception of comfort in the building.

4. Conclusions

The most well-known methodologies to evaluate the thermal comfort perception are: the standard model, the adaptive model and the adaptive variable model. These models seek to assess thermal comfort inside buildings in order to establish well-being for their occupants. But it also allows to establish adequate parameters for air conditioning systems, mainly when the Fanger model adopted by the ASHRAE 55 standard is applied, because it has been shown to be ideal for evaluating closed environments when occupants are exposed to long hours within the building.

For the study, Block 10 of the Universidad de la Costa was selected, for having its classrooms with standard measurements in the four floors that make up the building. The results showed that the thermal sensation for block 10 was fresh for 72% of the students surveyed, not reaching 80% as established by the ASHRAE 55 standard. The floor with the best results in terms of thermal sensation of comfort was the third floor, and in those that showed greater discomfort were the first and second floor with 67% and 33% respectively. Regarding thermal acceptability, 87% responded satisfactorily to indoor climate conditions in the classrooms. The highest thermal acceptability was on the first floor with 92%, followed by the second floor with 91%.

The measurement of the interior temperature was key in the analysis of perception of thermal comfort that students had in the building. 84% of the students found the greatest thermal sensation of comfort in the range of 21.1 to 23 ° C. Which indicates that the Universidad de la Costa can establish as a measure that the temperature of the set point is set in the air conditioners of the halls of building 10 between 21 and 23 ° C depending on the class schedule and the time of year.

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