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REMOTE EVALUATION OF THERMAL COMFORT CONDITIONS IN ACADEMIC LABORATORIES

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Abstract. *Most of existing buildings in Brazil did not take into account thermal comfort during the design stage. As people are spending more time in the indoor environment, this reality has been changing, and a special attention to both thermal comfort and energy efficiency are becoming challenges for building engineering. According to the Brazilian building and energy certification program, eight bioclimatic zones can be defined in the country, attesting that distinct design strategies should be considered in different regions in order to reach both thermal comfort and energy efficiency standards. This work presents an equipment capable to measure thermal comfort sensation. The apparatus has the characteristic of remote monitoring thermal comfort. In order to test the ComfortMeter, a case study in an academic laboratory was performed, in which the climatic factors were measured and associated with variables of each individual, professor and students, in order to calculate both Predicted Mean Vote (PMV) comfort index and the Percentage of People Unsatisfied (PPD). Results revealed thermal discomfort on hot days, showing that special attention to the indoor climatic conditions should be performed in order to do not affect students learning process. The usability aspects of the equipment was also reported in this work.*

Keywords: *remote evaluation, thermal comfort, building environment, PMV.*

1. INTRODUCTION

Thermal comfort can be defined as the sensation of well-being of an individual, related to the climatic factors of the environment (Fanger, 1970). It can be characterized by the balance between the heat produced by an individual and the heat loss to the environment. Olgay (1963) defines that the zone of comfort is the point at which the occupant of an environment consumes the least amount of energy possible for the adaptation to the environment thermal conditions.

Day-to-day activities are more concentrated indoors, as reported by Burnett et al. (2000), people from more developed countries spend more than 90% of their time indoors. For this reason, there is a greater concern about thermal comfort of the environments. A trend that has been treated since 1845, as stated in the work of Bernan (1845), which refers how important is the science of controlling the climate of indoor environments that are conditioned by artificial methods to maintain the longevity and health of human beings. This preoccupation, in practice, reflects that during building projects, it is important to take into account factors such as air quality and thermal comfort (Pereira et al., 2014; Hweij et al., 2016; Stazi et al., 2017). On the other hand, the energy efficiency of buildings has also been widely considered and cannot be ignored. By considering the world energy context, efforts have been performed in the building sector in in order to reduce energy demand (Freire et al., 2008; Walsh et al., 2017; Friess and Rakhshan, 2017).

Most of existing buildings did not take into account concepts of thermal comfort and energy efficiency. Many times, even in recent design projects, problems regarding thermal comfort of the occupants are reported (Huizenga et al., 2006). As it can be noticed, the constant monitoring and analysis of the environments in relation to activity performed by

occupants must be considered to ensure acceptable comfort conditions in indoor environments. Uncomfortable thermal conditions may cause lower performance in work activities, to increase both error probability and accident risks, physical and nervous exhaustion, besides leaving the body susceptible to diseases (Rivero, 1986).

Taking into account the thermal comfort importance, this work presents the development and test procedures of a ComfortMeter. Tests were performed considering an academic environment in Curitiba, Paraná state, Brazil. Taking into account that students and professors need to stay long periods inside both research laboratories and classrooms, where they may suffer from the symptoms caused by thermal discomfort, this work presents evaluates distinct profiles inside the environment considering different patterns of usage. Additionally, the southern region of Brazil presents considerable thermal variations during the same climatic season and even during the same day, which may considerable affect the occupants thermal sensation.

The next section of this paper presents the methodology adopted to develop the prototype and to perform the tests. In the sequence, section 3 describes the thermal comfort model and section 4 the ComfortMeter equipment. The case study is presented in section 5 and its results in section 6. Finally in section 7, the conclusions.

2. METHODOLOGY

This work presents a ComfortMeter prototype, where both development and validation procedures are reported in this work. The prototype consists of a measuring station that uses sensors to quantify dry bulb temperature, mean radiant temperature, relative humidity and air velocity. These variables were after associated to physical activity level and clothing index of the occupants in order to provide the Predicted Mean Vote (PMV) index, which was proposed by Fanger (1970). Associated to the PMV, an auxiliary index called Predicted Percentage of Dissatisfied (PPD) can be obtained, it indicates the percentage of people who are thermally unsatisfied within the environment.

To validate de prototype, an academic laboratory was considered as case study. The methodology take into account measures in three distinct points, the first considers professor's location and the other two where students are situated. The difference between them is that one is direct affected by wind provided by a ventilator. The measurements were carried out considering two distinct classes periods, during the day and at night considering three days of the week. In each situation, 1 hour of measurement with 5 minutes sample time were taken into account.

The analysis of the results were based on PMV and PPD measurements that were computed automatically by the ComfortMeter. After the data acquisition procedure, it is possible to classify the environment as comfortable or thermally uncomfortable according to the PMV-PPD analysis.

3. THERMAL COMFORT

The human organism has experienced several evolutions, and with them the development of mechanisms that might allow his adaptation to maintain well-being condition, i.e. the presence of elements that keep your physical health and your sense of satisfaction (Ruas, 1999). The feeling of satisfaction in an environment regarding thermal conditions refers to thermal comfort, which according to ASHRAE Standard 55 (ASHRAE, 2004) is the absence of heat exchanges of a person's body, since the temperature of the skin and sweat are within an acceptable limit. The importance is given, mainly, when you take into account that thermal comfort conditions can be used as stimulus to obtain the best performance of the occupants within an environment considering that they are not submitted to thermal stress.

There are several models to evaluate thermal comfort, those models include, at least, variables related to the indoor climate. However, more elaborated models, as the PMV, can incorporate variables related to the occupants. In this project, the model used is the PMV, proposed by Fanger (1970), to classify the level of comfort following a scale. The PMV calculation can be performed as Eq. (1):

$$PMV = (0,303e^{-0,036M} + 0,028) \cdot \{ (M - W) - 3,05 \cdot 10^{-3} \cdot [5733 - 6,99(M - W) - p_a] - 0,42 \cdot [(M - W) - 58,15] - 1,7 \cdot 10^{-5} \cdot m \cdot (5867 - p_a) - 0,0014 \cdot M \cdot (34 - t_a) - 3,96 \cdot 10^{-8} \cdot f_{cl} \cdot [(t_{cl} + 273)^4 - (t_r - 273)^4] - f_{cl} \cdot h_c \cdot (t_{cl} - t_a) \} \quad (1)$$

where M is the metabolic rate (W/m^2), W the mechanical work (W/m^2), I_{cl} the thermal resistance of clothes ($m^2 \cdot ^\circ C/W$), f_{cl} the ratio of the surface area of the body worn by the area of the body which is uncovered (dimensionless), t_a the air temperature ($^\circ C$), t_r the mean radiant temperature ($^\circ C$), v_{ar} the air velocity (m/s). Additionally, p_a represents the partial pressure of water vapor (Pa), h_c is the convective heat transfer coefficient ($W/m^2 \cdot ^\circ C$), and t_{cl} defines the surface temperature of clothing ($^\circ C$). By properly calculating the PMV, results obtained are between -3 and 3 , characterizing the thermal sensation felt by the individual(s). The closer to zero the calculated index the more thermally comfortable the analyzed environment. As it can be seen in Tab. 1.

Table 1. Scale proposed by Fanger (adapted) (ASHRAE, 2004).

PMV	Thermal Sensation	PPD
-3	Cold	99,1%
-2	Cool	76,4%
-1	Slightly cool	26,8%
0	Neutral	5,0%
+1	Slightly warm	26,4%
+2	Warm	75,7%
+3	Hot	99,1%

The Predicted Percentage of Dissatisfied (PPD), which is based on the estimated average vote and serves to measure the percentage of a certain number of people who may be thermally unsatisfied within the environment, is presented in Eq. (2). It is expected that there will never be 100% of people satisfied with the thermal comfort of the environment, so ASHRAE considers that an environment is thermally comfortable when at least 80% of the occupants are satisfied. A PPD equal or lower than 20% is considered reasonable for the indoor environment.

$$PPD = 100 - 95e^{-[0,03353.PMV^4 + 0,2179.PMV^2]} \quad (2)$$

3.1 Definition of the variables included in the PMV calculation

To measure thermal comfort by PMV, six factors are considered. Two that depend on the individual and four that depend on the environment, respectively. These variables are the activity performed by the individual, the thermal insulation of the clothes, the ambient temperature, the average radiant temperature, the air velocity and the relative humidity of the air.

From the food ingested, the human being produces energy. This energy is spent on vital physiological functions and on performing mechanical tasks. The remaining energy is released in the form of heat, and depending on the activity performed, it is released in an increased form. In order to generate the comfort value in ComfortMeter, some common activities performed by people were considered, which are mentioned in the section 4 of this paper, where the ComfortMeter is presented. A factor that hinders this release of energy in form of heat is the insulation coming from the clothes used by the individual, as it offers a resistance to the transfer of heat from the body and the environment. This resistance varies according to the fabric of the garment and the manufactured model. The clothing categories considered in ComfortMeter are also presented in the ComfortMeter section.

Among measured variables is the air temperature, which by definition is the degree of agitation of the molecules in the air. Another variable is the mean radiant temperature, which consists in the uniform temperature measured in an imaginary environment, in which the transfer of heat by radiation from the human body is equated with the heat transfer also by radiation from a non-uniform environment (Lamberts and Xavier, 2008). The air velocity is the magnitude of the velocity vector of the airflow considering any measurement point. Finally, the relative humidity of the air is the ratio of the amount of water vapor in 1m³ of air to the maximum amount of grams of water vapor that 1m³ may contain (saturation point) (Ruas, 1999).

4. THE COMFORTMETER

The purpose of ComfortMeter is to measure all the variables involved with thermal comfort, so that it is possible to determine the Predicted Mean Vote (PMV) to verify the comfort sensation. Sensors detailed in the following hardware section will measure variables that depend on the environment. The ComfortMeter user will select personal variables, those considered on the PMV calculation. Both metabolic rate, according to actual physical activity performed by the occupants, and the thermal insulation of the clothes, will be inserted in the equipment according to both Tab. 2 and 3. Predefined values (in W/m² and clo) are already specified and more options can be included in the code.

Table 2. Options to select from activity performed on ComfortMeter for comfort index generation.

Options to Select from Activity Performed	Metabolic Rate (W/m ²)
Lying or reclining	46
Sitting or relaxed	58
In sedentary activity (office, residence, school, laboratory)	70
In light foot activity (shopping, laboratory, light industry)	93
In average standing activity (clerk, domestic work in machines)	116

Table 3. Clothing categories to select on ComfortMeter that the user is using for comfort index generation.

Clothing Categories for Selection on ComfortMeter	Thermal Insulation (clo)
Underwear + dress + sandals	0,33
Underwear + short sleeve t-shirt + pants + socks + shoes	0,47
Underwear + long sleeve shirt + pants + socks + shoes	0,63
Underwear + long sleeve t-shirt + jacket + thick stocking + shoes	1,00

4.1 Hardware

Sensors to measure temperature, relative humidity, mean radiant temperature and air velocity were incorporated into a small box (12,7 cm × 12,7 cm × 9,50 cm), shown in Fig. 1.

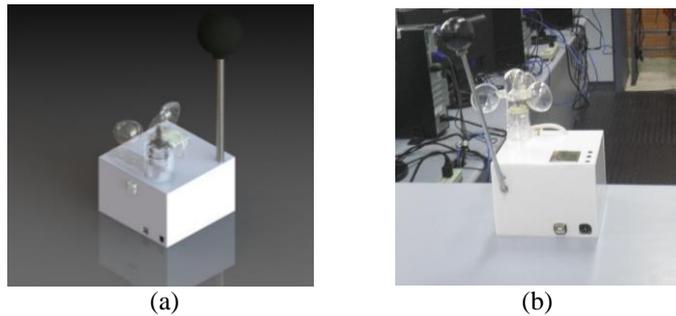


Figure 1. Isometric view of the ComfortMeter: (a) design; (b) prototype (Mudrek, 2015).

The same sensor can measure both temperature and relative humidity. The DHT22 is a digital sensor that comprises a capacitive humidity sensor and a thermistor, offering an easy to use interface. It is already calibrated at the factory and every 2 seconds offers the possibility of a new measurement. Its accuracy for humidity is 2% to 5%, in a range of 0 to 100%. And for temperature, an accuracy of ±0,5°C in a range between -40°C to 80°C is provided.

The air velocity is measured by a mug anemometer, which provides an accurate measure of the horizontal wind speed. When there is the presence of wind, and not just a breeze, the anemometer mugs moves the rotor. In this case, a pulse signal is sent from the magnetic sensor and the wind velocity is measured.

To measure the radiant temperature was used the globe thermometer or Vernon, made with a painted black matte sphere with a temperature sensor LM35 inserted inside it. As the diameter of the sphere is reduced, its average stabilization time is 5 minutes.

In addition, the hardware of the ComfortMeter includes an Arduino board for interpretation of all signals from the sensors, making all necessary calculations and displaying PMV and PPD information on the LCD for user interaction. A power supply and the circuits required for operation are also part of the ComfortMeter.

4.2 Software

The software used for monitoring was developed in LabVIEW (2017), by National Instruments. It is possible to monitor all climatic variables, and the comfort indices PMV and PPD. Charts are plotted and data can be saved to a file selected by the user. Figure 2 shows the software interface.



Figure 2. ComfortMeter monitoring software interface.

5. CASE STUDY

A practical test was proposed to investigate the operation of the ComfortMeter in an educational laboratory environment. The laboratory has $9.87\text{ m} \times 7.57\text{ m} \times 4.56\text{ m}$ of length, width and height, respectively. The layout is defined for two professors and twenty students distributed in four workbenches with five computers each. The two-floor building is located at Curitiba city, Paraná state, Brazil. Figure 3 shows the laboratory location and orientation according to the building geometry.



Figure 3. Building orientation and laboratory location (adapted from Google Maps) (GOOGLE, 2017).

Students and researches of engineering courses frequent the laboratory. The importance of this monitoring thermal comfort occurs when, due to the many hours of study, the occupants are subject to a thermal discomfort. This sensation could affect their productivity in the proposed activities and, especially, when taking into account the climate of Curitiba with considerable thermal variation during the whole day (Silva, 1994).

The monitoring procedures comprised the measurements in three situations. First considering a seated student during the class; the second, another seated student, but in this case near a fan; and the third one considering a stand-up professor during classes.

Inside the laboratory there are just two fans installed on the bottom of the room with natural cross ventilation coming from the windows, this when the access door remains open, which is a common practice in hotter days. On sunny days, especially during the afternoons, the solar radiation significantly affect the laboratory thermal conditions, as there are direct solar radiation on windows of the west side of the building. Therefore, measurements were performed in two periods, one in the daytime period and the other at night. A layout of the room is shown in Fig. 4 and the location of each person analyzed is indicated by the squares in this figure.

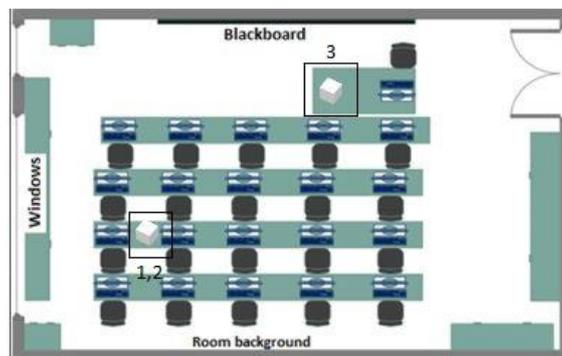


Figure 4. Laboratory plant.

Measurements were taken on three consecutive days in the winter season. In a typical winter in Curitiba, the cold fronts have an average of six to seven days between them and it usually rains only after this interval. When these cold fronts do not advance, hot days may occur and the low humidity predominates (Piva, 2015). The latter situation was the one that prevailed on the days of measurement, as can be seen on the weather data collected and presented in the next section.

6. RESULTS

The three situations were addressed: the first, a student attending a class, sitting and doing small exercises such as writing. The second, the same situation as before, but with the room fans running. The third situation, a teacher giving class, standing.

In the students' situations, as regards personal variables, the clothes considered were lighter due to the heat, i.e.: underwear; short sleeve t-shirt; pants; socks and shoes. As activity performed, it was considered a sedentary activity, because the students remain seated and making small movements.

In the teacher's situation, clothes that are more formal were considered: underwear; long sleeve shirt; pants; socks and shoes. And an activity that spends a little more energy than that of the students was considered: the light activity on foot, precisely by the teacher to remain most of the class standing and writing on the blackboard.

The climatic variables measured inside the laboratory can be verified in Tab. 4 and Tab. 5.

Table 4. Indoor climate conditions: day period.

Time (h)	Day 1 (September 4, 2017)			Day 2 (September 5, 2017)			Day 3 (September 6, 2017)		
	Temp. (°C)	Mean Radiant Temp. (°C)	Relative Humidity (%)	Temp. (°C)	Mean Radiant Temp. (°C)	Relative Humidity (%)	Temp. (°C)	Mean Radiant Temp. (°C)	Relative Humidity (%)
14:30	29.4	36.17	28.6	29.3	32.75	27.2	30.7	33.24	32.7
14:35	29.6	38.61	29.0	31.0	33.72	27.1	32.2	40.57	29.9
14:40	32.1	40.08	27.2	32.1	40.57	25.3	32.2	42.03	29.4
14:45	35.4	38.12	22.0	32.4	42.03	24.6	33.5	40.57	28.4
14:50	35.5	40.57	28.5	31.9	41.06	25.6	35.3	34.70	25.2
14:55	35.1	41.06	23.6	33.1	38.61	24.9	34.2	35.68	24.8
15:00	34.8	41.06	24.5	34.1	35.68	23.4	34.2	35.19	25.0
15:05	34.7	41.06	23.8	34.3	41.06	22.0	34.9	31.28	23.9
15:10	34.6	41.06	24.5	34.9	40.57	22.0	34.8	36.17	23.5
15:15	34.4	41.06	24.0	35.2	41.06	21.3	34.4	34.70	23.4
15:20	33.9	41.06	24.4	34.9	45.45	20.4	34.6	33.72	23.6
15:25	32.8	35.68	25.5	33.7	44.97	22.0	34.9	31.77	24.4
15:30	31.7	31.28	27.0	34.4	43.99	22.0	35.4	36.17	24.0
15:35	33.7	33.24	24.9	34.4	37.15	21.8	33.5	36.17	27.6
15:40	33.7	34.21	24.2	34.2	36.17	22.7	33.2	35.68	28.0
15:45	33.5	35.19	24.2	33.9	36.17	23.1	33.6	35.68	28.5
15:50	33.5	35.68	25.5	32.9	39.10	24.3	34.6	33.72	26.9
15:55	33.2	36.17	24.7	32.2	38.12	25.4	33.5	31.77	28.7
16:00	33.0	36.17	24.6	32.0	38.61	25.7	32.7	31.77	29.8
16:05	32.9	35.68	25.6	31.9	39.59	26.8	31.0	30.30	32.5
16:10	32.6	36.17	25.4	31.8	40.57	27.0	30.7	31.77	33.6
16:15	32.4	35.19	26.0	31.9	38.12	26.7	30.8	33.72	33.6
16:20	31.9	34.7	26.3	31.9	35.68	27.1	31.0	32.26	33.1
16:25	31.7	34.7	27.3	32.2	36.17	26.7	31.4	30.30	33.4
16:30	31.6	35.19	27.4	32.9	37.63	26.2	30.8	29.33	34.2
16:35	31.4	35.19	27.2	33.3	41.06	25.5	30.9	33.72	34.1
16:40	30.2	28.84	27.3	32.0	35.19	30.9	31.0	30.30	34.5
16:45	30.0	29.33	27.7	31.7	34.70	28.2	30.8	29.81	34.8
16:50	29.9	29.33	28.0	31.5	34.21	28.6	30.6	29.33	35.0
16:55	29.7	29.33	28.4	30.8	33.72	29.8	30.4	29.33	35.0
17:00	29.6	29.33	28.7	30.2	33.72	30.7	30.2	28.84	35.5
17:05	29.5	28.84	29.3	29.9	33.24	31.7	30.0	29.33	35.8
17:10	29.4	28.84	29.2	29.7	33.72	32.3	29.5	29.33	37.1
17:15	29.0	28.84	30.4	29.4	35.68	32.4	29.0	31.28	38.1
17:20	28.7	28.84	31.2	29.4	34.70	33.0	28.8	29.33	38.6
17:25	28.5	28.84	31.7	29.4	33.72	32.8	28.7	31.28	39.0
17:30	28.3	28.84	31.7	29.4	33.72	33.0	28.5	29.33	39.6
17:35	28.2	28.84	32.4	29.3	33.72	33.2	28.2	27.86	39.7
17:40	28.1	28.35	32.3	29.2	33.72	33.5	28.1	27.86	40.0

Table 5. Indoor climate conditions: night period.

Time (h)	Day 1 (September 4, 2017)			Day 2 (September 5, 2017)			Day 3 (September 6, 2017)		
	Temp. (°C)	Mean Radiant Temp. (°C)	Relative Humidity (%)	Temp. (°C)	Mean Radiant Temp. (°C)	Relative Humidity (%)	Temp. (°C)	Mean Radiant Temp. (°C)	Relative Humidity (%)
18:00	27.6	27.37	33.6	29.5	32.26	32.0	27.4	26.88	42.9
18:05	27.5	27.37	34.0	29.7	32.26	31.2	27.4	26.88	41.6
18:10	27.3	27.37	34.3	29.7	32.26	31.7	27.4	26.88	41.8
18:15	27.1	27.37	34.9	29.6	33.24	31.6	27.3	26.39	42.0
18:20	27.0	26.88	35.2	29.7	34.70	32.5	27.2	26.88	42.3
18:25	26.9	27.37	35.8	29.0	31.77	31.7	27.1	26.88	42.4
18:30	26.8	26.88	36.0	28.6	31.77	31.5	27.0	26.88	42.7
18:35	26.7	27.37	36.1	28.4	31.77	30.0	27.0	26.88	42.9
18:40	26.6	26.88	36.5	28.4	31.77	28.5	27.0	26.88	42.9
18:45	26.5	28.35	36.5	28.5	31.77	28.6	27.0	26.88	42.9
18:50	26.5	27.37	37.1	28.4	32.26	27.8	27.0	26.39	42.8
18:55	26.4	26.88	36.6	28.5	32.26	28.4	26.9	26.39	43.1
19:00	26.4	27.37	37.1	28.4	31.28	28.7	26.9	26.88	43.2
19:05	26.3	27.37	37.5	28.2	31.28	29.8	26.9	26.39	43.8
19:10	26.3	26.88	37.4	28.1	32.26	30.5	26.9	26.88	43.4
19:15	26.2	26.88	37.6	28.0	31.28	31.2	26.7	26.39	43.8
19:20	26.0	26.88	37.9	27.7	30.79	33.7	26.6	26.88	44.0
19:25	25.9	26.88	38.2	27.5	30.79	35.9	26.6	26.39	44.2
19:30	25.9	26.39	38.4	27.5	31.28	37.2	26.5	26.39	44.3
19:35	25.9	26.88	38.6	27.4	30.30	38.6	26.5	26.39	44.6
19:40	25.8	26.88	38.8	27.3	30.30	40.9	26.5	26.39	44.7
19:45	25.8	26.88	39.2	27.2	30.79	42.2	26.4	26.39	44.3
19:50	25.8	26.88	39.2	27.2	30.30	42.9	26.4	26.39	44.3
19:55	25.8	26.88	39.4	27.2	30.30	43.3	26.4	25.90	44.9
20:00	25.7	27.37	39.6	27.2	30.79	43.5	26.3	25.90	44.9
20:05	25.7	26.88	39.7	27.2	30.3	43.5	26.3	25.90	45.2
20:10	26.0	27.37	38.9	26.5	30.79	47.5	26.2	25.90	46.4
20:15	26.2	26.88	38.9	26.6	30.30	46.6	26.3	26.39	46.0
20:20	26.2	26.88	38.8	26.5	30.30	46.4	26.3	26.39	46.0
20:25	26.2	26.88	38.8	26.4	30.30	46.0	26.2	26.39	46.6
20:30	26.2	26.88	39.0	26.4	29.81	46.4	26.1	26.39	46.4
20:35	26.1	26.88	39.1	26.2	29.81	47.3	26.1	26.39	46.9
20:40	26.1	26.88	39.2	26.2	29.81	47.3	26.2	26.39	46.7
20:45	26.1	26.39	39.3	25.8	29.81	48.8	26.1	25.9	46.9
20:50	26.1	26.39	39.4	25.6	29.33	49.1	26.1	26.39	46.6
20:55	26.1	26.39	39.6	25.4	29.33	49.5	26.1	26.39	46.3
21:00	26.0	26.39	39.7	26.9	29.33	46.2	26.0	25.9	46.6
21:05	26.1	26.39	39.7	27.3	29.33	44.6	26.0	25.9	47.5
21:10	26.1	26.88	39.8	27.4	28.84	44.4	26.1	25.9	46.5

For comparison parameters, temperature data were collected on the AccuWeather site from the same measurement days with the ComfortMeter, which data is shown per hour according to the day chosen in Tab.6.

Table 6. Temperature data collected from AccuWeather site (adapted from AccuWeather, 2017).

Hours (h)	2 p.m.	3 p.m.	4 p.m.	5 p.m.	6 p.m.	7 p.m.	8 p.m.	9 p.m.
Monday (September 4, 2017)								
Temperature (°C)	26°	26°	26°	25°	22°	21°	18°	17°
Thermal sensation (°C)	29°	29°	27°	24°	21°	19°	17°	16°
Tuesday (September 5, 2017)								
Temperature (°C)	28°	27°	26°	24°	22°	20°	18°	17°
Thermal sensation (°C)	31°	30°	27°	24°	21°	19°	17°	16°
Wednesday (September 6, 2017)								
Temperature (°C)	23°	23°	22°	20°	18°	17°	16°	15°
Thermal sensation (°C)	27°	25°	22°	19°	17°	16°	14°	14°

It can be observed that on average the room temperature was 7 °C above when compared to the mean values obtained from the weather dataset during daytime period. During this period, there were no classes taking place, and just research activities are performed in the laboratory. In the night period, in which the room was at its maximum capacity, temperature reached 10 °C above external conditions, mainly due to the solar radiation incidence in sunny days and the high thermal capacity of the building materials.

With these data presented, it can already be noticed that there is a thermal discomfort coming from the laboratory. To prove this discomfort, graphs with the PMV and PPD indexes of the three days are presented, considering the students sitting (Fig. 5), the students sitting with the fan working (Fig. 6) and a teacher standing in front of the board (Fig. 7).

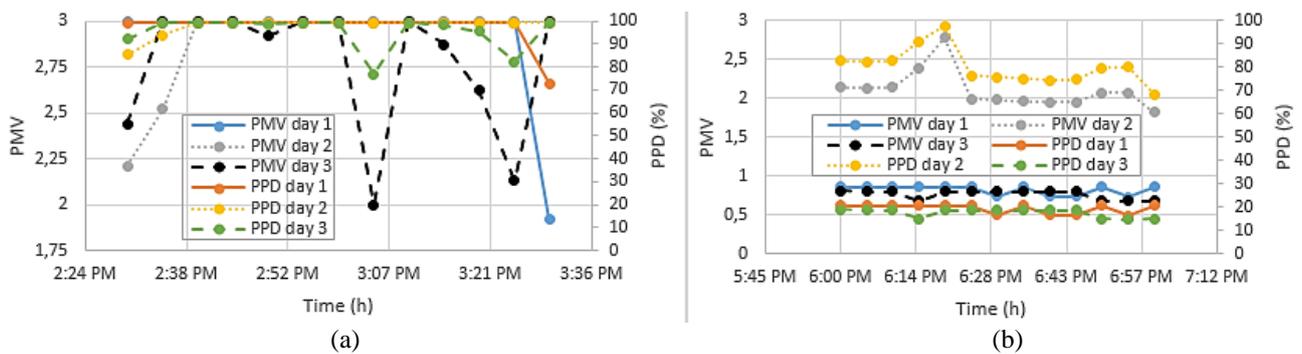


Figure 5. PMV and PPD charts of the category of students seated from the 3-day measurement: (a) day; (b) night.

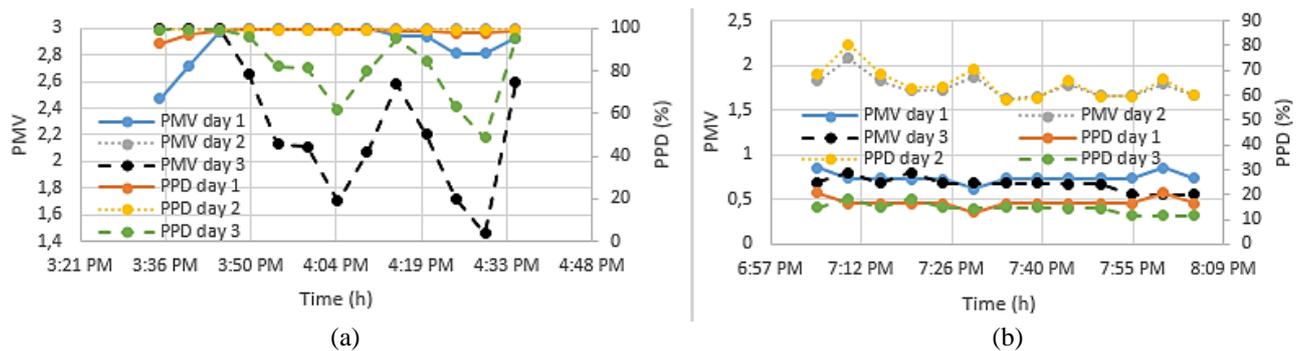


Figure 6. PMV and PPD charts of the category of students seated with the ventilator in operation during the 3 days of measurement: (a) day; (b) night.

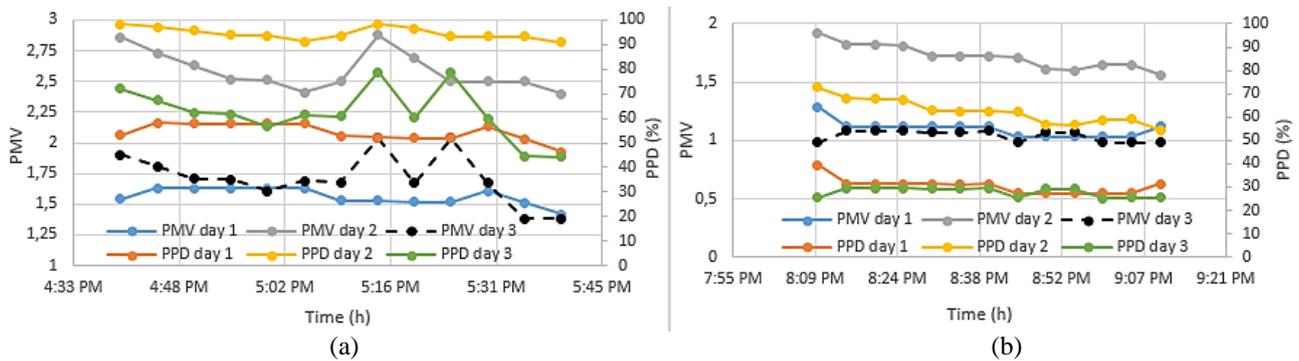


Figure 7. PMV and PPD charts of the teacher category giving a standing class of 3 days of measurement: (a) day; (b) night.

In order to provide thermal comfort, a PMV between -0.5 and 0.5 should be considered, with a PPD of less than 20% (ASHRAE, 2004). In the laboratory measurements, most of the measurements were framed as uncomfortable, a situation which is not the ideal for students professors in their class activities.

Especially in hot sunny days, the influence of direct solar radiation significantly affect thermal comfort, where the internal temperature of the analyzed laboratory became considerably higher than the external temperature. In the night period, due to the high incidence of the sun in the windows during the afternoons, and high thermal capacity of the materials, the temperature in the laboratory do not decreased. Associated to the internal gains provided by full occupancy at night classes and the use of both computers and educational plants, those responsible to dissipate a considerable amount of heat, thermal comfort conditions remain unfavorable.

It can also be stated that the environment presented a reasonable comfort index when the external temperature is below $18\text{ }^{\circ}\text{C}$, that is, with mild temperatures. The alternative to try to reduce the heat is the ventilators, but with this study, it can be verified that their presence does not significantly improve thermal comfort.

7. CONCLUSION

This work presented the development of a case study to validate the operation of the prototype of thermal comfort measurement, the ComfortMeter. As can be seen, the ComfortMeter has been able to measure the thermal comfort feeling of students and teachers within a lecture lab at an institution. Stating that the laboratory is uncomfortable thermally for high temperatures and comfortable only for days with mild temperatures. An alternative to this discomfort would be the installation of more efficient air conditioning equipment (not just fans) or hybrid systems that take into account the outside temperature to choose between ventilation or forced air conditioning.

This research exposed the evaluation of thermal comfort considering the PMV index. However, for natural ventilated spaces the most reliable index to comfort measures is the ASHRAE Comfort Standard (ACS) presented in ASHRAE (ASHRAE, 2004). In this way, the next step of this research is the inclusion of the ACS calculation in the prototype, providing an additional option to the users according to type of the air conditioning system adopted, natural based on window opening or forced based on air conditioning systems.

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9. RESPONSIBILITY NOTICE

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