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A thermal comfort evaluation in low-rise office buildings in Ghana

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ABSTRACT

A research project on the thermal performance of office buildings in Ghana was conducted and in the process, data loggers were used to record indoor environmental conditions over a period of 12 months in five office buildings. The temperature and relative humidity values recorded were analysed and plotted on psychrometric charts. The results of the study in 15 offices were placed in psychrometric charts which showed uncomfortable indoor environmental conditions. The reasons were high relative humidity values, although the temperatures in most of the cases were below 29°C. The impression gained during the observation period was that occupants had adapted to high humidity levels and therefore found maximum humidity levels of 80% comfortable, provided temperature values did not exceed 29°C. This significant clue calls for further study and the adjustment of the comfort scale for the climatic context of Kumasi, Ghana.

Keywords: Psychrometric; Environment; Occupants; Comfort; Thermal.

INTRODUCTION

Apart from the provision of space for diverse activities, the main task of designers is to ensure that occupants are comfortable and satisfied with the indoor environment. Moreover, designers usually provide building systems which must be operated by the occupants in order to attain comfort.

However, thermal comfort is a complex condition that determines the well-being of occupants, since numerous factors must be considered. Among the factors are the behaviour of occupants and their interaction with the environmental control systems. For instance, researchers [1 and 2] have observed that the operation of windows is a function of prevailing outdoor temperature. Others [3] concluded from studies of office buildings that beyond 28.1°C, the frequency of opening windows increases. Conclusions made in recent studies of office buildings showed that the operation of shades was a function of solar radiation on building facades [4 and 5]. Furthermore, they [4 and 5] noted that shades on the northern sides of buildings were operated less frequently than on the southern sides. Another researcher [6] found out that shades were normally fully raised or lowered. Building occupants interact with available building systems in an attempt to attain thermal comfort.

A summary of definitions was compiled by [7] stating that, "[8] defined thermal comfort as the absence of irritation and discomfort due to heat or cold, or in a positive sense, as a state involving pleasantness. Alternatively, [9] states that thermal comfort is the condition of mind which expresses satisfaction with the thermal environment. Further [9] notes that, because of biological variance, establishing a condition that will satisfy everyone is not likely to be achievable. Rather, the designer or the builder should instead seek to create a condition that will satisfy the largest number in a group of probable occupants."

The main factor of thermal comfort is the body's capability of balancing its own temperature with the thermal environment. This thermal balance depends on the internal heat load and energy flow (thermal exchange) of the body, which is executed through the processes of conduction, convection, radiation and evaporation (perspiration and respiration) [10]. The main conditions allowing heat to be lost are air temperature, humidity, air velocity and mean radiant temperature [11]. Other minor factors are age, sex, clothing, health and activity of occupants.

For tropical regions, a comfort range of 23 - 29°C with a relative humidity of 30 - 70% has been suggested [12]. In addition, [13] have proposed 22 - 27°C with an optimum temperature of 25°C. A researcher, [14] is of the opinion that the general consensus of suitable design set point for tropical buildings is 25°C and 60% relative humidity. Another research work [15] suggests 22 - 26°C and 30 - 80% relative humidity as optimal values for indoor comfort. The American Society of Heating, Refrigeration and Air-conditioning Engineering (ASHRAE), recommends 23°C to 26°C as temperature range for summer comfort [15].

According to [17], the neutral temperature (adaptive model) is the temperature at which a person should be neither too hot nor too cold. The comfort zone is 2°C below and above the neutral temperature (Equation 1). On the other hand, [18] has set the comfort zone for 90% acceptability to be 2.5°C above and below the neutral temperature after, [19].

$$Tn = 17.6 + 0.31 \times To.av \qquad (1)$$

Where, To.av. = the mean monthly outdoor temperature (°C)
Tn = neutral temperature (°C)

MATERIALS AND METHODS

Five buildings (see Table 1), situated in different locations in Kumasi, Capital of Ashanti Region of Ghana were selected for the studies. These buildings are representative of the majority of existing low-rise office buildings and house different functions (university offices, private companies, municipal offices, etc.). The applied cooling systems typically involve split air-conditioning units. The buildings were given the codes CAP, KCR, ROY, ANG and DCD.

Table 1- Overview of the selected office buildings with function, net floor area and thermal controls

Building	Function	Floor area (m²)	Thermal controls
CAP	University	795	Mixed mode
KCR	NGO	1100	Air-conditioned
ANG	Private	365	Air-conditioned
ROY	Construction company	1740	Air-conditioned
DCD	Community	280	Naturally ventilated

Data loggers were installed in 15 offices to measure indoor temperature and relative humidity levels (at 10 minutes interval) for a period of 12 months. Due to financial constraints, it was not possible to monitor outdoor weather conditions with a weather station at each building site. Therefore, five additional data loggers were used to record the outdoor temperature and relative humidity values. The recorded data was then compared with the mean maximum and minimum values received from the Kumasi weather station (see Fig. 1).

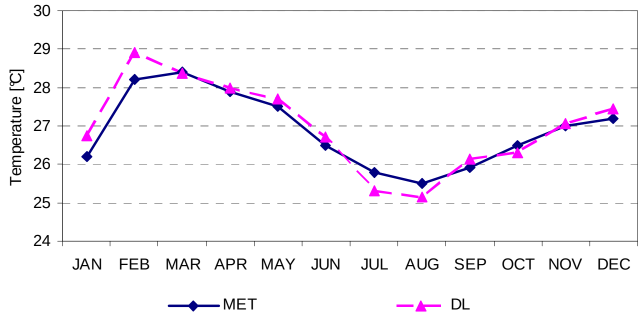

Fig 1 Comparison of mean outdoor temperature measurements at office locations (DL) with Kumasi weather station data (MET)

Table 2 shows the accuracy of the sensors. The measured data were analysed in spread sheets format and the various mean monthly values were plotted on psychrometric charts based upon the adaptive model (Table 3).

Table 2- Accuracy of the sensors

Sensor	Range	Error
Air temperature	-20 to 70 °C	± 0.4 °C
Relative humidity	5 to 95 %	± 3%

The adaptive model based on the work of [19] and recommendation by [18] for 90% acceptability was used to derive the comfort zone for Kumasi (Table 3 and Fig. 2). The generated mean maximum, minimum and hourly values during the working hours were then plotted on psychrometric charts.

Table 3- Neutral temperature for 90% acceptability (Adaptive model)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
To.av.	26.5	28.6	28.4	27.9	27.6	26.6	25.5	25.3	26.0	26.4	27.0	27.3
Tn+2.5	28.3	29.0	28.9	28.8	28.7	28.3	28.0	27.9	28.2	28.3	28.5	28.6
Tn	25.8	26.5	26.4	26.3	26.2	25.8	25.5	25.4	25.7	25.8	26.0	26.1
Tn-2.5	23.3	24.0	23.9	23.8	23.7	23.3	23.0	22.9	23.2	23.3	23.5	23.6

RESULTS AND DISCUSSION

The recorded indoor air temperature and relative humidity values (mean monthly hourly maximums, minimums and hourly means, during the working hours) have been plotted on psychrometric charts to analyse the thermal conditions pertaining in the office spaces (buildings CAP, KCR, ANG, ROY and DCD) in relation to the comfort zone.

In Fig. 2, a shift of the comfort zone to the lower (left) and to the higher (right) temperatures is demonstrated with the mean hourly temperature and relative humidity values in Kumasi for representative days in the months of February and August. The shift of the comfort zone is minimal because of the minor difference in the outdoor temperature (Tn difference of 0.9°C, Table 3) during the warmest month (February) and the coolest month (August).

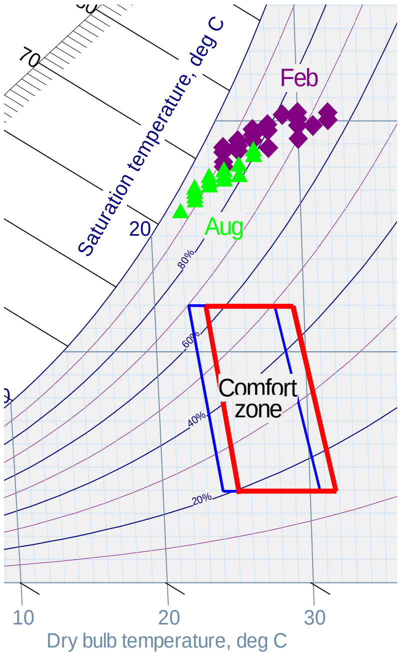

Fig 2 Mean hourly temperature and relative humidity values in Kumasi for representative days in the months of February and August

During the warmest period (dry season), mean temperature levels are high, and in some cases exceeding 30°C. However, the mean temperature levels hardly exceed 28°C during the rainy season, especially in the months of June, July and August. The relative humidity values are rather high, averagely 80% and the effect is the experience of uncomfortable sensations. This is a characteristic of warm and humid countries, where temperature and relative humidity values are high with intense solar radiation and cloudy conditions existing most of the time.

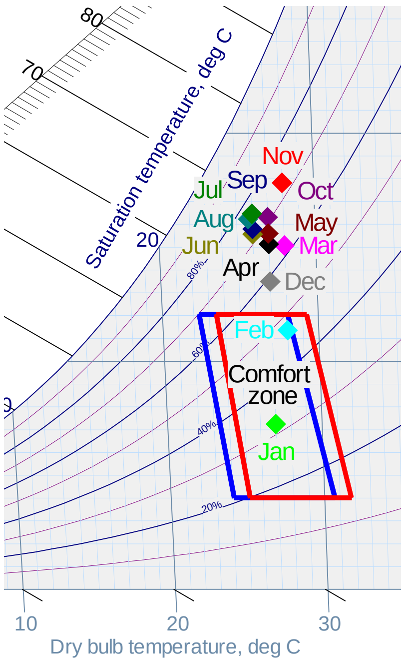

Fig 3 Mean monthly hourly maximum temperature and relative humidity values of offices in CAP (based on measured data from 8 to 17 hrs.)

CAP building

The mean monthly hourly maximum temperature and relative humidity values of the offices in CAP, based on measurements from 8 – 17 hours indicate that with the exception of the months of January and February, all months were above the comfort zone (Fig. 3).

The average relative humidity decreased from the outdoor value of 80% to 70%. The temperature values measured were below 28°C, however, the higher humidity levels resulted in most of the months being outside the comfort zone.

In Fig. 4, the mean monthly hourly temperature values measured resulted in only the month of January being comfortable. The month of February is just above the comfort zone. The mean relative humidity is around the 70% mark.

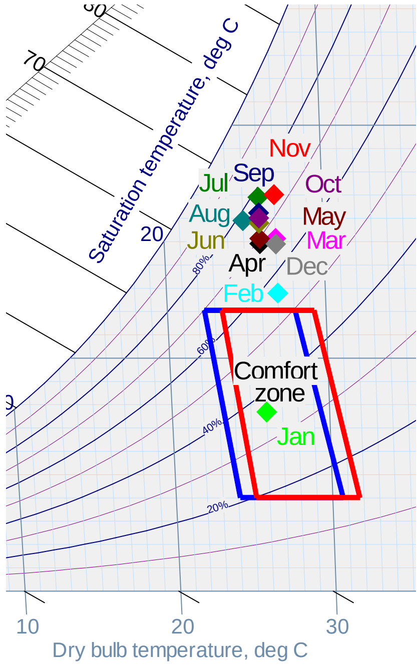

Fig 4 Mean monthly hourly temperature and relative humidity values of offices in CAP (based on measured data from 8 to 17 hrs.)

The mean monthly hourly minimum temperature and relative humidity also resulted in the month of January in the comfort zone. The mean temperature values were around the 25°C mark but the corresponding humidity levels were relatively high (Fig. 5).

The reasons for the performance of this building could be the effects of occupants regarding interaction with building systems (windows, fans, air-conditioners, etc.) (see [5 and 3]), and the efficiency of the environmental control systems [11]. Averagely, the temperature values were below 28°C and this shows that most of the occupants still considered the indoor climate to be comfortable. According to the comfort values given for tropical regions (23 - 29°C with a relative humidity of 30 - 70%) [12], this building could be seen as comfortable. The high humidity levels might not be a serious problem due to adaptive capabilities of the building occupants [20]. The evaluation of the office spaces on the measured temperatures alone would rate the building as a comfortable working environment. The effects of humidity on thermal comfort in the climatic context of Kumasi may need to be studied in detail.

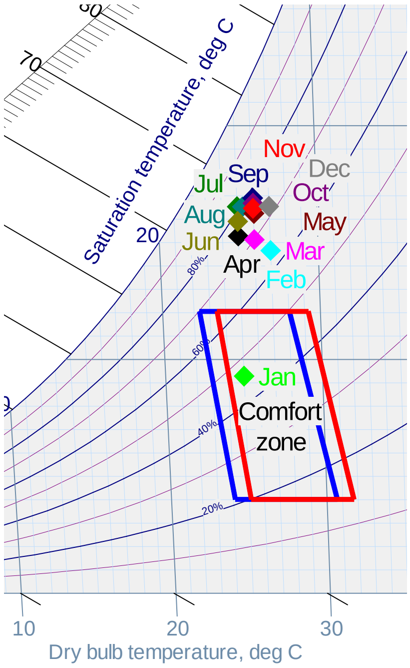

Fig 5 Mean monthly hourly minimum temperature and relative humidity values of offices in CAP (based on measured data from 8 to 17 hrs.)

KCR building

The mean monthly hourly maximum temperature and relative humidity values in KCR resulted in the months of January and February being in the comfort zone, even though the month of February is represented on the border line of the comfort zone (Fig. 6).

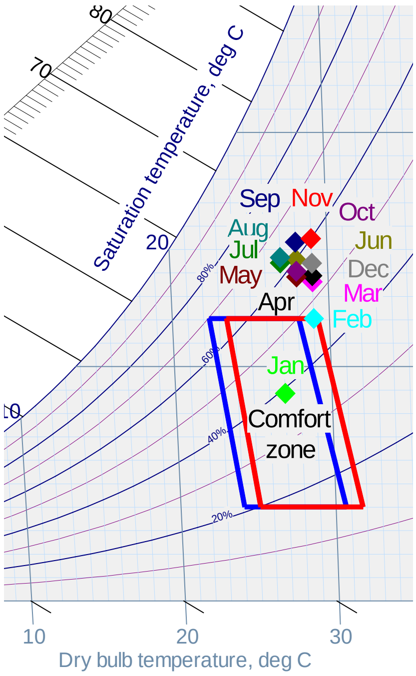

Fig 6 Mean monthly hourly maximum temperature and relative humidity values of offices in KCR (based on measured data from 8 to 17 hrs.)

The mean relative humidity values of the months outside the comfort zone decreased to about 58% when compared to the CAP building. This value is within the recommendations for comfort suggested by [12 and 15]. The recorded maximum temperature value was around 30°C. This is higher than the maximum value computed for 90% acceptability based on the adaptive model [18]. The discrepancies could be resulting from the efficiency of the air-conditioners and the different room sizes as related to air circulation [11]. The louvre blade and sliding glass windows in CAP (mixed-mode) and KCR (air-conditioned) with possible effects of frequency of operation are factors which influence thermal comfort [4 and 2].

In Fig. 7, the mean monthly hourly temperature and relative humidity values are represented. Comfortable months are January and February. The maximum temperature value was around 29°C and the mean relative humidity level was 60%.

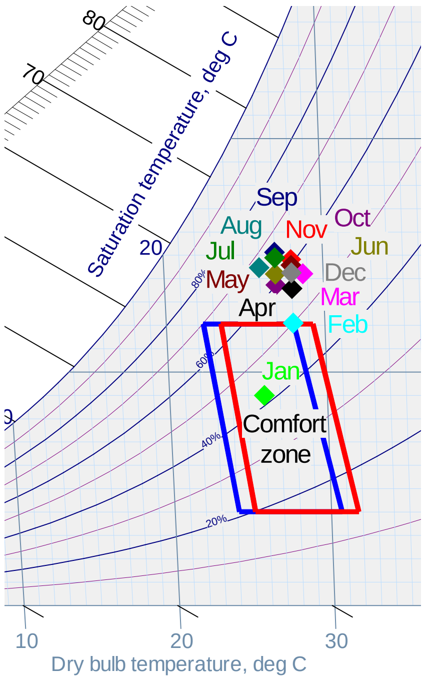

Fig 7 Mean monthly hourly temperature and relative humidity values of offices in KCR (based on measured data from 8 to 17 hrs.)

The mean monthly hourly minimum temperature and relative humidity values resulted in the comfort zone only in January. The mean temperature values were around the 27°C mark with the relative humidity value at 65% (Fig. 8).

The mean monthly hourly minimum values did not deviate much from the generally accepted design set point of 25°C and 60% relative humidity [14].

The relative poor performance of this building as compared to CAP could be due to the building form and orientation [10]. The CAP building, which is a rectangular block, had no windows on the eastern and western sides as compared to the L-shaped building of KCR. The behaviour of occupants at workspaces [6] and building system efficiency are also factors that could lead to thermal comfort problems [21]. It has been found that occupants mostly tend to switch on lights upon arrival in the office and lights are switched off generally at the close of work leading to higher thermal loads during the working hours [22 and 23].

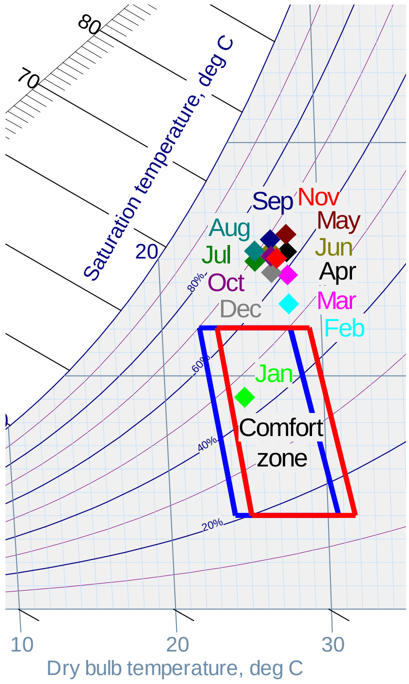

Fig 8 Mean monthly hourly minimum temperature and relative humidity values of offices in KCR (based on measured data from 8 to 17 hrs.)

ANsG building

At ANG, the mean monthly hourly maximum temperature and relative humidity values resulted in almost all the months being in the comfort zone (Fig. 9).

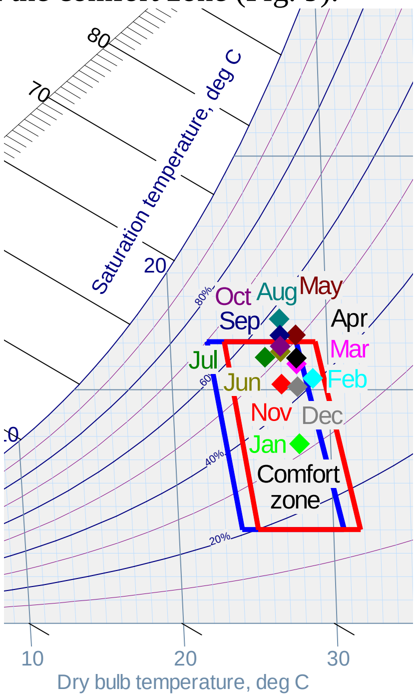

Fig 9 Mean monthly hourly maximum temperature and relative humidity values of offices in ANG (based on measured data from 8 to 17 hrs.)

The month of August was just above the comfort zone. The mean maximum temperature value was about 30°C; however, the relatively lower humidity levels of around 50% had the effect of the months being in the comfort zone. The temperature value alone would not have gained acceptance by 90% of the occupants [18].

The mean monthly hourly temperature and relative humidity values resulted in five months being outside the comfort zone (Fig. 10).

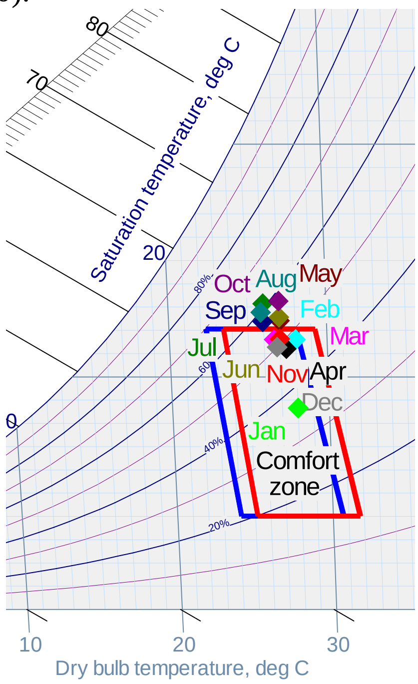

Fig 10 Mean monthly hourly temperature and relative humidity values of offices in ANG (based on measured data from 8 to 17 hrs.)

The mean temperature values were from 24 to 28°C. An increase in the humidity levels resulted in this representation. Even though the mean monthly hourly minimum temperature values in the offices were low, averagely 25°C, the relatively higher humidity levels caused all the months to be uncomfortable, with the exception of January (Fig. 11). This is against the temperature proposal of 22 - 27°C with an optimum value of 25°C as being comfortable, without considering the effect of relative humidity [13].

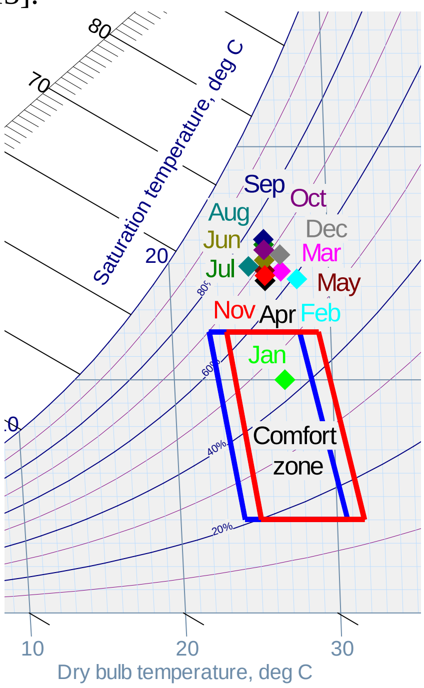

Fig11 Mean monthly hourly minimum temperature and relative humidity values of offices in ANG (based on measured data from 8 to 17 hrs.)

Possible aspects to explain this performance are the windowless offices (65% of the offices), orientation of the building, the relatively small sizes of the offices as compared to the other buildings, the efficiency of the air-conditioners and lastly the behaviour of the occupants in relation to thermal comfort [11 and 24].

ROY building

High mean temperature values were measured in the curtain wall building of ROY; a maximum value of 30°C in February, March and April (Fig. 12). With the exception of January, the months of February, October and September were on the border of the comfort zone. Comparatively, the maximum temperature values in ROY were higher than in the buildings discussed above.

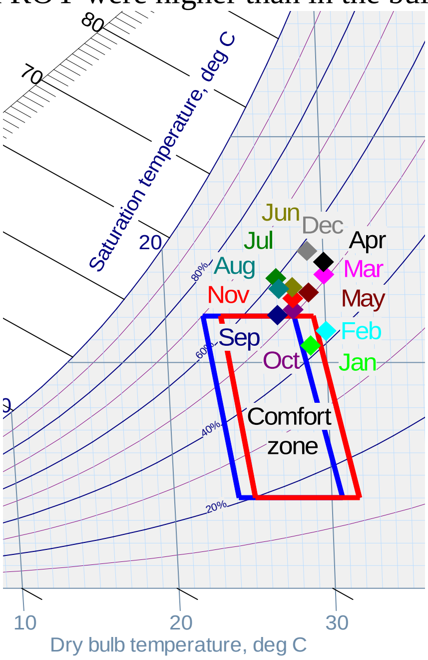

Fig 12 Mean monthly hourly maximum temperature and relative humidity values of offices in ROY (based on measured data from 8 to 17 hrs.)

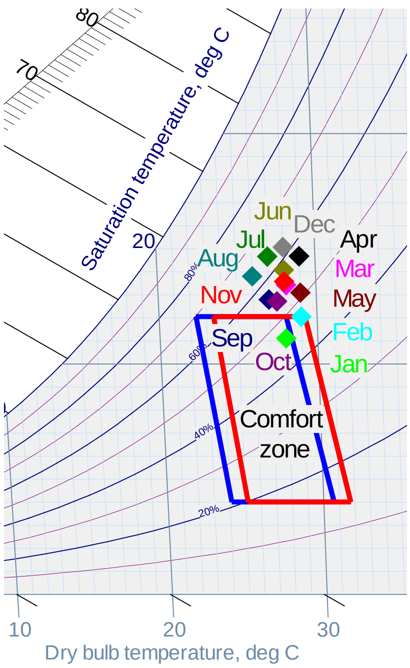

Fig 13 Mean monthly hourly temperature and relative humidity values of offices in ROY (based on measured data from 8 to 17 hrs.

The mean monthly hourly temperature and relative humidity levels resulted in the reduction of the air temperature to a mean value of 28°C (Fig. 13). The mean relative humidity value was about 58%.

The hourly minimum temperature and relative humidity values (Fig. 14) were similar to those in the other buildings. The humidity levels were high resulting in all the months being outside the comfort zone (January on the border line).

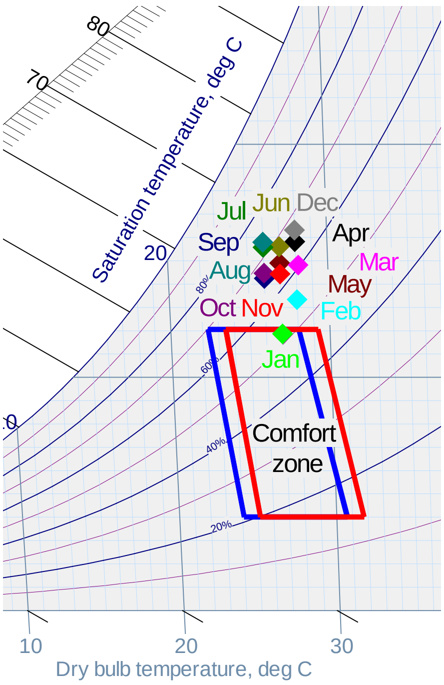

Fig 14 Mean monthly hourly minimum temperature and relative humidity values of offices in ROY (based on measured data from 8 to 17 hrs.)

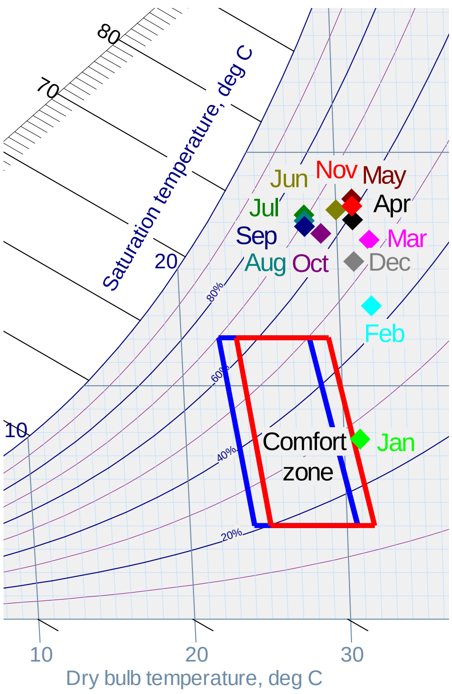

Fig 15 Mean monthly hourly maximum temperature and relative humidity values of offices in DCD (based on measured data from 8 to 17 hrs.)

The performance of the ROY building could be due to relatively more glazing on the façade and the effects of direct and reflected solar radiation regarding heat transfer through building envelopes. There are no shading devices on three sides of the monitored spaces and this worsens the situation when inefficient glazing and building systems are employed [25].

DCD building

From Fig. 15, the naturally ventilated building of DCD could be seen as uncomfortable. The mean maximum recorded temperature value (32°C) was higher than that in all the other buildings. An average temperature value of 30°C was computed. However, the mean humidity level was about 60%. This could be due to the effect of ventilation, reducing the humidity levels as opposed to the air-conditioned buildings.

The mean monthly hourly values of temperature and relative humidity could justify the month of January as comfortable (Fig. 16). The highest mean temperature value was 30°C and the lowest 26°C. The mean relative humidity level was about 70%.

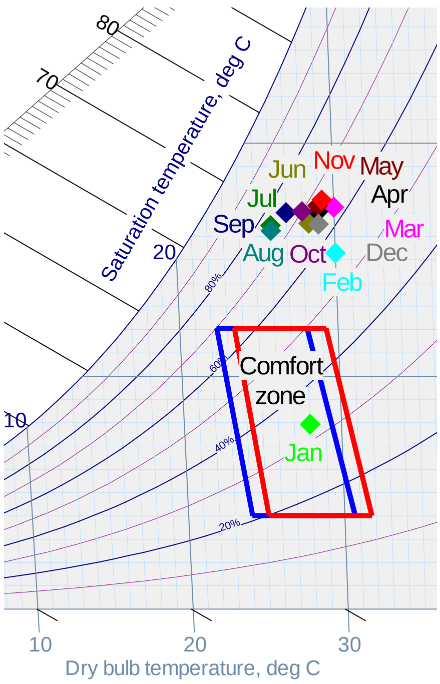

Fig 16 Mean monthly hourly temperature and relative humidity values of offices in DCD (based on measured data from 8 to 17 hrs.)

The mean hourly minimum values did not deviate much from Fig. 17 and only the month of January was comfortable.

The poor performance of building DCD could be due to the lack of efficient or even non-existing building systems, such as fans. The arrangement of the office spaces did not support sustainable design principles, therefore the positive effects of cross ventilation could not be utilised. Occupants' behaviour in operating the shades is also a factor, as curtain shades remained drawn until close of work, which resulted in a reduction of air speed. In similar studies of office buildings, shading devices were found to be often deployed in the southern sides of buildings and left closed or partly open until the close of the working day [26 and 5]. This behaviour was also observed in the case studied buildings. The guidelines for sustainable design principles should be followed in a consequent manner, in order to produce a favourable indoor climate, comfort and satisfaction [11, 27, 28, 29, 30, 31 and 32]. The attainment of a good indoor climate is paramount since people spend about 80% of their time in homes or offices [33]. The use of fans was found to help in the evaporative potential of the skin and should be a priority in all office buildings, especially in naturally ventilated types, since the effect would be thermal sensation reduction of air temperature values of 2 – 3°C [17].

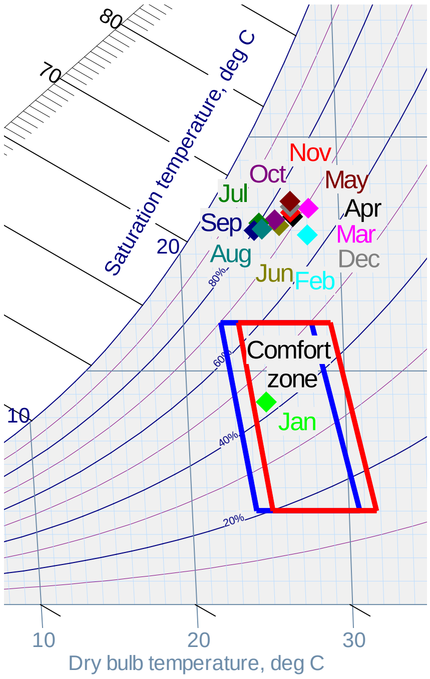

Fig 17 Mean monthly hourly minimum temperature and relative humidity values of offices in DCD (based on measured data from 8 to 17 hrs.)

CONCLUSION

The existing indoor conditions in the office buildings plotted on the psychrometric charts resulted in almost all the months being represented outside the comfort zone.

The reasons were the high humidity values, even though the temperatures in most of the cases were below 29°C. The impression gained during the observation period was that occupants were adapted to higher humidity levels and therefore could find maximum humidity levels of 80% comfortable, if temperature values did not exceed 29°C. However, this temperature is 3°C more than the suggestion of [15] but tallies with the maximum value under the neutral temperature table. The effect would be the representation of most of the months (temperature and relative humidity plots) inside the comfort zone on the psychrometric chart. This would call for the adjustment of the comfort scale for the climatic context of Kumasi, Ghana.

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