

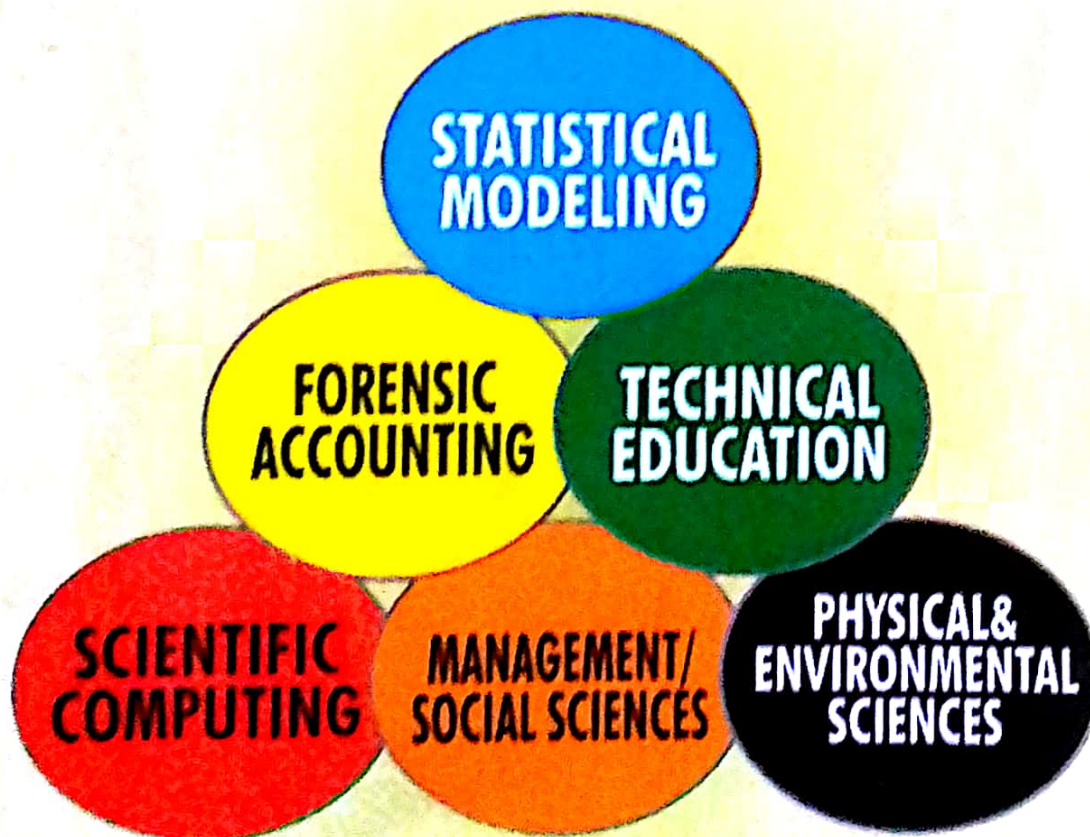


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TECHNICAL EDUCATION & MANAGEMENT SCIENCES

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MEASUREMENT OF RELATIVE HUMIDITY AND EVALUATION OF ITS IMPLICATION ON THERMAL COMFORT AT A TROPICAL ENVIRONMENT

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ABSTRACT

The attainment of a desirable combination of temperature, relative humidity and air movement for human beings in a tropical environment is studied and presented in this paper. Atmospheric influence on human's sensation of thermal condition depends on the interaction of heat, moisture and air i.e. Dry Bulb Temperature (DBT), relative humidity (RH) and air flow rate and thermal radiation with the human body. Each can have a dominating effect. In addition to a wet and dry bulb thermometer, an experimental evaporative humidifying unit constructed to aid in achieving thermal comfort was also employed. The DBT and WBT (Wet Bulb Temperature) in an isolated room were measured alongside the thermal conditions of some human beings of different sex and ages between 30 and 35 years of age (the human subjects were engaged in normal activities and wearing normal clothing) in a room of dimension 8.24m x 3.46m x 3.89m. Variation in their thermal comfort was noted with varying RH and air speed for the months of August, September and October 2004. Their thermal comfort range was observed to be between the RH ranges of 59 and 70%, DBT range of 26 to 31°C, and air flow rate of between 4.18 and 6.27m³/s. There are no psychological and physiological differences in response to exposures of the above ranges in the room and Thermal shock was not experienced by the human subjects on moving out of the room.

Keywords: Dry bulb temperature, Relative humidity, air flow rate, thermal comfort.

1.0 INTRODUCTION

Humidifier is a device for adding water vapour to the air in a room or building to increase the relative humidity. Small portable humidifiers are used in houses especially in winter in cold regions and when the air is very dry i.e., during harmattan. Large units of

humidifiers are used in cigar factories, textile mills, printing establishments, and other industrial plants to provide optimum relative humidity for processing materials and products. Humidifiers also serve to reduce static electricity. Humidifiers add moisture to the air by any of the several basic methods. These include spraying water into a room or air stream; spraying water into an enclosed unit, or using wetted wicks or pads in such a unit, with fan to distribute the moist air.

1.1 COMFORT CONDITION

Comfortable condition results from attainment of a desirable combination of temperature, humidity, air movement and air cleanliness (Fanger, 1970). However, one may have comfort under varying values of these factors. Extensive tests have been conducted on people in order to determine the effect of temperature, humidity and air velocity on their thermal comfortability with respect to heat sensation feeling (though results obtained are not in complete agreement). The human body is able to accustom itself only to a certain amount of change in a given length of time. Therefore, it becomes necessary to regulate air conditioning equipment so that it will produce only a certain output. While this will be less comfortable, it will not subject the person to too great a shock on entering this conditioned space, or when going out into the normal outdoor atmosphere.

1.2 HUMAN RESPONSE TO HEAT

Heat or rather the thermal state of the environment is perceived by the skin surface of a living body. The skin temperature sensors are most sensitive around 34°C, and quite small changes or differences in the temperature are perceived. The sensitivity decreases towards the very low and extremely high temperatures.

Heat from the environment can reach the body surface by any of all the three mechanism of heat transfer (conduction, convection and radiation) while the skin perceives the total combined thermal effect. Thermal balance exists when the heat produced by the body is fully dissipated to the environment. The heat produced in the deep-body tissues is continuously transported to the skin surface (and to the lungs), where it is emitted to the

environment by convection, radiation and evaporative heat transfer, and some also by conduction (Fanger, 1970).

1.3 THERMAL COMFORT

The limits of existence can be defined in terms of deep-body temperature as lying between 35 and 40°C, the normal being approximately 37°C. The skin temperature (normally at 33.7°C) must always be lower than the deep-body temperature. The temperature of the environment, in turn must be below the skin temperature, if heat is to dissipate. The range of environmental temperatures which will allow sufficient, but not excessive heat dissipation, and will therefore be judged as 'comfortable', is referred to as the comfort zone (Givoni, 1994).

1.4 MAIN FACTORS THAT INFLUENCE THERMAL COMFORT

AIR TEMPERATURE (DBT):- This is the temperature of the air around us and is the most important of all the above factors. The human body's primary response is towards the changes in temperature and it is this temperature that we attempt to keep within comfort conditions while designing structures for habitation (Shelton et al, 1983).

RELATIVE HUMIDITY (RH in %):- Humidity of the atmosphere has little effect on thermal comfort sensation at or near comfortable temperatures, unless it is extremely low or high. Of the various measures of humidity, the relative humidity, RH, is the most immediately relevant, as it determines the possible evaporation rate (Fanger, 1970). Moisture from the skin evaporates much more quickly in a dry than a humid atmosphere. At high temperatures, skin evaporation is the most important heat dissipation channel.

AIR MOVEMENT:- This can produce different thermal effects at different air temperatures in the following two ways:

(i) It increases convective heat loss, as long as the temperature of the moving air is less than the skin temperature. If this condition is not fulfilled, the air actually warms the skin.

(ii) It accelerates evaporation, providing a physiological cooling. Its effect is insignificant at humidity lower than 30%.

THERMAL RADIATION (MRT):- Next to air temperature, radiation has the greatest effect on thermal sensation. Radiation falling on the body surface activates the same sensory organs as the warmth of the air. Falling on an intervening surface, such as clothes, the radiant heat is converted to long-wave electromagnetic radiation causing sensible heat, which is then conducted through that material to the skin.

MRT is the mean of the thermal radiation from all materials around us including walls, floors, other human bodies etc. It is the kind of radiation that comes from heated stone. There can be a difference between MRT and the temperature of the air.

ACTIVITY (Met):- Generally speaking, the human body generates more heat when active in comparison to when at rest. A very important principle involved here is that of metabolic rate. The human body constantly produces heat, but at a varying rate. Metabolism is the term describing the biological processes within the body that leads to the production of heat.

Table 2 TYPICAL METABOLIC HEAT GENERATION FOR VARIOUS ACTIVITIES

ACTIVITY	HEAT (W/m ²)	Met
Sleeping	41.02	0.7
Seated, quiet	56.80	1.0
Writing	56.80	1.0
Typing	63.10	1.1
Filing, standing	82.03	1.4
Driving Car	56.80 - 116.74	1.0 - 2.0
Flying Aircraft, combat	138.82	2.4
Heavy vehicle	186.15	3.2
Cooking	91.50 - 116.74	1.6 - 2.0
House cleaning	116.74 - 138.82	2.0 - 2.4
Dancing, socials	138.82 - 255.56	2.4 - 4.4
Calisthenics/exercise	123.53 - 233.47	3.0 - 4.0
Basketball	283.95 - 441.70	5.0 - 7.6

(Roberts, 1997)

CLOTHING (Clo): The individual can exert a considerable degree of control over most form of heat exchange between his body surfaces and the environment by choosing his/her clothes. Calculation of heat transmission through clothing would be extremely cumbersome, so the CLO unit has been devised to simplify the handling of the insulating cover. This corresponds to an average U-value of $6.5 \text{ Wm}^{-2} \text{ degC}^{-1}$ over the whole of the body surface. Under still-air conditions, when a person is engaged in a sedentary activity the variation of 1clo would be compensated for by some 7°C temperature change. Under windy conditions, or if one is engaged in heavier work, the effect would be more pronounced.

Table 3 GARMENT INSULATION VALUE (CLO)

Description	Clo	Heat (W/m^2)
Men's brief	0.04	0.260
Panties	0.03	0.195
T-shirt	0.08	0.520
Sandals	0.02	0.130
Boots	0.10	0.650
Sleeveless, scoop-neck blouses	0.12	0.780
Short-sleeve, dress shirt	0.19	1.235
Long-sleeve, dress shirt	0.25	1.625
Trousers	0.24	1.625
Sweatpants	0.30	1.950
Single breasted suit	0.36 - 0.44	2.340 - 2.860
Sleeveless sweater	0.13 - 0.22	0.845 - 1.430
Long-sleeve sweater	0.25 - 0.36	1.625 - 2.340
Skirt	0.14 - 0.23	0.910 - 1.495
Long-sleeve skirt dress	0.33 - 0.47	2.145 - 3.055
Long-sleeve, long gown, thick	0.46	2.990
Long-sleeve, pajamas, thick	0.57	3.705
Short-sleeve, pajamas, thin	0.42	2.730

(Robert, 1997)

1.5 OTHER FACTORS THAT INFLUENCE THERMAL COMFORT

There is a range of subjective, non-quantifiable factors which affect the thermal preference of the individual by either changing the metabolic rate or influencing the heat dissipation mechanisms. There are almost no indices to go by, but it is useful to keep such factors in mind in situations where the intended design is for people that could be identified with one or more of the factors below (Robert, 1997).

- 1. Acclimatization:** - It happens when one moves from one geographic region to another that is different in its climatic conditions. The body has to come to terms with the change in the environment. Different researches done across a time – period of decades seem to indicate that there is no significant difference in the thermally neutral conditions between the temperate and tropical locations. Or, expressed rather more cautiously, if a difference does exist between the comfort conditions, then it is slight, and not of engineering significance.
- 2. Age and Sex:** - Although it is widely expected that elderly persons prefer warmer environments, there are no experimental results to support the hypothesis. The reason for the existence of the above hypothesis is that the basal metabolic rate decreases slightly with age. However, so does the insensible perspiration for the elderly.
- 3. Body Build:** - It is argued time and again that since a tall, thin body has a greater surface-to-volume ratio than a rounded figure, and so loses proportionately more heat, a thin person prefers a higher temperature. Also, the fats under the skin act as an insulator, reducing the conduction of heat from deep-body tissues to the surface. But no supporting experimental evidence has been cited.
- 4. Conditions of Health:** - When a person is ill the metabolic heat production may change without proper functioning of the regulatory mechanisms. Consequently, external means may have to be substituted for the normal internal controls. The environmental temperature should be changed inversely to the metabolic rate.
- 5. Food and Drink:** - The intake of food causes an increase in internal heat production. The consumption of alcohol does not change the production of internal heat noticeably.

though by skin vasodilation, it gives a sensation of warmth. At high doses of alcohol the resulting hypaesthesia will, of course, make the concept of thermal sensation and comfort meaningless (Fanger, 1970).

2.0 METHODOLOGY

A constructed experimental humidifier was used in a room, shielded from direct solar radiation, of dimension 8.24 m x 3.46 m x 3.89 m. All through the periods the experiment was carried out, the room had at least one occupant and at most eight. The room was equipped with a ceiling fan of 360 RPM as its maximum speed, and fan blade length of 0.6 m.

The DBT and WBT inside the room and the natural outside environment were measured using a sling Psychrometer and recorded at an hourly interval from 8 am to 18 hours local time daily, starting from the first day of August, 2004. The data obtained were then read on the Psychrometric Chart or the Wet Bulb Depression Chart to determine the RH value for each reading.

The human subjects also express their feelings as being not good, fair and good.

The test was carried out under different air flow rates i.e. 0Q, 0.2Q, 0.4Q, 0.6Q corresponding to 0, 2.09, 4.184 and 6.277m³/s respectively.

3.0 RESULTS AND DISCUSSION

Fig. 1a presents variation of indoor relative humidity (RH) with local time. The variations of the parameter in the three months show the same pattern, i.e. the RH at 8 hour was around 72%. This value remained almost constant till about 13 hour after which a gradual increment was noticed. The October value is the highest followed by September and August respectively.

It is understood that the humidifier functions as expected by raising the humidity in the room. The implication of this observation on human thermal comfort is that higher RH is not favourable for achieving thermal comfort as the human subjects complained when RH is high.

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The DBT and WBT inside the room and the natural outside environment were measured using a sling Psychrometer and recorded at an hourly interval from 8 am to 10 hours local time daily, starting from the first day of August, 2004. The data obtained were then read on the Psychrometric Chart or the Wet Bulb Depression Chart to determine the RH value for each reading.

The human subjects also express their feelings as being not good, fair and good.

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Fig. 1b gives the variation of outdoor RH with local time. This shows an irregular pattern of the parameter in the three months. The RH during August at 8 hour is observed to decrease for the next two hours and suddenly rose at the 11 hour and decreases from then to 13 hour when a slight but continuous increase is noticed up to 18 hour. But in September, a rather general gentle decrease is observed, except the sudden sharp increase at 11 hour. October pattern shows a general decrease in RH. It increases between the 14 and 16 hour and decreases to its lowest value at the 17 hour from where it started to rise.

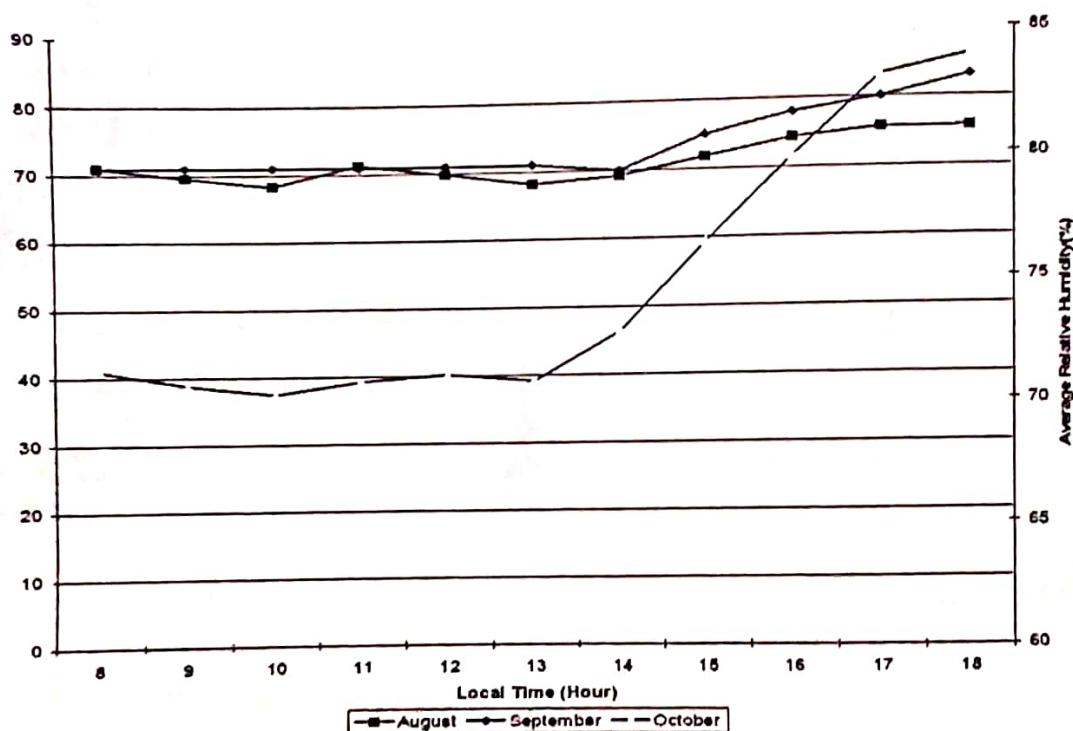


Fig. 1a Graph of the Variation of Hourly average indoor RH in Ilorin for the months of August, September and October, 2004

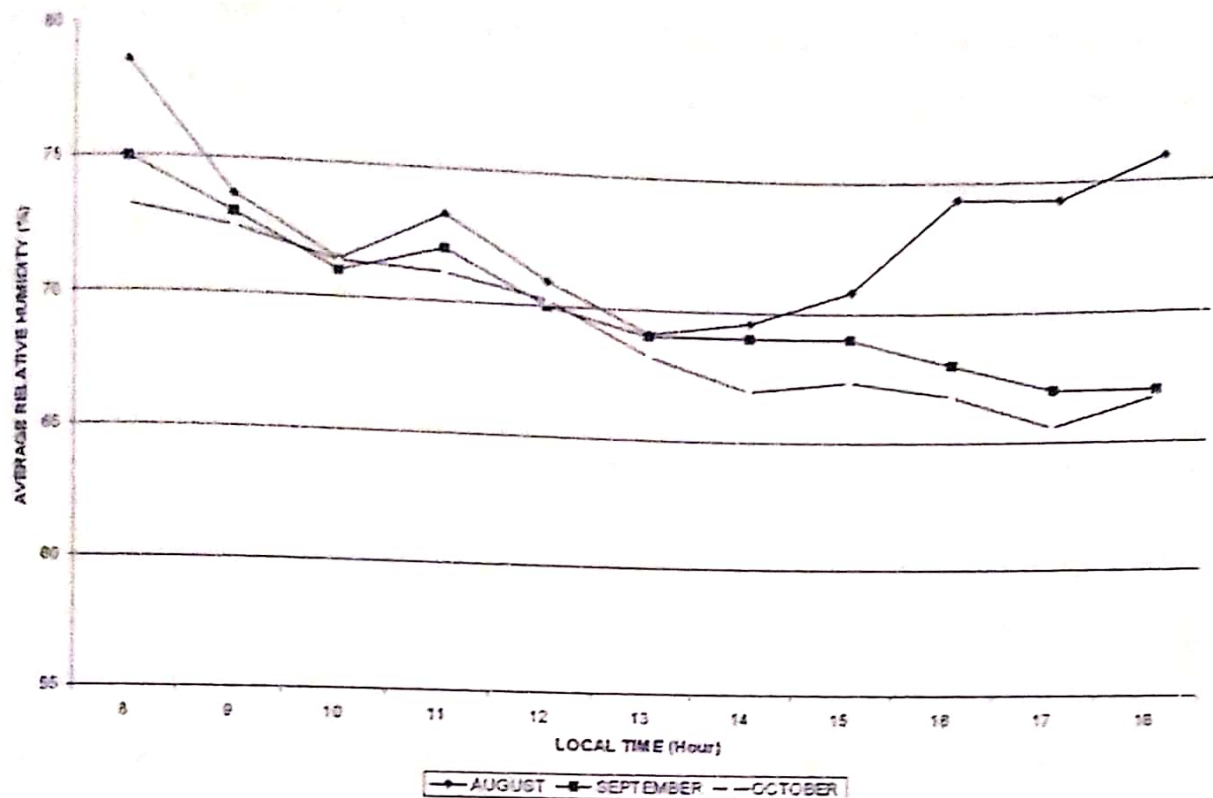


Fig. 1b Graph of the Variation of outdoor Hourly average RH in Ilorin for the months of August, September and October, 2004.

Fig. 2a shows the variation of the **difference** between the observed average indoor relative humidity (RH) and the average comfort RH of 45% (Arens et al, 1992). The difference in average hourly RH and the average comfort RH for the three months shows almost the same pattern. It was observed to be almost constant from 8 to 12 hour. There is a general RH increase from 13 hour.

This observation shows how far off the average comfort RH the observed average indoor RH is. The implication of this on thermal comfort is that the farther the observed averages of RH stray from the average comfort RH the more uncomfortable the human subject experiencing such will feel.

Fig. 2b gives the variation of the **difference** between the observed average outdoor relative humidity (RH) and the average comfort RH (45%). There is a general decrease in the difference from 8 to 13 hour when the difference in August changes from what was observed in September and October. There is a general decrease in the difference

during the months of September and October, while in August an increase was observed.

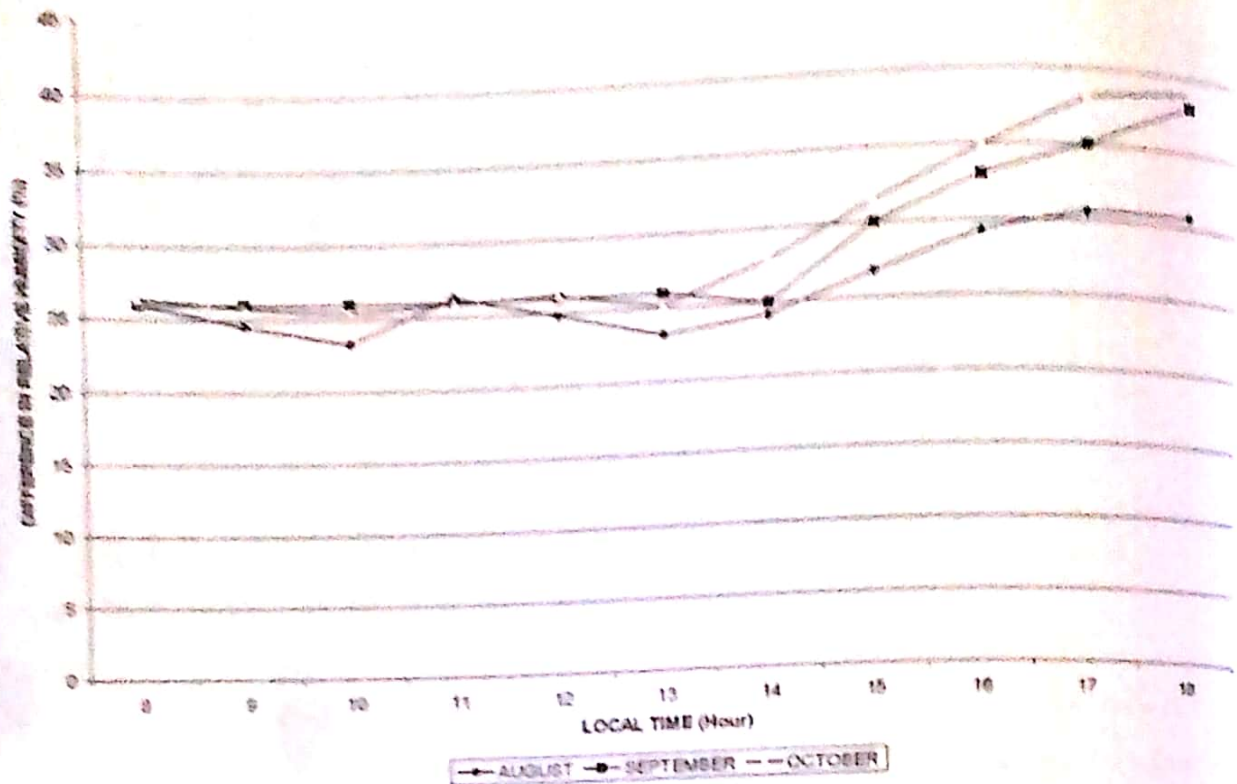


Fig. 2a Graph of difference between the observed hourly average indoor RH in Ilorin and the Comfort RH (45%) for August, September and October, 2004

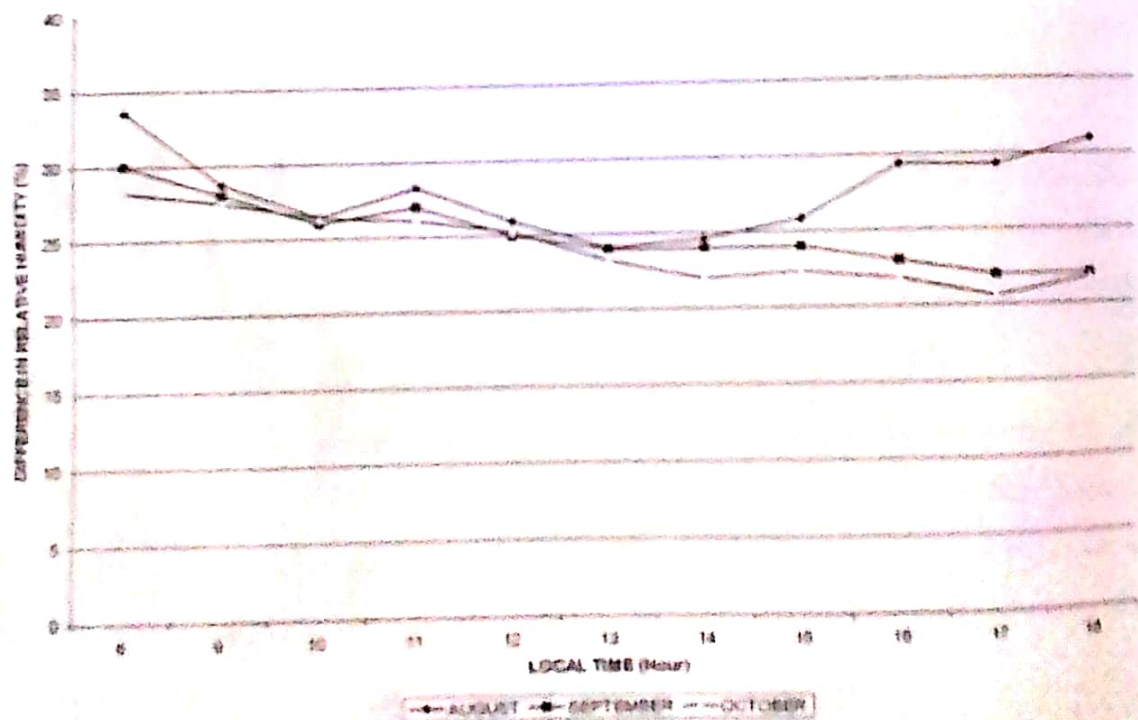


Fig. 2b Graph of the difference in the observed outdoor hourly average RH in Ilorin and the Comfort RH (45%) for August, September and October, 2004.

Fig. 3a presents the variation of the hourly average indoor relative humidity (RH) and dry bulb temperature (DBT) with time in August, 2004. The DBT value was observed to be at its peak value between 12 and 15 hour which corresponds to the least value of RH. The DBT then decreases gradually with time thereafter and this also corresponds to the gradual increase in RH.

Fig. 3b presents the variation of the hourly average indoor RH and DBT with time in September, 2004. The DBT value was observed to be at its peak value between 12 and 15 hour which corresponds to the least value of RH. RH was also seen to increase with decrease in the DBT.

Fig. 3c presents the variation of the hourly average indoor RH and DBT with time in October, 2004. The DBT was observed to be at its peak value between 12 and 14 hour which also corresponds to the least value of RH. The RH was again seen to increase with decrease in the DBT.

The above observations show an inverse proportionality relationship between DBT and RH. This is because as the DBT rises, the volume of air also increases and its capacity to hold moisture increases which consequently lowers the RH (Fanger, 1970). It also shows that the experimental humidifier functions as expected i.e. by increasing the humidity in the room.

The implication of this is that ordinarily high RH is compensated for by a low DBT to enable the body experience a temperature that is not too high or too low. The human subject feels more comfortable in the early hours of the day than towards the evening in the room because of the 'forced' greenhouse effect.

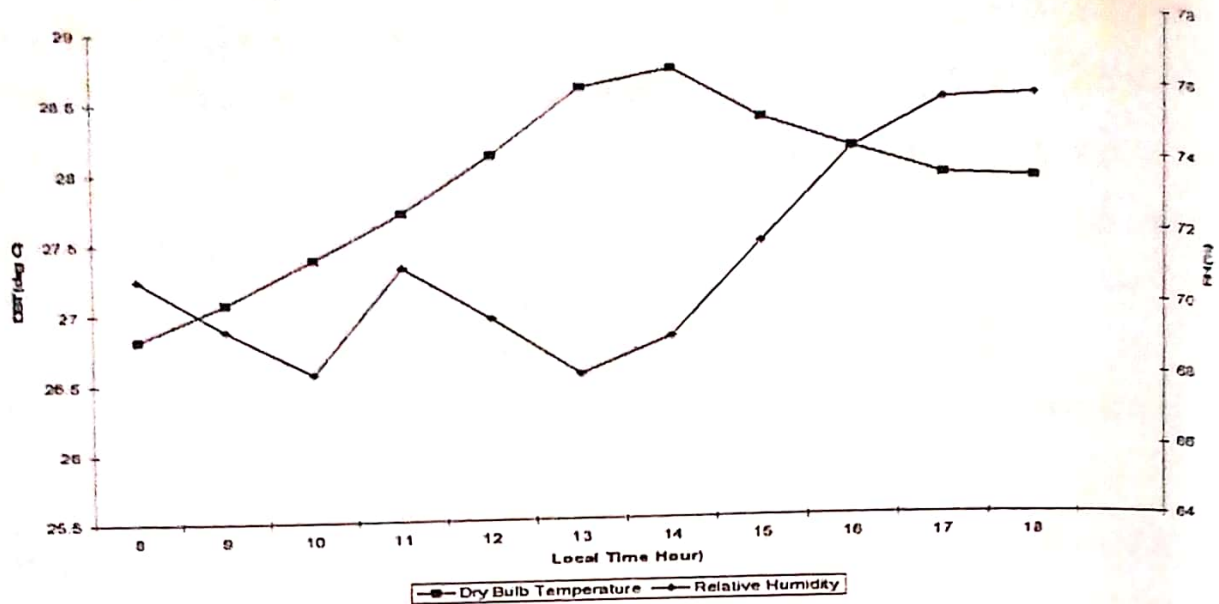


Fig. 3a Graph of the variation of the hourly average indoor RH and DBT in Ilorin for August, 2004

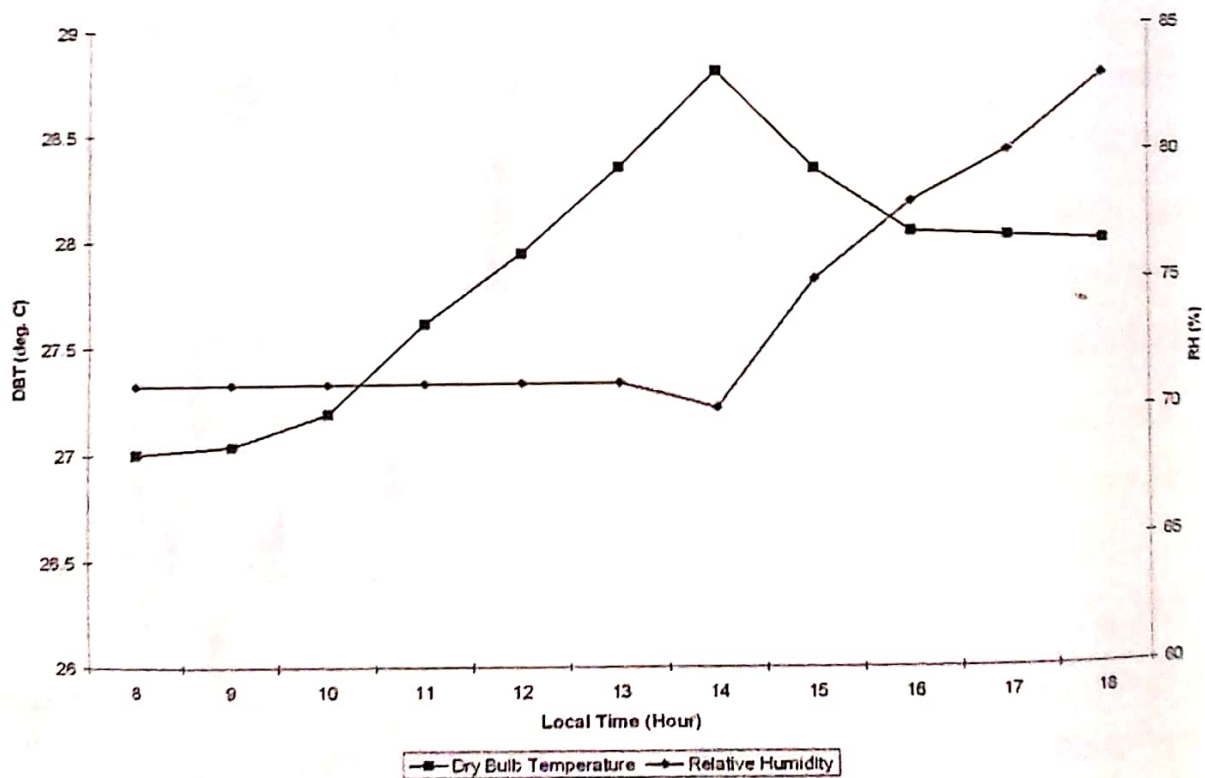


Fig. 3b Graph of the variation of the hourly average indoor RH and DBT in Ilorin for September, 2004

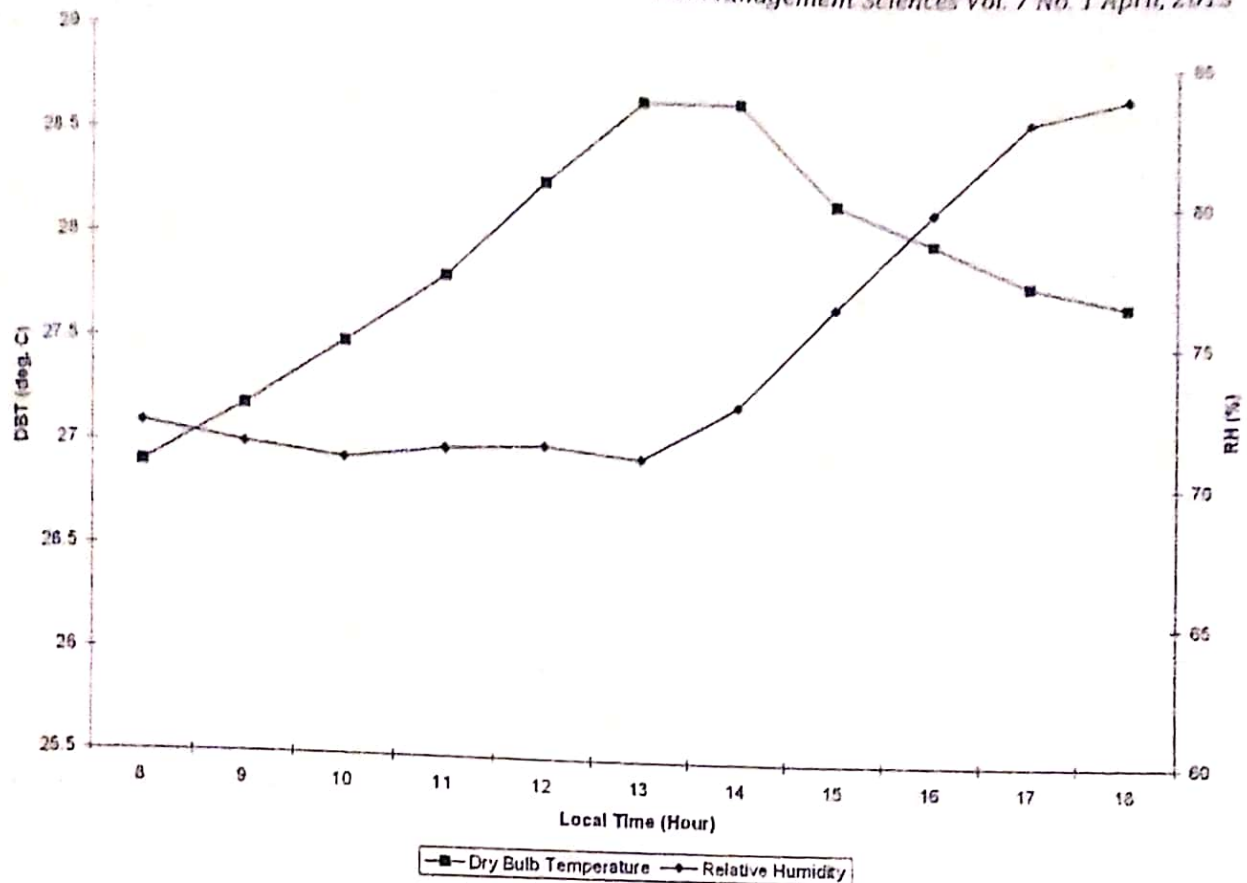


Fig. 3c Graph of variation of hourly average indoor Relative Humidity and Dry Bulb Temperature in Ilorin for October, 2004

Fig. 4a presents the variation of the outdoor hourly average RH and DBT with time in August, 2004. The DBT is observed to be at its peak value between 12 and 15 hour and RH also decreases with increase in DBT.

Fig. 4b shows the variation of the outdoor hourly average RH and DBT with time in September, 2004. The DBT is observed to be at its peak value between 12 and 15 hour and the RH was observed to decrease generally.

Fig. 4c shows the variation of the outdoor hourly average RH and DBT with time in September, 2004. The DBT is observed to be at its peak value between 12 and 15 hour and the RH was observed to decrease generally.

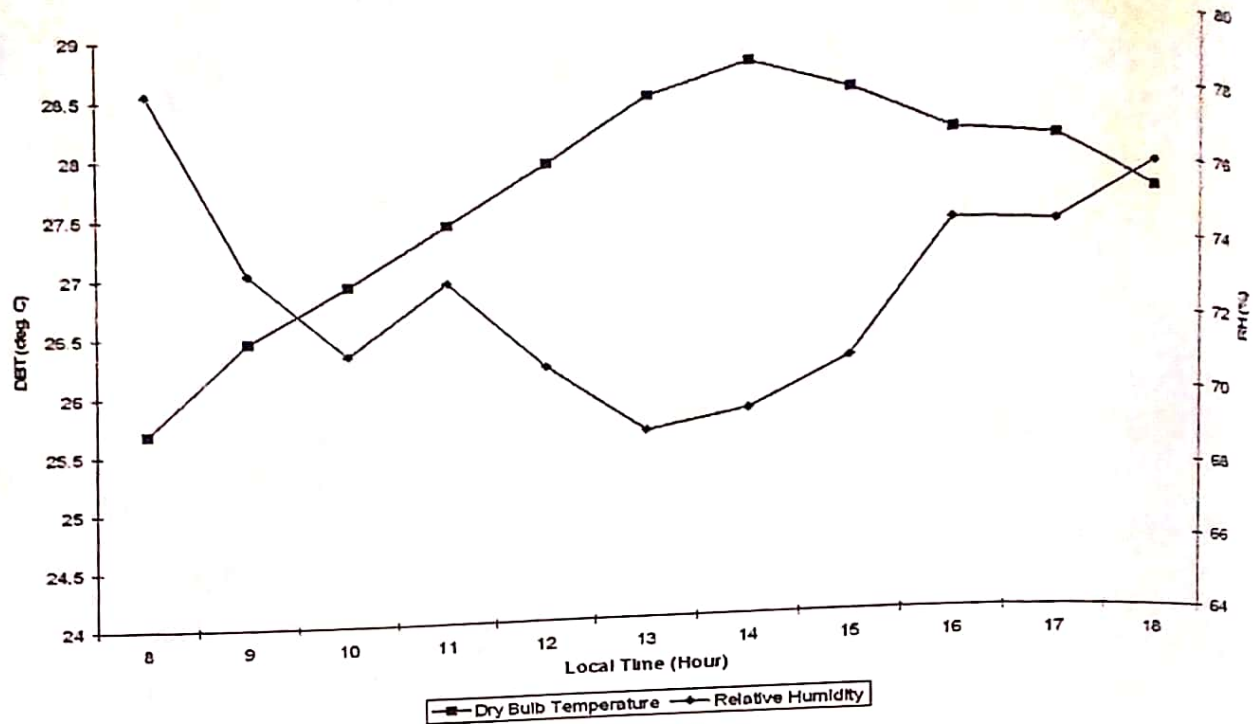


Fig. 4a Graph of variation of the outdoor hourly average RH and DBT in Ilorin for August, 2004

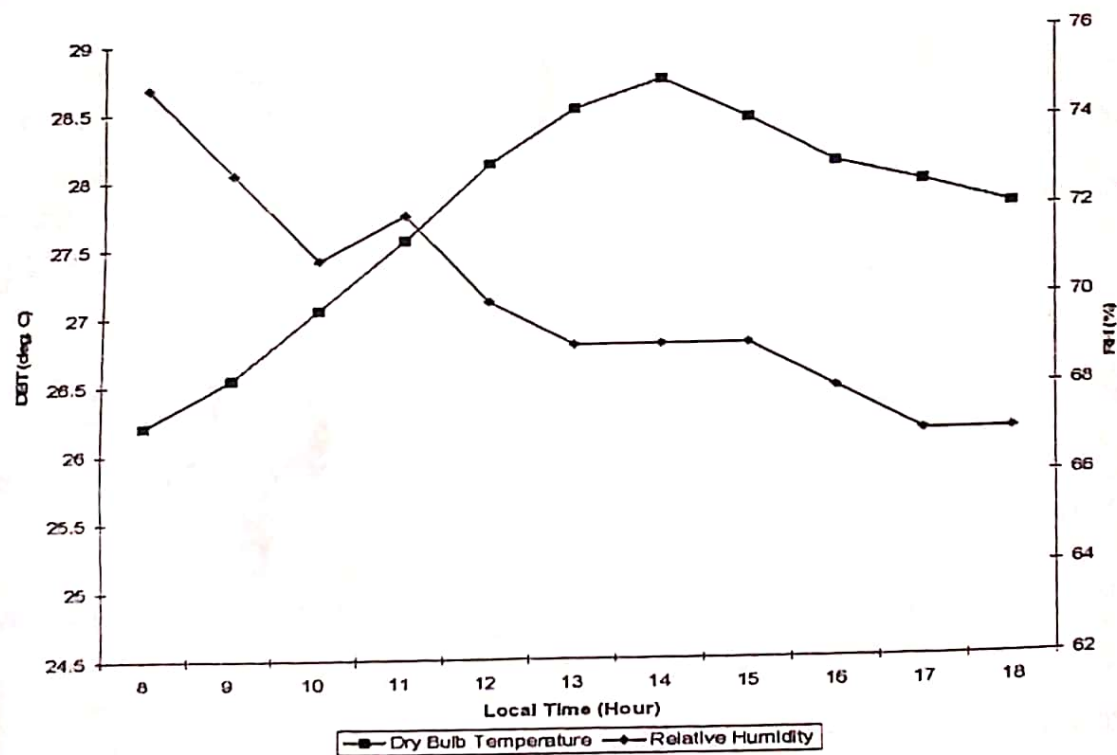


Fig. 4b Graph of variation of the outdoor hourly average RH and DBT in Ilorin for September, 2004

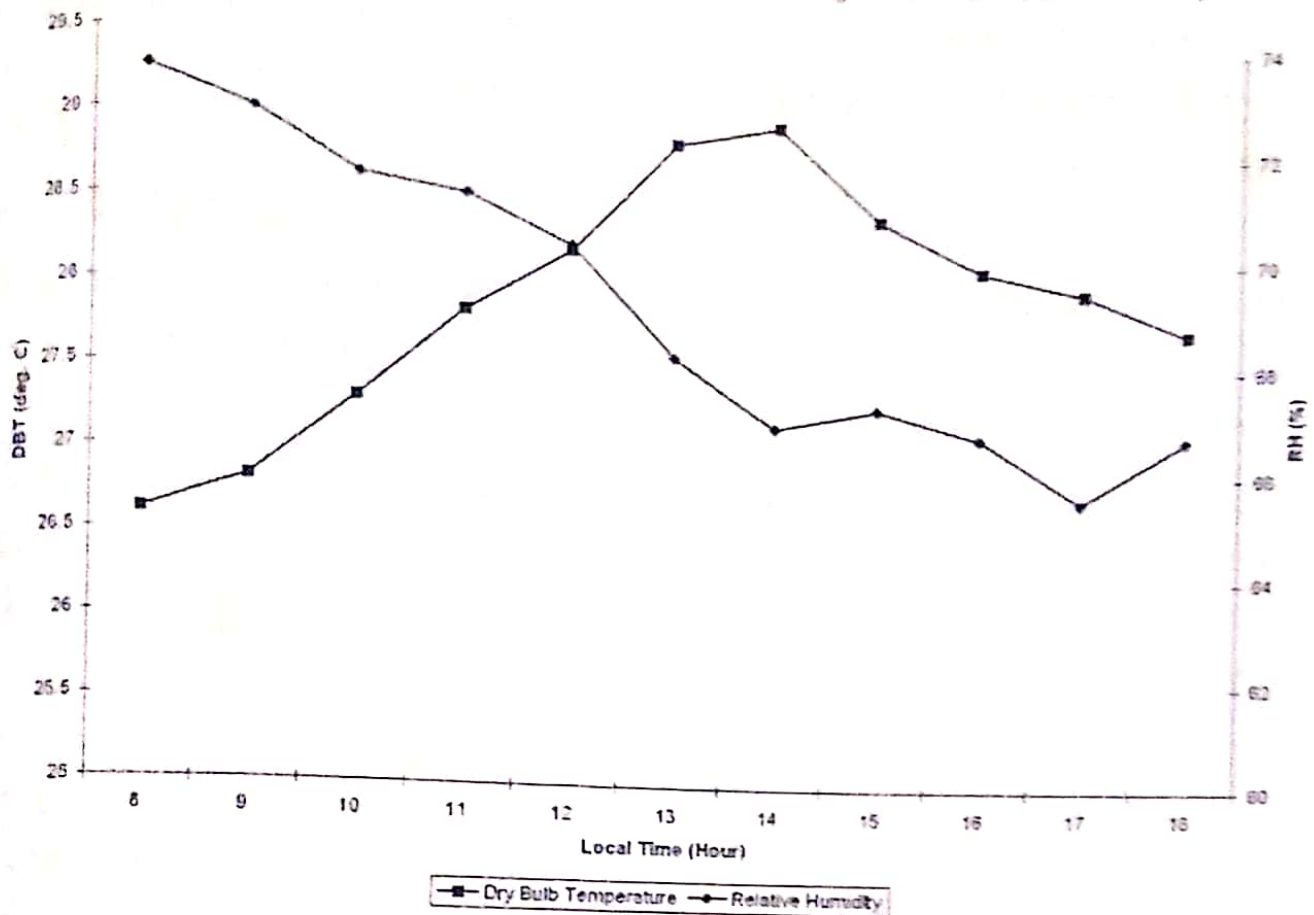


Fig. 4c Graph of variation of the outdoor hourly average RH and DBT in Ilorin for October, 2004

3.1 EFFECTS OF RELATIVE HUMIDITY ON HUMAN COMFORT AND ITS REMEDY

High RH causes thermal discomfort for human beings in the sense that it makes it difficult for humans to perspire thereby not releasing the heat generated in the body.

A combination of high DBT and RH is also not good for thermal comfortability of human being because as the body is being warmed by the hot air, high humidity also makes it impossible to dissipate the body heat.

To remedy the above observation, the air flow rate inside the room was increased from $0\text{m}^3/\text{s}$ to $2.092\text{m}^3/\text{s}$ but the thermal comfort of the human subject did not improve. Their thermal comfortability increased when the air flow was increased to $4.184\text{m}^3/\text{s}$ but thermal shock was observed by anyone leaving or coming into the

enclosure. When the air flow rate was increased to $6.277\text{m}^3/\text{s}$, the level of thermal comfortability increased and thermal shock disappeared.

4.0 CONCLUSION

During the three months of investigation, the observed RH averages indoor were found to be higher than the average comfort RH (45%). Therefore, humidifying the air may not be necessary but rather increasing the air flow rate so as to produce the thermal comfort sensation required.

A total of eight human subjects were engaged under steady state condition in this controlled environment. They were exposed to a full range of air flow rate ($0\text{m}^3/\text{s}$ to $6.27\text{m}^3/\text{s}$) temperature (26 to 31°C) and RH (57 to 88%). Subjects wore typical informal attire with an insulation value of 0.5 clo.

Significant psychological and physiological differences in response to exposures between 57 and 88% RH for the temperature range $26\text{-}31^\circ\text{C}$ were recorded during this period. These are the result of the onset of sweating and the increase in skin temperature that occurs when metabolism increased. There was no variation of this comfort mechanism with variations in RH level. On one subjective scale, direct assessment "of air RH acceptability", the subject indicated that 88% RH was unacceptable at all temperatures but with increase in air speed comfort condition will be achieved. None of the other subjective scales indicated consistent statistically significant effects. One concludes, though not with statistical support, that

1. The 88% RH is typically the least favourably rated,
2. 80% RH condition was not apparently worse than the 57 or 70%
3. The 70% RH condition was frequently more favourably rated than the 60% condition.

The data are consistent with the ASHRAE 55-95a Addendum. Finally, for metabolic rate of 1.6met and above, it was concluded that no reasonable limit on humidity will lower the percentage dissatisfied below 25% (Arens et al, 1992).

RH has been discovered to have more effect on thermal comfort than temperature. But this can be reduced with the help of fan blowing air at high speed of between $4.18\text{m}^3/\text{s}$ and $6.27\text{m}^3/\text{s}$.

RECOMMENDATION

The following were recommended:

1. that the same test should be carried out for the whole year so as to cut through all weather.
2. human subjects to be used should include teenagers and 40 years and above.

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