# EXERGETIC METABOLISM OF BLOCK LAYING ACTIVITY IN AN OUTDOOR ENVIRONMENT

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# EXERGETIC METABOLISM OF BLOCK LAYING ACTIVITY IN AN OUTDOOR ENVIRONMENT

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***ABSTRACT***

*This study analysed the metabolic exergy of human body during block laying in an outdoor environment. Two hundred and four masons were investigated across the three senatorial districts of Ogun State, Nigeria with distributions of 50.98, 30.88 and 18.14% for Central, West and East respectively using snowball sampling technique. This technique was used due to the inaccessible and hard to find masons that laid blocks outdoor. The meteorological (air temperature, and radiant temperature, relative humidity, wind speed and solar radiation), physiological (skin temperature, and core temperature) were measured and recorded hourly for 10 hours per day at an average of 17 masons every month from May 2013 to April 2014. Models were developed to determine the metabolic exergy, exergy in* $[(1-T_a/T_c)\ \chi_M]$*, exergy out* $[(1-T_a/T_{sk})\ \chi_M]$*, exergy destroyed* $[(1-T_a/T_c)\ \chi_M - (1-T_a/T_{sk})\ \chi_M]$*, The data collected were subjected to descriptive statistics using SPSS 21.0. The mean values of air temperature, radiant temperature, relative humidity, wind speed and solar radiation were 33.13 ± 2.34* $^oC$*, 34.00 ± 2.13* $^oC$*, 55.32 ± 6.40%, 0.48 ± 0.03 m/s and 662.73 ± 100.31 W/m*$^2$ *respectively. The skin temperature and core temperature were 34.02 ± 0.54, 36.39 ± 0.14* $^oC$*, respectively. The metabolic exergy* $\chi_M$*, exergy in, out and destroyed by the mason were 120.62 ± 10.38, 10.25 ± 6.19, 2.38 ± 6.40 and 7.88 ± 1.99 W respectively. The study concluded that the rate and proportions of the different components in the exergy balance equation (exergy input, destroyed, and output) vary according to the outdoor temperature and humidity. The metabolic exergy of the mason was determined as 120.60 (±10.38) W which conformed to the ISO standard.*

**Keyword:** *Exergy, Metabolic, temperature, Human body, Blocklaying, Outdoor, Mason*

## 1. INTRODUCTION

Exergy is the maximum available energy that could be converted into useful work and also measures the potential work between a system and its environment (Musa, 2016). However, human body exergy analysis gives more accurate information as thermal energy which is not utilizable and rejected to the environment (Ala-Juusela and Shukuya, 2014). The exergy which is the part of energy that has the potential to do work or be changed to another form of energy is dependent on environmental conditions. The human body consumes exergy in the performance of tasks and this consumption is related to the need of the body to get rid of extra heat and reduce exergy storage rate.

Pellegrini *et al*. (2010) presented an exergy of the human body under physical activity by developing a model that considered the heat and mass transfer between the lungs, tissues and blood. The Exergy model developed and analysed by Pellegrini et al. (2010) was based on human respiratory and thermal systems. Furthermore, different meteorological conditions as well as human parameters may sharply affect the performance of blocklaying activities in an outdoor environment (Musa, 2016). In contrast to the relatively stable thermal environment, outdoor conditions such as air temperature, relative humidity, wind velocity and solar radiation intensity fluctuate. Human anthropometrical and psychological adaptations are more pronounced such that masons are able to consciously or unconsciously adjust themselves to such fluctuating outdoor environmental conditions.

Block laying activities are performed in an outdoor and there is need to determine the human body exergy consumption rate which will give an indication of comfort during the activities. There is sparse literature on the exergy of human body during blocklaying in an outdoor environment. Similarly, there is little or no literature on exergy studies as it relates to human body (Musa, 2016). The human body derives heat from ingesting food. While the energy value of food is turned over to produce heat and energy for work, the human body ‘tries’ to maintain their body temperature at a ‘constant’ level. The human body produces heat from food when combined with oxygen in the cell. The total process is called ‘Metabolism’. A reclined and resting person at 21°C shows the lowest level of activity and it is called ‘basal metabolism’ and is the metabolic rate of a resting sedentary person. Metabolic rate is related to people’s body surface area, sex, age, the level of fitness, environmental temperature and the amount of clothing (Havenith *et al*., 2002).

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Metabolic rate can be determined in either direct or indirect calorimetry. Direct calorimetry measures the amount of heat an individual produces and emits to a thermal chamber. In the case of indirect calorimetry, the heat production is calculated from the increase of carbon dioxide and the decrease in oxygen through respiration (ACSM, 2006). Metabolic rate can also be estimated by activity. Regression equations have been expressed through laboratory experiments, and there are metabolic equations for walking, treadmill and running, leg ergometry, arm ergometry and stepping. When a person is stepping on and off a step as in a standard 'step test', ACSM (2006) suggests how to find the estimated value of metabolic rate through step height and step speed. To perform the exergy analysis, it is necessary to determine the metabolic exergy of the human body but there is not yet a consensus in its calculation (Mady and Oliveira, 2013).

Prek (2005, 2006) and Simeone *et al.,* (2011) performed exergy analysis of the human body to obtain the relationship between the exergy destroyed, thermal comfort and thermal sensation conditions. In their research, the metabolic exergy was considered as a heat which revealed that the metabolism on energy and exergy has one order of magnitude of difference.

Lem (2009) performed the exergy analysis of the cellular metabolism. The result obtained accounted for efficiencies up to 60% considering the conversion of carbon fuel into Adenosine triphosphate (ATP) in living cells. Mady and Oliveira (2013) also calculated the exergy metabolism based on the oxidation of glucose and palmitic acid which resulted in the formation of carbon dioxide and water while the oxidation of amino acid also resulted in carbon dioxide, water and urea. Different authors presented different ways of determining the exergy metabolism depending on the physical activities or based on conditions of the human body. Literature reveals that the difference between the energy and exergy metabolism is not more than 2% (Hayne, 2008). Mady and Oliveira (2013) verified the validation of an approximation of exergy metabolism and energy metabolism for physical activities which was earlier performed by Batato *et al* (1990). They concluded that during physical activities, the differences between the exergy and energy metabolism was lower than 5%. Exergy metabolism is the available work done per unit time which is the metabolic heat production of human body. The aim and objective of the research is to determine the metabolic exergy of the human body laying blocks in outdoor conditions within Ogun State, Nigeria.

## 2. MATERIALS AND METHOD

### *Sample Selection*

This study analysed the exergy of human body during blocklaying in an outdoor environment. Two hundred and four masons were investigated across the three senatorial districts with distributions of 50.98, 30.88 and 18.14% Central, west and East of Ogun State using snowball sampling technique between May 2013 and April 2014 at 8.00am to 5.00pm.

The snowball sampling technique was used due to the inaccessible and hard to find masons that laid blocks in outdoor environment. To this end, a few potential respondents were contacted who did the link to other masons that perform that work outdoors. The meteorological parameters such as air temperature ($^oC$), relative humidity (RH) and the wind speed (v) (m/s) were measured. The solar radiation ($W/m^2$) and radiant temperature ($^oC$) were also measured and recorded. The physiological parameters (skin and core temperatures) were recorded. Figure 1 shows the set up of the measuring instruments.

The parameters to determine the work done was measured and recorded. Figure 2 to 4 respectively showed the procedure of measuring of blocks, trowel and mortar respectively using digital weighing scale. Similarly, figure 5 and 6 showed the mason performing block laying activities in an outdoor environment.

### *Metabolic exergy*

For this research, available work done by the mason is equal to the product of force and the distance moved to lift the block to the laying level. The summation of the mass of concrete block ($M_{block}$), mass of mortar ($M_{mortar}$), mass of trowel ($M_{trowel}$) and multiply by acceleration due to gravity ($g$ $m/s^2$) is the force applied, $F_{(kg)}$.

$$F_{(kg)} = (M_{block} + M_{trowel} + M_{mortar}) \times g_{(m/s2)} \quad (1)$$

Metabolic heat production, $H_{M\,(Watts)}$ = (Force x distance) / Time taken

Therefore,

$$H_{M\,(Watts)} = [(M_{block} + M_{trowel} + M_{mortar}) \times g_{(m/s2)} \times \text{distance}] / \text{Time taken}_{(Sec)}. \quad (2)$$

The metabolic heat production is the rate of production of energy with respect to time. The body utilizes oxygen and food to produce energy and the rate at which this occurs is termed metabolic rate.

Most of the energy produced is measured as heat but some will be used by body in performing external work (W).

Metabolic heat production ($H_M$) = Exergy Metabolic rate ($\chi_M$) – External work (W).

Therefore,

Exergy metabolic rate ($\chi_M$) = Metabolic heat production ($H_M$) + External work (W). (3)

The data collected were inputted into the system and subjected it to descriptive statistics using SPSS version 21.0 and Microsoft Excel 2013 to determine the mean and standard deviation.

*Figure 1: Set up of the measuring instruments.*

*Figure 2: Measurement of Mass of Trowel and Mortar ($M_{Trowel + Mortar}$)*

*Figure 3: Measurement of Mass of block ($M_{block}$)*

*Figure 4: Measurement of block distance*

*Figure 5: Mason lifting block*

*Figure 6: Mason performing laying of block*

## 3. RESULT AND DISCUSSION

Meteorological conditions and physiological responses were recorded around the subject. The average mean values of meteorological conditions and physiological responses outdoors are presented in Table 1 while Table 2 to 4 showed the average metabolic rate, exergy destroyed by the mason and the summary of the results over the 12 months.

***Table 1: Mean Values of the Meteorological and Physiological*** **Responses**

| Months | | Air Temp (°C) | R.H (%) | Wind Speed (m/s) | Solar Radiation (w/m²) | Radiant Temp (°C) | Skin Temp (°C) | Core Temp (°C) |
|---|---|---|---|---|---|---|---|---|
| **May'13** | Mean | 31.6 | 58.0 | 0.5 | 571.0 | 34.6 | 33.1 | 36.3 |
| | SD | 2.30 | 6.33 | 0.16 | 160.9 | 4.66 | 0.58 | 0.07 |
| **Jun'13** | Mean | 33.3 | 58.0 | 0.4 | 583.0 | 36.9 | 33.2 | 36.3 |
| | SD | 2.34 | 5.57 | 0.16 | 82.18 | 3.37 | 0.51 | 0.00 |
| **Jul'13** | Mean | 27.9 | 69.0 | 0.5 | 551.0 | 29.5 | 34.4 | 36.3 |
| | SD | 1.39 | 3.23 | 0.12 | 105.21 | 3.10 | 0.49 | 0.05 |
| **Aug'13** | Mean | 30.5 | 56.0 | 0.4 | 779.0 | 31.6 | 33.5 | 36.3 |
| | SD | 2.10 | 4.16 | 0.17 | 240.87 | 3.07 | 0.74 | 0.06 |
| **Sept'13** | Mean | 33.1 | 55.0 | 0.5 | 668.0 | 33.9 | 34.0 | 36.5 |
| | SD | 3.40 | 6.02 | 0.16 | 166.64 | 4.18 | 0.47 | 0.00 |
| **Oct'13** | Mean | 32.8 | 56.0 | 0.5 | 771.0 | 32.5 | 33.9 | 36.3 |
| | SD | 4.81 | 5.67 | 0.15 | 167.88 | 3.44 | 0.52 | 0.05 |
| **Nov'13** | Mean | 36.1 | 58.0 | 0.5 | 725.0 | 33.4 | 33.9 | 36.4 |
| | SD | 3.54 | 5.52 | 0.17 | 223.84 | 4.02 | 0.52 | 0.05 |
| **Dec'13** | Mean | 32.8 | 53.0 | 0.5 | 806.0 | 32.9 | 34.1 | 36.5 |
| | SD | 3.68 | 5.32 | 0.08 | 220.82 | 3.40 | 0.45 | 0.06 |
| **Jan'14** | Mean | 34.2 | 57.0 | 0.5 | 648.0 | 35.6 | 34.3 | 36.5 |
| | SD | 3.24 | 5.44 | 0.14 | 191.15 | 5.03 | 0.19 | 0.05 |
| **Feb'14** | Mean | 35.0 | 42.0 | 0.5 | 484.0 | 35.6 | 34.5 | 36.2 |
| | SD | 1.97 | 6.61 | 0.13 | 105.51 | 5.03 | 0.86 | 0.05 |
| **Mar'14** | Mean | 36.1 | 54.0 | 0.5 | 706.0 | 35.8 | 34.8 | 36.5 |
| | SD | 2.55 | 5.52 | 0.14 | 185.47 | 5.56 | 0.30 | 0.00 |
| **Apr'14** | Mean | 34.4 | 48.0 | 0.5 | 660.0 | 35.6 | 34.6 | 36.7 |
| | SD | 2.21 | 5.81 | 0.14 | 211.46 | 5.03 | 0.17 | 0.05 |

**Table 2: Mean value of the mason activity**

| | Mass of block $M_{block}$ (Kg) | | Mass of trowel + Mortar $M_{TM}$ (Kg) | | Distance moved (m) | | Acceleration due to gravity g ($m/s^2$) | | Work done (J) | | Time taken (Sec) | | Metabolic heat production (Watts) | | Exergy Metabolism (Watts) | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Months** | Mean | SD | Mean | SD | Mean | SD | Mean | SD | Mean | SD | Mean | SD | Mean | SD | Mean | SD |
| **May ‘13** | 21.03 | 0.06 | 2.07 | 0.06 | 0.47 | 0.01 | 9.81 | 0.00 | 106.51 | 2.27 | 10.70 | 1.13 | 9.95 | 1.03 | 116.46 | 2.73 |
| **June ‘13** | 19.13 | 0.06 | 2.07 | 0.06 | 0.47 | 0.02 | 9.81 | 0.00 | 97.06 | 3.62 | 9.90 | 0.17 | 9.80 | 0.26 | 106.87 | 3.86 |
| **July ‘13** | 21.07 | 0.06 | 1.90 | 0.26 | 0.51 | 0.12 | 9.81 | 0.00 | 114.73 | 25.14 | 15.93 | 3.00 | 7.20 | 0.29 | 121.93 | 9.37 |
| **Aug ‘13** | 19.00 | 0.00 | 1.93 | 0.06 | 0.45 | 0.06 | 9.81 | 0.00 | 93.24 | 1.33 | 10.53 | 0.45 | 8.85 | 0.29 | 102.09 | 1.18 |
| **Sept ‘13** | 20.03 | 0.06 | 2.13 | 0.15 | 0.59 | 0.34 | 9.81 | 0.00 | 128.30 | 7.99 | 16.20 | 0.87 | 7.92 | 0.19 | 136.22 | 8.09 |
| **Oct ‘13** | 21.10 | 0.00 | 1.83 | 0.15 | 0.52 | 0.11 | 9.81 | 0.00 | 117.84 | 25.60 | 15.43 | 2.22 | 7.64 | 0.50 | 125.48 | 26.09 |
| **Nov ‘13** | 20.03 | 0.06 | 1.93 | 0.21 | 0.49 | 0.04 | 9.81 | 0.00 | 104.91 | 8.28 | 12.17 | 1.80 | 8.62 | 0.60 | 113.53 | 7.69 |
| **Dec ‘13** | 20.00 | 0.00 | 1.80 | 0.20 | 0.60 | 0.07 | 9.81 | 0.00 | 127.53 | 13.35 | 16.03 | 1.67 | 7.96 | 0.08 | 135.49 | 13.05 |
| **Jan ‘14** | 19.00 | 0.00 | 1.90 | 0.10 | 0.53 | 0.03 | 9.81 | 0.00 | 108.67 | 5.59 | 13.10 | 1.05 | 8.30 | 0.25 | 116.97 | 5.32 |
| **Feb ‘14** | 19.10 | 0.00 | 2.10 | 0.26 | 0.56 | 0.06 | 9.81 | 0.00 | 115.76 | 12.10 | 14.80 | 2.59 | 7.82 | 0.59 | 123.58 | 11.51 |
| **Mar ‘14** | 20.07 | 0.06 | 1.90 | 0.10 | 0.52 | 0.03 | 9.81 | 0.00 | 111.34 | 5.66 | 13.40 | 1.54 | 8.31 | 0.53 | 119.65 | 5.16 |
| **April ‘14** | 20.07 | 0.06 | 1.93 | 0.06 | 0.56 | 0.03 | 9.81 | 0.00 | 120.85 | 5.30 | 14.5 | 1.71 | 8.33 | 0.60 | 129.18 | 4.70 |

*Table 3: Mean value of monthly exergy destroyed*

| Months | $T_a$ (°c) | $T_c$ (°c) | $T_{sk}$ (°c) | Exergy Metabolism $X_M$ (Watts) | Exergy In $X_{in}$ (Watts) | Exergy Out $X_{out}$ (Watts) | Exergy destroyed $X_{destroyed}$ (Watts) |
|---|---|---|---|---|---|---|---|
| **May '13** | 31.6 | 36.3 | 33.1 | 116.46 | 15.08 | 5.28 | 9.80 |
| **June '13** | 33.3 | 36.3 | 32.2 | 106.87 | 8.83 | -3.65 | 12.48 |
| **July '13** | 29.9 | 36.3 | 34.4 | 121.93 | 21.34 | 15.95 | 5.40 |
| **Aug '13** | 30.5 | 36.3 | 33.5 | 102.09 | 16.31 | 9.14 | 7.17 |
| **Sept '13** | 33.1 | 36.5 | 34.0 | 136.22 | 12.69 | 3.61 | 9.08 |
| **Oct '13** | 32.8 | 36.3 | 33.9 | 125.48 | 12.10 | 4.07 | 8.03 |
| **Nov '13** | 36.1 | 36.4 | 33.9 | 113.53 | 0.94 | -7.37 | 8.31 |
| **Dec '13** | 32.8 | 36.5 | 34.1 | 135.49 | 13.74 | 5.17 | 8.57 |
| **Jan '14** | 34.2 | 36.4 | 34.3 | 116.97 | 7.07 | 0.34 | 6.73 |
| **Feb '14** | 35.0 | 36.2 | 34.5 | 123.58 | 4.10 | -1.79 | 5.89 |
| **Mar '14** | 36.1 | 36.5 | 34.8 | 119.65 | 1.31 | -4.47 | 5.78 |
| **April '14** | 34.0 | 36.7 | 34.6 | 129.18 | 9.50 | 2.24 | 7.26 |

*Table 4: Summary of the results for the research year*

| Activities | No of Months | Minimum | Maximum | Mean | Std. Deviation |
|---|---|---|---|---|---|
| Air Temp ($^oC$) | 12 | 27.90 | 36.05 | 33.13 | 2.34 |
| Relative Humidity (%) | 12 | 42.10 | 69.00 | 55.32 | 6.40 |
| Wind Speed (m/s) | 12 | 0.42 | 0.53 | 0.48 | 0.03 |
| Solar Radiation ($w/m^2$) | 12 | 484.90 | 806.20 | 662.73 | 100.31 |
| RadiantTemp ($^oC$) | 12 | 29.48 | 36.91 | 34.00 | 2.13 |
| SkinTemp ($^oC$) | 12 | 33.12 | 34.76 | 34.02 | 0.54 |
| CoreTemp ($^oC$) | 12 | 36.20 | 36.70 | 36.39 | 0.14 |
| Work done (J) | 12 | 93.24 | 128.30 | 112.22 | 10.90 |
| Metabolic heat production (W) | 12 | 7.20 | 9.95 | 8.39 | 0.82 |
| Metabolic Exergy (W) | 12 | 102.09 | 136.22 | 120.62 | 10.38 |
| Exergy In (W) | 12 | 0.94 | 21.34 | 10.25 | 6.19 |
| Exergy Out (W) | 12 | -7.37 | 15.95 | 2.38 | 6.40 |
| Exergy destroyed (W) | 12 | 5.40 | 12.48 | 7.88 | 1.99 |

The human physiological responses were observed with 204 participants in various environmental conditions over 12 months. It is very difficult to determine the constant relationship between the human responses and outdoor climate. Similarly, the exergy of heat supplied by thermal energy to the body is equivalent to the output work of the mason performing physical activities in an environment.

The weather conditions of Ogun state, Nigeria was mild from May, 2013 to April, 2014 with the lowest average mean air temperature, 27.9 (±1.39)$^0$C recorded in July, 2013 while the highest average mean air temperature, 36.1 (±3.54)$^0$C occurred in November, 2013 and March, 2014. Though, it was a mild weather condition over a year but a person may be able to get cold stress or heat stress. In July, 2013, it is possible for any mason to get cold stress due to the type of cloth worn. The result showed that highest average relative humidity of 69 (±3.23) % occurred with the lowest, 42 (±6.61) % in February, 2014. At high humidity levels, skin moisture tends to increase discomfort (Berglund, 1995), particularly skin moisture that is physiological in origin (water diffusion and perspiration). As a matter of fact, relative humidity affects the evaporation from the skin, which is the prevailing way of heat loss at high air temperatures, normally from 26°C. At lower relative humidity more sweat is allowed to evaporate from the body, while at higher values it is harder for this process to happen, because the air's moisture content is already elevated (La Roche, 2011).

Therefore, very humid environments (relative humidity > 70-80%) are usually uncomfortable because the air is close to the saturation level, thus strongly reducing the possibility of heat loss through evaporation (Wolkoff and Kjaergaard, 2007). On the other hand, very dry environments (relative humidity < 20-30%) are also uncomfortable because of their effect on the mucous membranes (Wolkoff and Kjaergaard, 2007). At high humidity levels, thermal sensation alone is not a reliable predictor of thermal comfort (Tanabe *et al*., 2002). The discomfort appears to be due to the feeling of the moisture itself, increased friction between skin and clothing with skin moisture (Gwosdow *et al.,* 1986). To prevent warm discomfort, ASHRAE (2001) recommended that on the warm side of the comfort zone the relative humidity should not exceed 60%.

The wind speed seems to have a tendency around a year which cut across the season. The fluctuation between the highest mean wind speed 0.5 (±0.16) m/sec and the lowest 0.4 (±0.16) m/sec in each month was very minimal and it may be considered that particular tendencies exist. The lowest wind speed of 0.4 (±0.16) m/sec occurred in June and August 2013 and the rest of the year showed higher wind speed. The average mean wind speed throughout the research year was between 0.4 m/s and 0.5 m/s.

The result also showed that mean average solar radiation was higher, 779 (±240.87) W/m$^2$ in August, 2013 while the lowest radiation occurred in February 2014 with 484 (±105.51) W/m$^2$. Fluctuation of solar radiation occurred in the year due to the revolution and the change of altitude of the sun. However, the lower solar radiations in the different months seem to be influenced by cloud cover rather than the altitude. Air pollution may also have effect on the solar radiation reaching the ground. The average mean radiant temperature was also at maximum at 36.9 (±3.37) $^o$C in June, 2013 while 29.5 (±3.10) $^o$C was recorded as the minimum mean radiant temperature in July, 2013. This was also seemly affected by the change in the altitude. The fluctuation of the radiant temperature occurred throughout the year due to the change of the altitude of the sun.

However, the aural temperature and sweat loss seemed to have been strongly affected by air temperature. Hence, the mean skin temperature is highly influenced by mean radiant temperature. It was discovered that the highest mean skin temperature for the mason, 34.5 (±0.86) $^o$C occurred in February, 2014 while the lowest of 33.1 (±0.58) $^o$C occurred in May, 2013. The mean value of the skin temperature throughout the season was 34.02 (±0.54) $^o$C which was in line with ASHRAE standard (ASHRAE, 2001). If the skin temperature is greater than 45 $^o$C or less than 18 $^o$C it causes pain (ASHRAE, 2001). Skin temperatures associated with comfort at sedentary activities are 33 to 34 °C and decreases with increasing activity (ASHRAE, 2001).

The human skin can absorb radiation and the skin temperature cannot be a major index for thermal comfort under large heat exchange by radiation. Hence, the skin temperature was not corrected with the thermal conditions of the individual. The core temperature showed the highest value of 36.7 (±0.05) $^o$C in April 2014 with the lowest value of 36.2 (±0.05) $^o$C in February, 2014. In contrast to skin temperature, internal temperatures rise with activity. The temperature regulatory center in the brain is about 36.8°C at rest in comfort and increases to about 37.4°C when walking and 37.9°C when jogging (ASHRAE, 2001). The mean value of the core temperature throughout the year was 36.4 (±0.14) $^o$C and was also a normal internal temperature for a healthy individual.

The results showed that majority of the mason were healthy during their activities. An internal temperature less than about 28 °C can lead to serious cardiac arrhythmia and death, and a temperature greater than 46 °C can cause irreversible brain damage (ASHRAE, 2001). Therefore, the careful regulation of body temperature is critical to comfort and health. However, human responses seem to be influenced by actual outdoor climate condition which consist of solar radiation and wind speed and people could have different responses due to various internal body temperature or various skin temperature and this could affect the performance output which is the subject of the exergy effectiveness and the exergy stored for the mason.

Masons laid different type of sandcrete blocks due to different locations and manufacturers. The highest metabolic exergy rate ($\chi_M$) of the mason was 136.22 (±8.09) W in September, 2013 while the lowest was 102.09 (±1.18) W in August 2013. The lowest metabolic exergy rate was due to the work done, 93.24 (±1.33) J performed by the mason in August 2013. Mady and Oliveira (2013) reported that increase in physical activity or work done increases the metabolic rate. The results showed that exergy metabolic rate of the mason were 106.87 (±3.86) W and 102.09 (±1.18) W in June and August 2013 respectively due to the decrease in the work done in those months and this was not consistent with ISO 8996 (1990) but the rest of the months were within standard. ISO 8996 (1990) classified the metabolic exergy rate of mason to be between 110 to 160W. The mean metabolic exergy of the mason was 120.6 (±10.38) W which conformed with the ISO standard.

The exergy destroyed by the mason depends on the temperature of the environment (air temperature), internal temperature (core temperature), exergy in and exergy out. Average minimum value of exergy in, 0.94 W of the mason occurred in November 2013 while the maximum value of 21.34 W occurred in July, 2013. Similarly, the minimum value of exergy out, 7.37 W also occurred in November and the maximum value, 15.95 W occurred in July 2013 as well. The summary of the results for the research year showed that the mean metabolic exergy rate of the mason was 120.62 (±10.38) W while the average exergy in, exergy out and exergy destroyed to the environment by the mason were 10.25 (±6.19) W, 2.38 (±6.40) W and 7.88 (±1.99) W respectively.

## 4. CONCLUSIONS

In conclusion, it is important to realised that exergy does not represent the amount of work that mason will actually deliver but the upper limit of the amount of work he can deliver without violating any thermodynamic laws.

The study concluded that the rate and proportions of the different components in the exergy balance equation (exergy input, destroyed, and output) vary according to the outdoor temperature and humidity. The metabolic exergy of the mason was determined as 120.60 (±10.38) W which conformed to the ISO standard. Thermal discomfort has been known to lead to sick building syndrome symptoms and could affect the performance of the work output by the mason. The combination of high temperature and high relative humidity serves to reduce thermal comfort and outdoor air quality.

Human responses to the thermal environment are inherently difficult to predict due to subjective assessment of outdoor users but not part of the scope of this study. The outdoor condition is non-steady state and it is generally accepted that human responses can be considered as the responses under transient condition. It is recommended that Mason should be tested and evaluated for their fitness for blocklaying task, and their working duration should also be optimized without discomfort to maximum efficiency of the worker for the designated task which will increase the net output. Further study should be conducted in other state so as to have a database for the country and make a general conclusion on exergy analysis for mason performing block laying activities in an outdoor environment.

Future research should also be done and considered in a wider range of environmental conditions. Furthermore, the exposure time could be considered for human responses and their strain during outdoor activity and figure out the maximum exposure time depending on environment condition would also be very important. So, more data collection would also be needed for quantifying human responses to outdoor thermal condition.

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