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Adaptation and comparative study of thermal comfort in naturally ventilated classrooms and buildings in the wet tropical zones

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ABSTRACT

This paper presents the results of a study relating to thermal comfort in 28 buildings and schools, in the coastal and central areas of Cameroon. This research was conducted during the dry and rainy seasons, employing the adaptive approach, in naturally ventilated buildings, in accordance with ASHRAE 55/2004, ISO 7730 and ISO 10551. Wind speed, air temperature, relative humidity and CO_2 levels were measured, and 2650 questionnaires were distributed simultaneously. The results revealed that 76.7% of the voters in Douala found the results environmentally acceptable, as against 82.6% in Yaoundé. On average, 74.6% of the respondents found that these were within the comfort range, while 25.3% were neutral. When the local thermal comfort factor was analysed, it was found that the percentage of dissatisfied persons exceeded 40% in both cities, Yaoundé in particular, due to its higher average temperature.

1. Introduction

A comfortable and healthy environment is a prerequisite for robust human health. The concept of thermal comfort is quite complex and varies according to each subject [1]. However, although many international standards have defined the range of comfort, opinions still stand still widely divided. Comfort has been defined as the state of mind that expresses satisfaction with the environment [2]. As people spend a great percentage of their time in indoor ambiences [3], the indoor environment should be designed and operated to ensure the thermal comfort and health of its occupants. The results obtained from various studies showed that people do not wholly express their feelings regarding thermal preferences in naturally ventilated environments. The research works conducted [4–7] revealed the influence exerted by the physical, physiological and psychological feelings of peoples' preferences in a naturally ventilated environment. Different approaches were used in the studies performed over the past few years to ascertain the optimum levels of thermal comfort. This proactive approach is a development of the analytical approach initiated by Fanger [8]. It is based on the calculation of the predicted mean vote (PMV) and predicted percentage of the dissatisfied (PPD) from six main parameters established by Macpheson [9] including, clothing and metabolic resistance, dry bulb temperature, radiant temperature, relative humidity and wind speed. Today, most researchers opt for the adaptive or proactive model. The work performed in Australia, besides those conducted in the USA, Africa and Europe [10–19] highlight the importance of the adaptive models. The results obtained varied widely, depending upon the location of the study and the climatic seasons prevalent there. In particular, air temperature is one of the elements which directly affects the thermal comfort in a room. Several studies in the literature emphasised the importance of thermal comfort on productivity in buildings, offices, classrooms and other enclosed spaces. Therefore, Hussein and Hazrin [20] headed a case study in a health clinic located in southern Malaysia. Their results showed that over 80% of the respondents voted the thermal conditions to be acceptable and, despite this, those who were neutral were not always satisfied with the thermal conditions. Furthermore, Hens [21], using two practical case studies of thermal comfort during working hours, found a PMV of zero and a PPD greater than 5%, in clear disagreement with the actual standards. Consequently, new models, like local thermal comfort indices, must be analysed under such conditions.

On the other hand, in a field survey performed in Jos (Nigeria) developed by Ogbonna [22], the range of acceptable conditions in tropical classrooms has been recommended. Furthermore, in

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Fig. 1. Location of the city studied.

the research done by Zingano in Malawi [23] the importance of comfort-level temperature has been specified. Finally, Miyazawa [24] demonstrated that during the different sleep stages, the temperature range of thermal neutrality hovers between 19 °C and 25 °C. This study aims to compare the results obtained from an experimental study of thermal comfort in the tropical wet and warm (e.g., Douala) and tropical wet and cold (e.g., Yaounde) regions. In the present research work, a study is presented on the thermal comfort in 28 buildings and schools in the coastal and central regions of the Cameroon, based on the adaptive approach and local thermal comfort models. The questionnaire method was employed and physical measurements were taken simultaneously to obtain the neutral thermal comfort conditions in these regions. This first study can be the key to defining new strategies to improve thermal comfort conditions and reduce the building energy consumption in these indoor ambiences.

2. Field study

2.1. Cities analysed

Douala and Yaoundé rank among the largest cities in Central Africa, as seen in Fig. 1. Douala is the economic capital of Cameroon, the main business centre and one of the major cities in the country, located on the Atlantic Ocean coast, between 4°03′N and 9°42′E, covering an area of nearly 210 km^2. The climate in Douala is tropical wet and hot, characterised by temperatures between 18 °C and 34 °C, accompanied by heavy precipitation, especially during the rainy season from June to October. The air nearly always records 99% relative humidity during the rainy season and about 80% during the dry season, between October and May.

The city of Yaoundé, on the other hand, is the political capital of Cameroon, located centrally, at an altitude between 600 m and 800 m and approximately 300 km from the Atlantic coast. It enjoys a sub-equatorial climate (tropical wet and cold), with four seasons, including a long dry season (mid-November to late March), a short rainy season (April to mid-June), a short dry season (mid-June to mid-August), and a long rainy season (mid-August to mid-November). The city is spread over several hills, and enjoys a relatively fresh climate, much better than that along the coast, with the maximum temperature ranging between 30 °C and 35 °C and a minimum temperature of 15 °C.

2.2. Materials

In this study, the indoor air velocity, relative humidity, CO_2, temperature and surrounding light intensity were measured using the Thermo-Anemometer Model C.A1226, CO_2 Monitor model CO200 and a Light Meter IM-1308, respectively. The outdoor temperature, wind speed, and relative humidity values were simultaneously collected from the National Weather Station System. The main characteristics of the measurement system employed in this work are shown in Table 1. All equipment were calibrated before each experiment to ensure reliability and accuracy in the readings recorded during the field studies.

2.3. Methodology

The study was conducted during the summer and winter seasons in naturally ventilated buildings, adopting the adaptive approach and using questionnaires to obtain quantitative data on the actual conditions prevailing in these habitats. To achieve this objective, two data collection methods were used, namely, a questionnaire as the subjective measurement and a physical measurement of certain parameters that influence the thermal comfort conditions in buildings. In each building, in accordance with prior research works, sampling processes were performed between two and five days per season, in each different room or office. For multi-storey buildings, the offices chosen were those that supported a greater number of occupants. Table 2 shows some of the study periods. Regularly and prior to the distribution of the questionnaires, some questions were filled up regarding the occupants, such as personal data (age, sex) and micro thermal aspects (climatic control), to elicit better responses to the questionnaires.

The mean radiant temperature (T_r) was estimated using the regression model shown in Eq. (1) as a function of the air temperature measured (T_a) proposed by Nagano [29] under a determination factor of 0.99.

$$T_r = 0.99 \times T_a - 0.01, \quad R_2 = 0.99 \tag{1}$$

At the same time, the operative temperature (T_o) was determined from the air temperature measured (T_a) and the mean radiant temperature (T_r), as seen in the following equation [2]:

$$T_o = A \times T_a + (1 - A) \times T_r \tag{2}$$

where the weighting factor (A) depends on air velocity (w), as the following equation:

$$\begin{aligned} A &= 0.5 \quad \text{for} \quad w < 0.2\,\text{m/s} \\ A &= 0.6 \quad \text{for} \quad 0.2 < w < 0.6\,\text{m/s} \\ A &= 0.7 \quad \text{for} \quad 0.6 < w < 1\,\text{m/s} \end{aligned} \tag{3}$$

2.3.1. Field measurement of the environmental parameters

Measurements were taken every 20 min at a height of 1.2 m from the ground level in strict accordance with the prescriptions of the ASHRAE Standard 55 [2] and ISO 7730 Standard [25]. Once the devices were installed, measurements were recorded starting from 8:00 AM, to enable each unit to get adapted to the environment. The data were noted regularly until 7:00 PM. These measurements provided four of the six parameters established by Macpheson [9] including those of air velocity, relative humidity, ambient temperature and average radiant temperature. These parameters were then