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DETERMINATION OF INDOOR CONDITIONS AND HEARTBEAT LEVELS FOR HUMAN THERMAL COMFORT INILORIN, NIGERIA

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ABSTRACT

The paper presents an experimental determination of indoor conditions for human thermal comfort for four different structural positions in Ilorin, Kwara State, Nigeria. The Fanger's model was used to determine the optimum productivity level of occupants of the location under investigation. Experimental results and heat balance equation were coupled to determine the heat loss due to regulatory sweating in the zone. The results show the relationship between structural positions, skin temperature and ambient temperature of the enclosed space. For thermal comfortability, the expected indoor conditions for people sitting relaxed in their parlours, offices, and students receiving lectures should be 22°C and a relative humidity of 59.6% while for offices where documentations and businesses are done in seated and typing structural positions, a temperature of 21°C with a relative humidity of 59.3% are required for optimum productivity.

KEYWORDS

Heat loss, Optimum productivity, Structural positions, Thermal comfort.

1. INTRODUCTION

Man has always strived to create a thermally comfortable environment, unlike other animals such as bear and fox that are born with inbuilt furs. The search for thermal comfort dates back to the beginning of human history (Cingel and Chajar, 2015). This search is evident in the type of building tradition around the world from ancient history to present day. At present, creating a thermally comfortable environment is still one of the most important parameters to consider when designing a building plan. Humidity which is a function of dry and wet bulb temperatures has a considerable effect on human comfort directly or indirectly too. According to the American Society of Heating, Refrigerating and Air conditioning Engineers (ASHRAE, 2004), thermal comfort is defined as "the condition of the mind in which satisfaction is expressed with the thermal environment". The definition of thermal comfort points out that the idea of thermal comfort is perception based and involves many input variables and, it is as a result of physical, physiological and psychological processes. Human thermal comfort depends on four environmental parameters and two personal parameters. The four environmental parameters are: dry bulb temperature, mean radiant temperature, relative humidity, and air velocity. The two personal parameters are clothing insulation and level of activities. The indoor climatic conditions need special attention because the large portion of human population spends 23 hours out of 24 hours in artificial climate- in dwellings, at workplaces, at amusement, and cultural centres or during transportation by car, train, ship or aeroplane (Fanger, 1973). Having the right temperature is therefore a key requirement in buildings (Alwetaishi, 2016). Unsatisfactory indoor climatic conditions mostly are as a result of unsatisfactory thermal conditions (Fanger, 1973). Also, it is important to mention that thermal comfort is linked to an individual's state of health (Alwetaishi, 2016).

The human body carries out some metabolic activities to convert the food consumed into heat energy and chemical energy in order to carry out the daily activities. Human metabolism is basically made up of three parts which are the resting metabolism, thermic effect of food and physical activities (Hills et al., 2014). The present study pertains physical activities which involve the amount of energy the body burns during daily activities such as exercise, recreational activities, domestic activities, etc. The intensity, frequency and duration of any activity all have effect on the rate of metabolism (Hills et al., 2014). Heat is generated when the human body carries out some metabolic activities; the metabolic heat generated is dissipated to the environment through the skin and the lungs by convection and radiation as sensible heat, and by evaporation as latent heat. The metabolic activities that take place in the body operate on a heat and mass transfer phenomenon. The driving force for heat transfer is temperature

gradient while the driving force for the mass transfer is the concentration difference. Therefore, the human body can be considered as a heat engine which uses food as fuel and generates waste heat which is rejected to the environment. The rate of heat generation depends on the level of activities while the rate of heat transfer is a function of temperature difference (Cingel and Chajar, 2015).

For an indoor environment to be thermally comfortable, 80% of the occupants must enjoy a body sensation comfort (ANSI/ASHRAE Standard 55-2013). Therefore, it is important as engineers to design and build systems/ devices that have the capacity of controlling the main variables that affect human thermal comfort in indoor environments. There are two major methods that are used in estimating human thermal comfort namely, the Predicted Mean Vote (PMV) and the Percentage of Dissatisfaction (PPD) (Backer and Pacuik, 2009). The two methods are based on the work of (Jang et al., 2007), who considered both the human and environmental factors.

Air conditioning systems are designed to create a thermally comfortable environment so as to improve the performance and productivity of those within that environment (Cingel and Chajar, 2015). The term “air conditioning" means to condition the air to a desired level by heating, cooling, humidifying, dehumidifying, cleaning and deodorizing.

2. LITERATURE REVIEW

A lot of works which include theoretical, practical, and numerical investigations of human thermal comfort have been done. Some of the investigators include (Katafygiotou and Serghies, 2014), who investigated the influence of gender on thermal comfort. They submitted that girls and boys have varied thermal sensations and that girls are more sensitive to low temperatures. The researchers opined that the difference in thermal comfort experienced by both genders was as a result of the difference in metabolism and skin surface of each gender. Rohles and Nevins, 1971 studied the nature of thermal comfort for sedentary men. Their study revealed that men felt warmer than women during the first hour at a given thermal condition. In the view of Rohles, (1971), temperature is seven times more important than relative humidity in influencing how a man feels, for a woman, temperature is nine times more important than relative humidity. Their study shows that male adapt to thermal environment faster than females. In China, Cui et al studied two group of subjects (one exposed to temperature variation and the other to 26℃). They concluded that a warm discomfort environment has a negative effect on performance. The study recommended a temperature range of $22℃ - 26℃$ for optimal performance. Kekalainen

et al., (2010) performed investigation on productivity carried out in an office building during the summer, self-estimated work efficiency decreased when the temperature is above 22℃. Several research works have been carried out in university buildings in hot and humid climate some of which include Hwang et al, who conducted field studies in 10 naturally ventilated and air conditioned classrooms in Taiwan. Their study showed that relative humidity has no major influence on the assessment of thermal sensation. Zamba and Ayoadealso conducted similar studies and concluded that mental and physical performance of an individual is highest when the individual is thermally comfortable and that when one is not thermally comfortable for a long duration, it will impart negatively on their health.

Adegun et al., (2009) worked on experimental determination of indoor conditions for human thermal comfort in Nigeria, a case study of Ilorin. It was concluded that the indoor condition for lecture room should be at a temperature of 20.19°c and specific humidity of 0.0112 in other to obtain best performance of lecturers.

3. GOVERNING EQUATIONS

The comfort equation derived by Fanger, 1972 was adopted for the present study.

3.1. Heat balance

For the occupants of a building to be thermally comfortable, the system must be thermally neutral. This condition can be expressed mathematically using the general comfort equation. The equation is given by equation (1) (Fanger, 1972).

$$H - E_d - E_L - E_{esk} - E_s = R + C \quad (1)$$

$$C = f_{cl}h(T_a - T_{cl}) \quad (2)$$

$$E_d = 3.05 \times 10^{-5}[5765 - 7.04M(1 - e) - P_v] \quad (3)$$

$$E_s = 1.4 \times 10^{-3}M(34 - T_a) \quad (4)$$

$$H = M(1 - e) \quad (5)$$

$$R = 3.96 \times 10^{-8}f_{cl}[(T_a + 273)^4 - (T_{mrt} + 273)^4] \quad (6)$$

The heat transfer from the skin to the outer surface of the clothed body (K), is given by equation (7)

$$K = T_s - \frac{T_{cl}}{0.18I_{cl}} \quad (7)$$

The specific humidity relation is given as

$$\emptyset = \frac{P_v}{P_{sat}} \quad (8)$$

4. METHODOLOGY

The following instruments were used to obtain the data needed for the statistical analysis:

- Thermal Camera (Flir T620 Series)
- The Digital Stethoscope (For Heart pulse Measurement)
- Weight Scale (Human weight scale)
- Data Logger (Ambient temperature and relative humidity logger)

4.1. Thermal camera

Thermal camera was used for taking thermal imaging. It measures infrared wavelength emitted by object and then convert the temperature information into an image. The image features a colour palette that represents a temperature range of the image displayed



Fig. 1. Thermal camera (source: davis.com/thermal imaging).

4.2. Digital stethoscope

Digital stethoscopes offer new opportunity to computerize the analysis of heart sound. Since the heart sounds are not stationary signal, it's important to study both their temporal and frequency contents (Singh et al, 2013).

The digital stethoscope (Littman 3200 digital stethoscope) was operated as follows.

i. The stethoscope was powered on by depressing and releasing the power button. The stethoscope was powered by AA battery which is capable of providing approximately 50-60 hours of continuous use.

ii. The headset was positioned in the forward direction as it was being inserted into the ear canal. The required type of filter was then selected. The sound amplification level was then adjusted appropriately using the (+) and (-). The stethoscope sensor was located at the centre of the chest piece. It was then used to obtain the frequency of the heart beat which was displayed on the LCD.



Fig. 2. An electronic stethoscope (3MTMlittmann ®electronic stethoscope model 3200) available at (http://www.littman.com).

4.3. Experimental set-up

The experimental set-up comprises the experimental chamber, measuring device and the specimen

i. **Measuring Device**

The ambient temperature and relative humidity were measured using a data logger from which air partial pressure was estimated. Thermal camera and Clinical thermometer (digital-type) were used to take the skin temperature, Ts and the clothing temperature, Tcl

ii. **Specimen**

The specimens used for the research work were some selected undergraduate students (male and female) of the University of Ilorin. Five students were used for each activity.

4.4. Experimental procedures

Four series of human exposure experiments were carried out in a conditioned chamber. The experiment was carried out as follows:

i. before the students(specimen) were admitted into the experimental chamber, the air condition system was turned on, set to a particular temperature and left for hours, in order to allow the room attain uniform and desired temperature. The room temperature was measured at different points to verify the temperature uniformity.

ii. The specimen skin and cloth temperatures were obtained with the aid of thermal camera, and the heartbeat was measured with an electronic stethoscope before admitting the specimen into the experimental chamber.

iii. After achieving a uniform temperature, each specimen was admitted into the experimental chamber. Each of the students was then asked to perform a given activity for about 15 minutes, the student was asked “how he/she felt?” For a negative answer, the room temperature was varied using the air conditioning until a comfortable temperature was attained.

iv. When the answer was postive, the room temperature was measured using a data logger, the skin and cloth temperatures were measured with thermal camera and the heart beat was also measured using an electronic stethoscope. The readings for Ts, Tcl, Tco, ω, and heart beat were read and recorded against each structural position (activity position) performed.

v. The above procedure was repeated for other specimens. The mean value of the readings for Ts, Tcl, Ta, ω, and heart beat was calculated and recorded against each structural position (activity level). Some of the captions taken while performing the experiments are shown below.

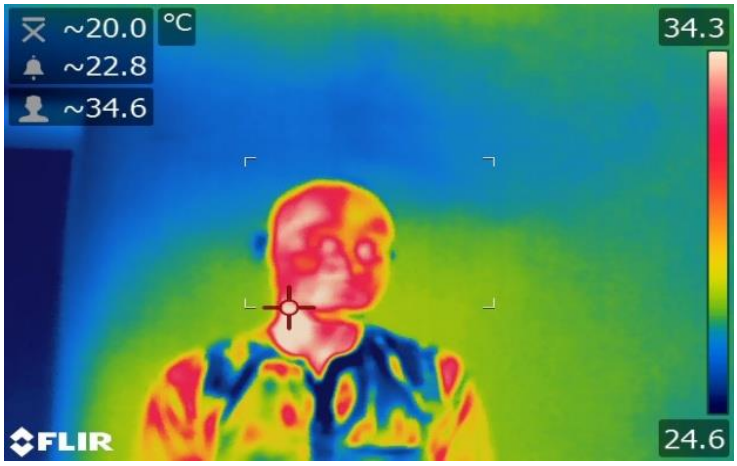


Fig. 3. Caption taken using the thermal camera while in standing position.

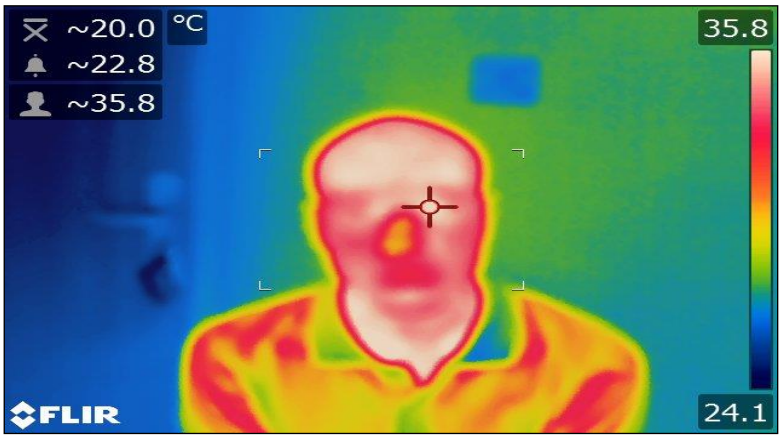


Fig. 4. Caption taken using the thermal camera when the specimen was quietly seated.



Fig. 5. Caption taken using the thermal camera while in seated typing position.

5. RESULT AND DISCUSSION

The data obtained for each structural position were recorded as thermal comfort parameters.

5.1. Results

At the end of the experiment for the different structural positions at which the activity was done, the data obtained for each activity per specimen was recorded and the results are discussed below.

5.2 Discussion of results

Fig. 6 shows that as the metabolic rate increases, the heat loss due to respiration also increases. It could therefore be inferred that for a human body to be thermally comfortable, and to avoid the storage of thermal internal energy, the rate at which heat is lost through respiration must (EL) increase with increase in metabolic rate (M); else heat energy will be stored in the body and the specimen becomes thermally uncomfortable which leads to depletion in the productivity of anyone performing an activity in the structural positions considered.

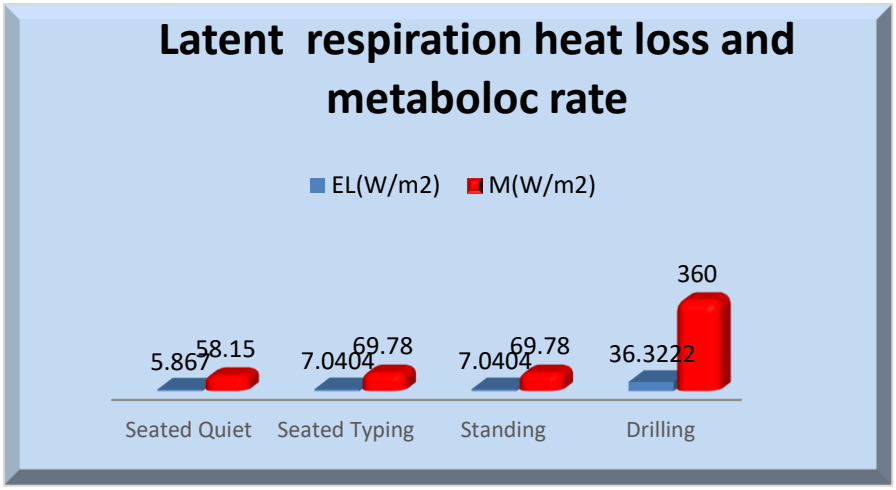


Fig. 6. Showing latent respiration heat loss, EL (w/m2) and metabolic rate M (w/m2).

Fig.7 presents the various metabolic rates with the average skin temperature for different activities. It can be observed from the chat that at comfort condition (temperature of the skin), an increase in metabolic rate causes temperature slump of the skin surface. This is because at comfort, an increase in the metabolic rate necessitated an increase in heat loss to achieve thermal comfort which invariably lowered the skin surface temperature as observed in Fig. 6.

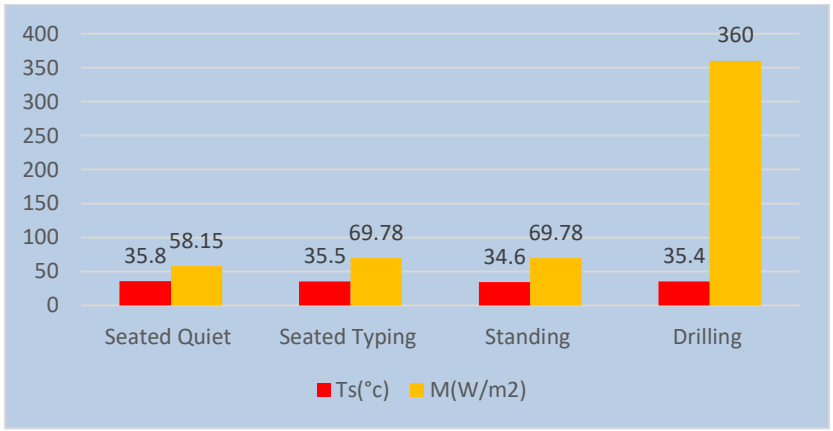


Fig. 7. Skin temperature, T_s(°c) and metabolic rate M (w/m^2).

Fig. 8 shows that to be at comfort condition, the ambient temperature must reduce with increasing metabolic rate. Also, as the metabolic rate increases, there is also an increase in the internal thermal energy. Therefore, to avoid the storage of energy in human body, the ambient temperature must be lowered which leads to temperature depression of the skin. The temperature depression of the skin occurred as a result of heat transfer mechanism between the human body and its environment. The chart also reveals that as the metabolic rate increases, the ambient temperature decreases in order for heat transfer from the body to the environment to take place.

Fig. 9 presents the chart of the various activities against heartbeat. The chat shows that as the metabolic rate increases, the heart pulse also increases. Therefore, for anyone performing any of the activities studied, under an uncomfortable thermal condition, there will be an increase in the heart pulse due to stored thermal energy in the body. It can also be observed from the experimental results that when one is thermally comfortable, the heartbeat reduces compared to the former. Therefore, it can be concluded that the drop in the heart beat when one is thermally comfortable is as a result of lack of energy storage in the body.

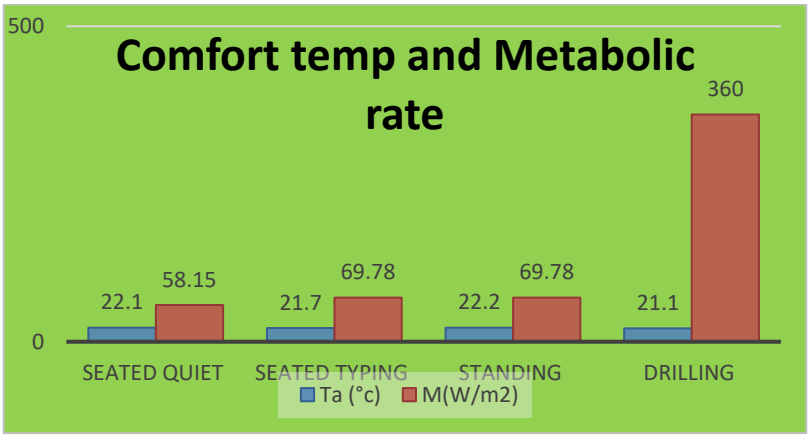


Fig. 8. Showing Ta (0c) and M (w/m2).

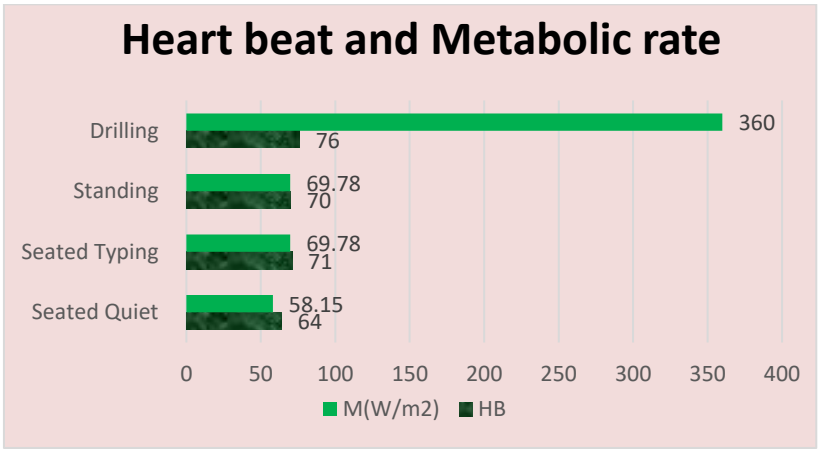


Fig. 9. Metabolic rate M (w/m2) and heartbeat.

Fig. 10 shows that at a comfortable condition, there is a significant effect of the metabolic rate on the heat loss due to regulatory sweating. This is because an increase in the metabolic rate necessitates a decrease in the ambient temperature which results in a decrease in the skin temperature. A significant effect can also be seen under an uncomfortable thermal condition where the body stores up energy as a result of high ambient temperature. It therefore shows that the rate of heat generation depends on the level of activities while the rate of heat transfer depends on temperature difference. Therefore, for one to be thermally comfortable and for heat

transfer to take place, the ambient temperature must reduce with increasing metabolic rate as shown in Fig. 8.

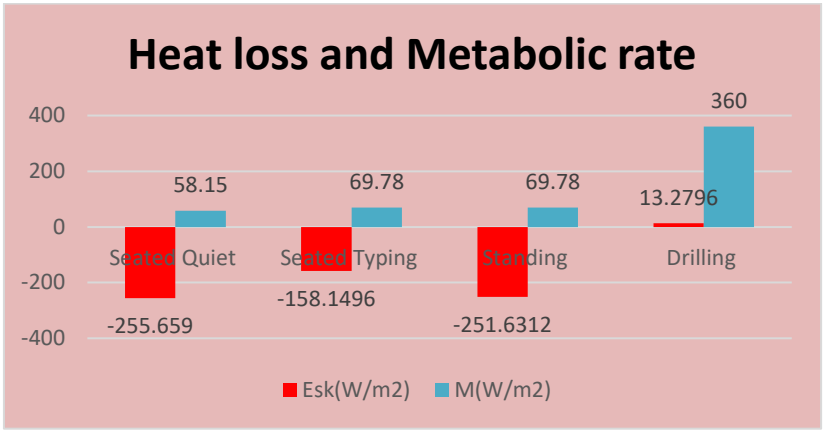


Fig. 10. Heat loss due to regulatory sweating, Esk(W/m2) and Metabolic rate, M (w/m2).

Fig. 11 is a chat of relative humidity and metabolic rate against various activities. From Figs. 10 and 11, it can be deduced that as the metabolic rate increases, the heat loss via perspiration increases and thereby causes an increase in the water vapour of the ambient. The results in Fig. 11 reveal that the higher the metabolic rate of the activities, the higher the water vapour and hence the higher the relative humidity; and therefore, for a specimen to be at thermal comfort, the temperature of the indoor condition must be worked on to increase the rate at which heat is being dissipated from the body (by lowering the indoor temperature).

Fig. 12 shows vapour pressure and metabolic rate at comfort condition. The chart reveals that the more the water vapour in the ambient, the more the vapour pressure.

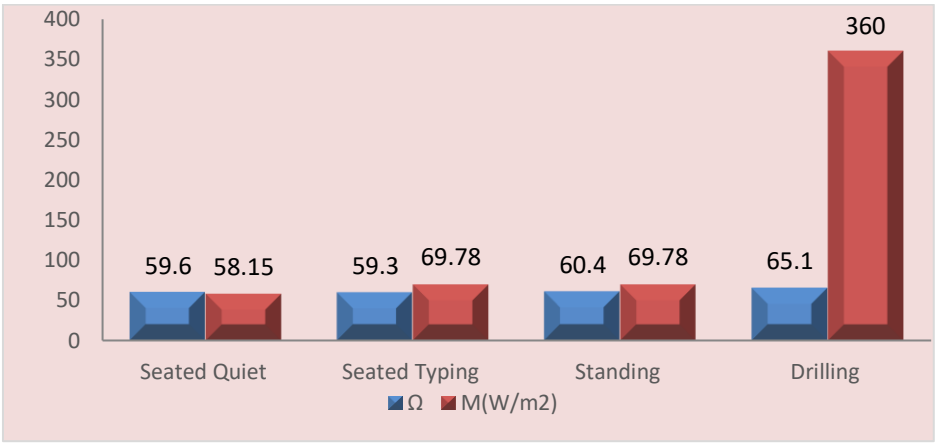


Fig. 11. The Chat of relative humidity and metabolic rate.

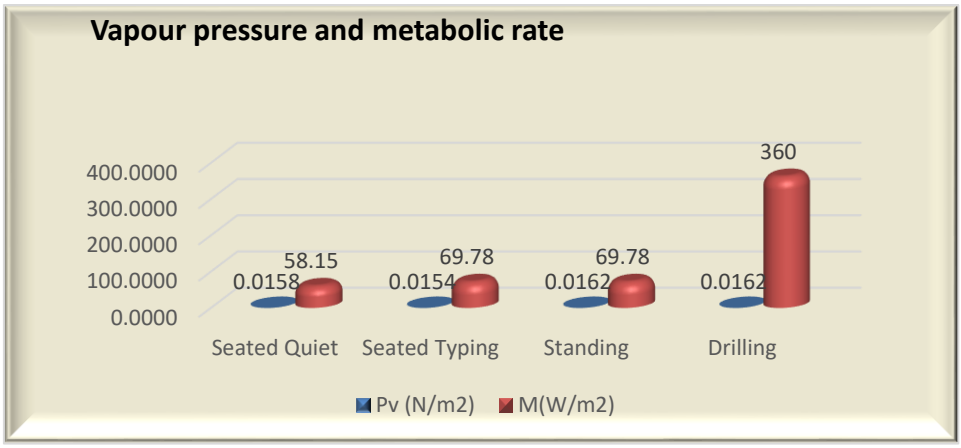


Fig. 12. Vapour pressure, Pv (N/m2) and metabolic rate, M (w/m2)

6. CONCLUSION

A micro climatic condition for human thermal comfort in Ilorin and its environ has been studied and the following conclusions were made:

- For People sitting relaxed in their parlours, offices and students receiving lectures in Ilorin geographical location and its environs, the indoor condition of the of the room should be at a temperature of 22℃ and relative humidity of 59.6% in other to be thermally comfortable.
- For optimum performance of people working in offices where documentation and businesses are done in a seated and typing structural positions, the indoor conditions of the working environment should be at 21.7℃ and relative humidity of 59.3% .
- To achieve thermal comfortability in indoor recreational centres and gym centres, the indoor temperature of the room should be 21℃and relative humidity of 65.1%.
- For an individual
- For hearts to pump blood effectively, the beats per minutes for a person seated quietly, seated typing, standing relaxed, and under drill should not exceed 64 *bpm*, 71 *bpm* , 70 *bpm* and 76 *bpm* respectively. These results are in agreement with the (British Heart Foundation) range of heart beats for adults.

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