Journal of Sustainability Science and Management
Volume 17 Number 6, June 2022: 38-51

eISSN: 2672-7226

THE FEASIBILITY STUDY OF EVAPORATION COOLING USING POROUS MATERIALS

LEE YEE YONG[1]*, ATHILIA ABDULLAH[1], TING SIM NEE[1] AND LEE YEONG HUEI[2]

[1]Department of Civil Engineering, Faculty of Engineering, Universiti Malaysia Sarawak, 94300 Kota Samarahan, Sarawak, Malaysia. [2]Department of Civil and Construction Engineering, Faculty of Engineering and Science, Curtin University, CDT250, 98009 Miri, Sarawak, Malaysia.

**Corresponding author: yylee@unimas.my*

Submitted final draft: 29 September 2021 *Accepted: 31 October 2021* http://doi.org/10.46754/jssm.2022.06.004

Abstract: Human thermal comfort evaluation is essential to avoid heat illness and can be used as an indicator for city development and thermal manikin is one of the tools for it. In this paper, porous materials such as red clay, white clay and plaster are investigated for outdoor thermal comfort evaluation in developing sweating thermal manikin. Unglazed red clay and white clay pots are filled with water and covered with an aluminium foil. However, unglazed plaster pots are filled with absorbent cotton wool saturated with water. They are compared with control specimens (those without water filling). The weights of the pots are measured every hour to check the evaporation rate and the surface temperatures and ambient temperature of all pots are also measured. Based on the analysis, the rate of evaporation for the porous material increases as the ambient temperature increase. The surface temperature of control samples was slightly higher than the samples filled with water where the increase in ambient temperature raised the evaporation cooling effect. In comparison, the white clay pot with its porosity characteristics shows more consistent results. The outcome of this investigation can be used as a reference for the development of sweating thermal manikin to achieve sustainable cities status.

Keywords: Porous materials, sweating, evaporation, thermal comfort, ceramic.

Introduction

Efforts are being made to achieve global sustainable energy efficiencies. In the construction industry, this is being seen in green building development which accelerated the growth of sustainable building rating systems (Tang *et al.,* 2020). Most of the rating involve the criteria of water efficiency, energy efficiency, material efficiency, indoor environmental quality, outdoor environment and waste management etc.

Human comfort is one of the major factors of energy consumption in a building (Lee *et al.,* 2017) and potentially can affect the green building rating. These efforts include thermal insulated concrete (Tay *et al.,* 2021a; 2021b), lightweight concrete (Lee *et al.,* 2018; 2021; Amran *et al.,* 2020), slag concrete (Amran *et al.,* 2021), etc. To achieve indoor thermal comfort, heating, ventilation and air conditioning (HVAC) systems are required and are the source of energy consumption (Lee *et al.,* 2021) and some precautions can be taken to achieve outdoor human thermal comfort.

Many indices for heat stress including empirical, logical and direct were defined in different categories of human thermal comfort evaluation. To assess these metrics, the metabolic rate of the person, the isolation of clothes and physiology measurements such as skin temperature, pulse rhythm, deeper body temperature, sweat intensity and weight loss due to sweating must also be measured. These are some of the occupational variables considered. Previous studies have also considered the human-centric approach by establishing over 100 indices to address thermal comfort in hot and cold environments such as a discomfort index (Thom, 1959; Din *et al.,* 2014), predicted mean vote (Chen & Ng, 2012; Johansson *et al.,* 2014), thermal sensation index (Rose *et al.,* 2010), universal thermal climate index (Johansson *et al.,* 2014) etc.

Thermal manikin is the simultaneous system of human thermal comfort which would be regulated by the human body's finite element physiology model (Lee *et al.,* 2018). There are several manikins that can simulate human sweating mechanism and provide information about the heat exchange through evaporation (Burke *et al.,* 1994).

This view is also supported by recent studies where the physiological model, which calculates the distribution of skin and internal temperature and surface sweat rates, collected skin heat transfer rates and sent information to the manikin, which generated the prescribed skin temperature, surface sweat rates and breathing rates (Rugh & Lustbader, 2006). Prior to this, the thermal manikin had been used to study the interaction of the human body in a thermal environment. To obtain accurate thermal comfort, it is essential to include the sweating mechanism in current thermal manikin.

To obtain more reliable data for energy consumption planning, thermal manikin with sweating mechanisms should be developed. This paper describes the experimental investigation of porous materials evaporation with the inclusion of human sweating parameters for further analysis.

Development of Sweating Manikin

Previous Sweating Manikin

Many current thermal manikins have considered sweating features (Wang, 2008; Pang *et al.,* 2014) which include Finnish manikin "Coppelius", Swiss manikin "SAM", Hong Kong manikin "Walter" and US manikin "Newton". Table 1 shows the previous developed sweating manikins.

Porous Materials in Evaporation

Many evaporative cooling systems require the use of weathered porous materials that are fed with water. This is done via direct evaporative cooling system when the hot outside air flows over a porous wetted medium, it loses its

Table 1: Previous sweating manikins and their features (Mandal *et al.,* 2017)

Manikin	Materials	Number of Sweat Glands	Sweating Rate (g/m²/h)	Application
Coppelius	Nonwoven inner and microporous outer later	187	0-200	Under different temperatures between −50 to +50ºC and relative humidity between 15 - 95%
SAM	Plastic	125	0.41	Under different temperatures between −30 to +40ºC, relative humidity between 20 - 90%, wind speeds between 0.2 - 40 m/s
Walter	Polytetrafluroethylene Gortex membrane	Not applicable	Depends on the type of the clothing tested	Under different temperatures between 10 - 40ºC, relative humidity between 30 - 80%, wind speeds between 0.3 - 5 m/s
ADAM	Porous metal	120	Depends on the applied physiological thermoregulation model	Under transient and non-uniform thermal environments of automobiles, e.g., vehicles, aircrafts
Newton	Carbon-epoxy composite	134	Depends upon the experiment	Under different temperatures between −20 to +50ºC and relative humidity between 0 - 100%

sensitive heat to the water, causing the latter to evaporate, thus reducing the temperature of the air and increasing its contention with humidity.

Insulation, cushioning, impact protection, catalysis, membranes and building materials and other porous materials have been commonly used. They contain a number of pores. In contrast, lightweight concrete, together with water and sand is constructed utilizing lightweight aggregates that have more pores than regular aggregates. Initial studies demonstrated (Chao *et al.,* 1979) used cooling effect theory which applies to porous materials. The body heat diffusion through human tissue was also demonstrated using porous material.

This view was backed by later research done by Frankenberger *et al*. (1997) on sweating, explicitly on achieving a layer of uniform distribution of humidity across the entire body's outer surface, to do so, a manikin was produced with porous material on the outer layer which is typically is clay. They transferred their findings into an empirical model for the mechanism of thermal system in regulation of the human head. In addition, the research suggested that sweating, where a manikin that had an external layer of porous material clay was used to achieve a homogeneous distribution of humidity over the external surface of the body.

In recent studies of human sweating simulation, they used porous materials where the humid layer resembled the sweating mechanism that occurred in the human body. Hence, there is a formation of a uniformly distributed humid layer and it stayed on the porous body's external surface (Mendes & Silva, 2004). In addition, it also had a capillary effect on the porous material and the created a moist layer on the outside surface. It displayed an almost identical trait to that of human skin. Hence, simulating human evaporation cycle was quite fitting. However, the experiments received critiques as the cooling effect was overestimated in respect to the real sweating mechanism of the human body (Mendes & Silva, 2004). Currently, researchers suggest that the porous ceramic materials used have stable structural and non-corrosion properties, due to their strong thermal conductivity and porosity (Liu & Chen, 2014). Therefore, in this study, different porous mediums such as red clay, plaster and white clay were saturated and used to simulate and study human heat transfer through evaporation cooling.

Materials and Methods

The aim of this experimental study is to determine the evaporation rate of red clay, white clay and plaster with their porosity characteristics in response to the sweating process. To simulate the sweating process, unglazed pots of each material were selected and exposed to sunlight for a week prior to the collection of data. Meteorological measurement, surface temperature and weight of the pot were recorded for further analysis. The evaporation rate of red clay, white clay and plaster pots were compared and correlated to the human sweating process.

Materials

The three different types of porous materials pots (red clay, white clay and plaster) were used as shown in Figure 1. All pots were unglazed as a layer of the coating on the surface of a pot will affect its porosity.

Figure 1: Unglazed pots

Experimental Procedures

There were three specimens for each of the materials used. The evaporation rates of all pots were obtained by measuring the weight loss of the pots every hour during daytime. The porosity of all pots was measured by weighing the specimens. They were immersed in water for several days to ensure all pots were saturated. They were weighed again and the increase of the weight was calculated. Meanwhile, the environmental parameters such as air movement, ambient temperature and relative humidity were obtained from the recording of data logged Hobo U12-012.

For red and white clay samples, water filled in the cylinder was initially filled to ensure the surface walls of the porous material were saturated with water. The saturation on the walls must be verified so that it could last throughout the experimental design period. This was not applicable to the plaster specimen as the permeability is high and the amount of water saturation fell on the proving specimen's external surface. Water which left the plaster body without evaporation did not give any cooling effect and created difficulties in quantifying the proving sample's thermal losses.

The identical phenomenon would occur on the human skin surface and human body in humid and warm environments and high metabolic rate where sweat falling reflects a loss of the bodies capability to cool effectively. To overcome this, the internal volume of the plastic specimen was lined with water-saturated absorbent cotton wool. With this, a complete humidification of the plaster-proving sample's solid walls is provided that can last for several hours. The experimental setup of plaster pots is shown in Figure 2. At the same time, the surface temperatures of all pots were measured and recorded every hour using the thermocouple and data logger. Then, two thermocouples were connected to each of the pots and linked to the data logger to obtain and record the surface temperature. Figure 3 shows the overall setup with thermocouples.

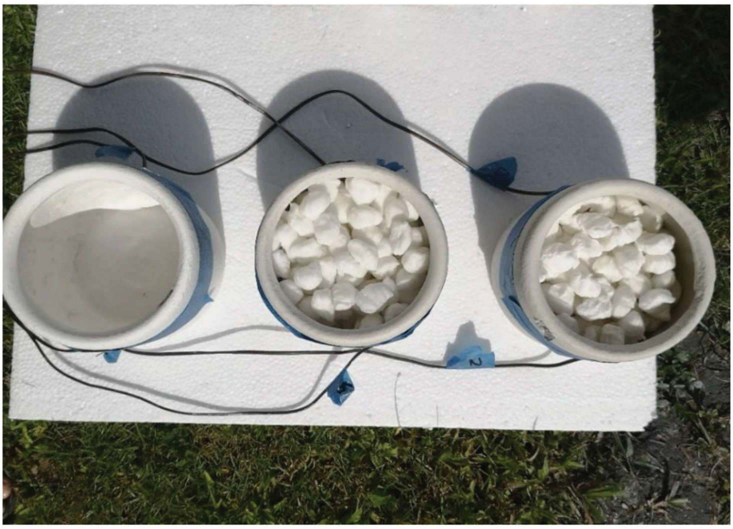


Figure 2: Plaster pots with wet absorbent cotton wool

Figure 3: Thermocouples connected to all pots during the experiment

Thermal Comfort Calculation

To determine the relationship between the white clay pots and thermal comfort evaluation, Thom's discomfort index (DI) (1959) was used as shown in Equation 1.

$$DI=T-0.55(1-0.01RH)(T-14.5) \quad \text{(Equation 1)}$$

where T is the ambient temperature in ºC and RH is the relative humidity in %. In the study of Din *et al*. (2014), the DI classification and range proposed would use to characterise the white clay pots with thermal comfort evaluation. Table 2 shows the criteria of DI.

Results and Discussion

The dry and wet weight of all pots were recorded simultaneously with the data collection of ambient temperature, surface temperature and relative humidity during experimental period.

Surface Area and Porosity

The external surface area of all pots was determined by using formula as shown in Equation 2.

$$\text{Surface area, } A = 2\pi rh+\pi r^2 \quad \text{(Equation 2)}$$

where h is the height and r is the radius.

The porosity of each sample was determined by using the formula shown in Equation 3. Table 3 shows the average porosity of white clay, red clay and plaster samples. It is confirmed that the greater the porosity of the material, the greater the rate of evaporation. This in line with the fact that the increase in porosity helps to increase the absorption of the porous material, which allows the liquid to permeate more quickly (Sellami *et al.,* 2019).

$$\text{Percent porosity} = \frac{\text{Wet weight}-\text{dry weight}}{\text{Wet weight}-\text{suspended weight}} \times 100$$

(Equation 3)

Table 2: The criteria of DI from Din *et al.* (2014)

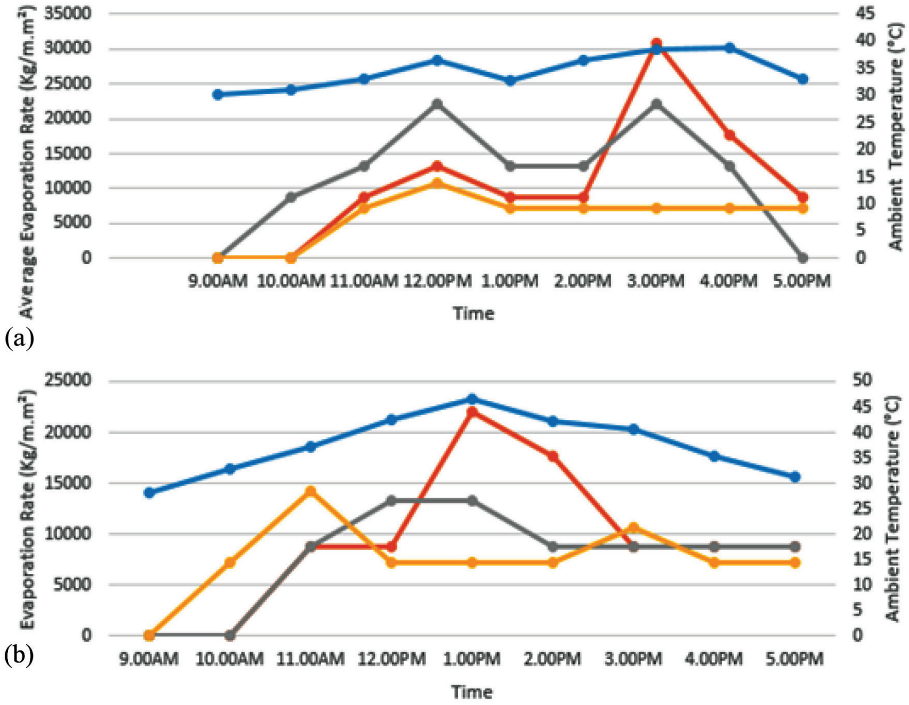
DI	**≤ 14.9**	**15 ~ 19.9**	**20.0~30**	**≥ 30.1**
Sense	Uncomfortable	Comfortable	Partially comfortable	Uncomfortable

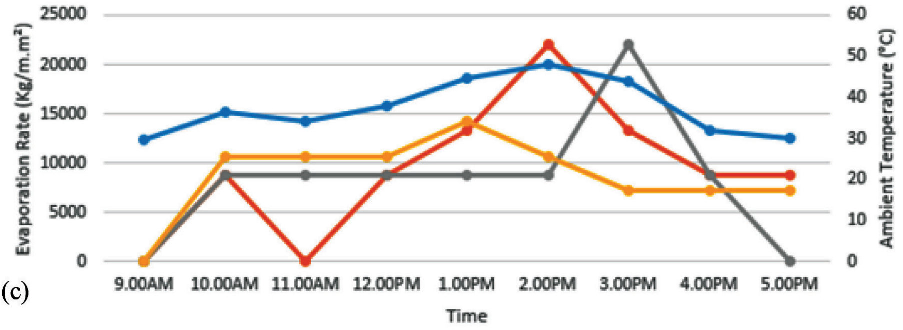
Table 3: Specimens' surface area and porosity

	White Clay	**Red Clay**	**Plaster**
Height, h (cm)	11	11	12
Radius, r (cm)	6.25	6.25	7.0
Surface area, A (cm^2)	554.687	554.687	681.725
Dry weight (g)	559	570	410
Suspended weight (g)	1657	1530	1392
Wet weight (g)	636.5	586.5	487
Total weight loss (g)	77.5	16.5	77
Porosity (%)	7.59	1.75	8.5

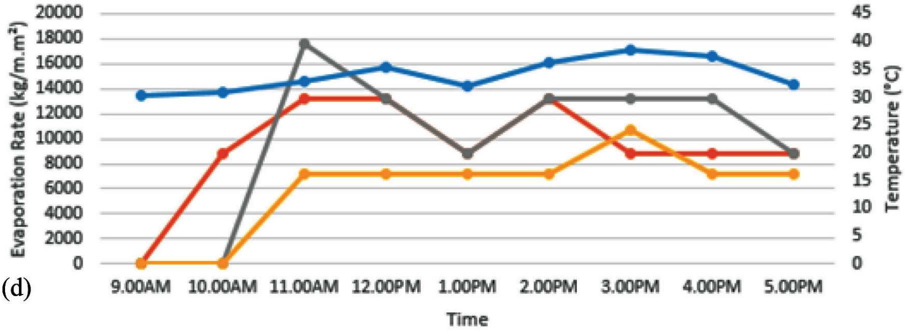
Correlation between Ambient Temperature and Evaporation Rate of Porous Materials

Based on the data analysis, the rate of evaporation for the porous material increases as the ambient temperature increase. The water inside the porous pots undergoes latent heat process and turns into gas form. The water vapour then flows through the pores by capillary action. Which causes water loss and the weight of pots to reduce. The overall results are illustrated in Figure 4.

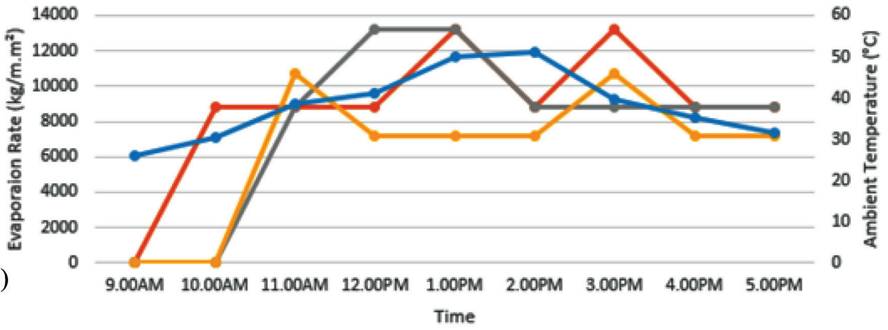



Evaporation Rate (Kg/m.m^2)
25000
20000
15000
10000
5000
0
60
50
40
30
20
10
0
Ambient Temperature (°C)
9.00AM
10.00AM
11.00AM
12.00PM
1.00PM
2.00PM
3.00PM
4.00PM
5.00PM
Time

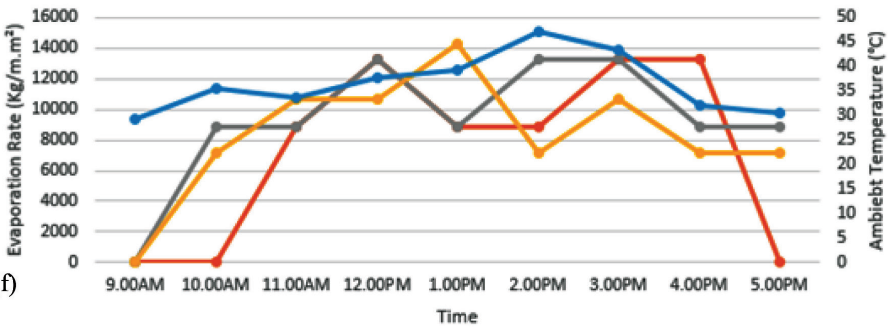
(c)


Evaporation Rate (kg/m.m^2)
20000
18000
16000
14000
12000
10000
8000
6000
4000
2000
0
45
40
35
30
25
20
15
10
5
0
Temperature (°C)
9.00AM
10.00AM
11.00AM
12.00PM
1.00PM
2.00PM
3.00PM
4.00PM
5.00PM
Time

(d)


Evaporaion Rate (kg/m.m^2)
14000
12000
10000
8000
6000
4000
2000
0
60
50
40
30
20
10
0
Ambient Temperature (°C)
9.00AM
10.00AM
11.00AM
12.00PM
1.00PM
2.00PM
3.00PM
4.00PM
5.00PM
Time

(e)


Evaporation Rate (Kg/m.m^2)
16000
14000
12000
10000
8000
6000
4000
2000
0
50
45
40
35
30
25
20
15
10
5
0
Ambiebt Temperature (°C)
9.00AM
10.00AM
11.00AM
12.00PM
1.00PM
2.00PM
3.00PM
4.00PM
5.00PM
Time

(f)

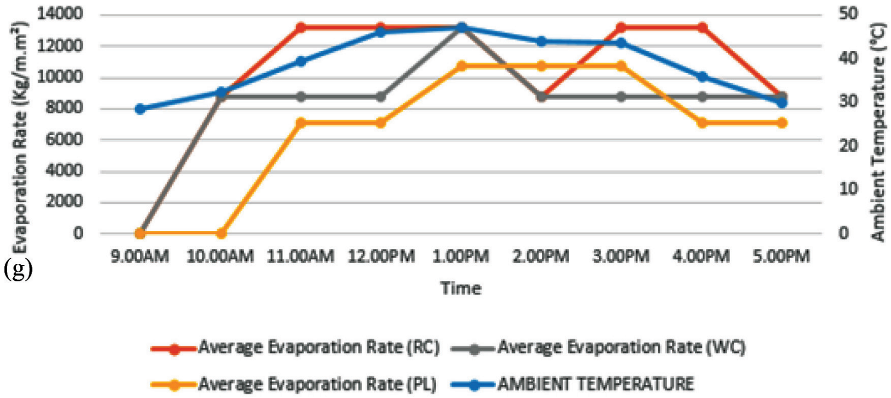


Figure 4: Evaporation rate of red clay, white clay and plaster for (a) day 1, (b) day 2, (c) day 3, (d) day 4, (e) day 5, (f) day 6 and (g) day 7

Based on the analysis, as the ambient temperature increased, evaporation rate also increased. This is because water molecules are bonded by hydrogen molecules. When temperature increase, kinetic energy between the molecules increases which causes the hydrogen bond between Oxygen (O) and Hydrogen (H) to break. The molecules are now free and evaporation is said to occur.

Porosity also affects the evaporation rate. For example, on day 6, at 11.00 am, the ambient temperature increased to 33.75ºC. Evaporation rate also increased to 8823.53 kg/(m.m^2), 8823.53 kg/(m.m^2) and 10714.29 kg/(m.m^2) for red clay, white clay and plaster, respectively. The evaporation rate of plaster was comparatively higher than white clay and red clay because the porosity percentage of plaster is higher than red clay and white clay. According to Sellami *et al*. (2019), this increased porosity increases the permeability of the porous material, allowing the liquid to permeate faster.

Generally, the evaporative cooling did not occur immediately in this experiment as the water molecules require ample amount of time to absorb energy to change its physical state from a liquid state to a gaseous state. The evaporation process occurred when the ambient temperature was increased until the heat was absorbed by the water in the saturated red clay pots as latent heat of vaporisation. It was then transported away by the dispersing vapour molecules. Therefore, it can be seen that the saturated sample pots require longer time and possibly more heat energy to induce the evaporative process for evaporative cooling to occur.

Correlation between Ambient Temperature and Surface Temperature of Porous Materials

Control samples were the pots that are not filled with water. Control samples were put under the same conditions to find how surface temperature differentiates when evaporation occurs and when it does not occur. From the collected results, the surface temperature of control samples was slightly higher than the samples filled with water when placed under the same condition. This situation occurred because no cooling effect happened on the controlled samples. For the other samples filled with water, the water would absorb heat and water molecules changed from liquid to gaseous state and escaped through the pores in the form of evaporation, similar to the sweat evaporation process that takes place on human skin.

Correlation of Evaporation Rate with Human Sweating Process

The evaporation rate of red clay pots was within the range of 0.00 kg/m.m^2 to 30882.35 kg/m.m^2. The evaporation rate of white clay pots was within the range of 0.00 kg/m.m^2 to 22058.82

kg/m.m^2. The evaporation rate of plaster pots was within the range of 0.00 kg/m.m^2 to 14285.71 kg/m.m^2. When the surrounding temperature increased, the human bodies temperature also increased and the person experienced sweating. When the sweat gets enough energy, it changes from liquid to water vapour and eventually evaporates into the atmosphere, which makes the human skin cool down. This process was represented by the samples filled with water that acted as human skin under saturated condition by simulating sweating mechanism and cooling down effect. It can be seen that as the ambient temperature increased, surface temperatures of sample pots increased. Hence, water absorbs energy and evaporation occurs.

The surface temperature of control samples was however higher than the sample pots because it was not filled with water. Thus, no evaporation occurred and the surface temperatures remained high. Chen (2011) stated that increasing the temperature of the air increased the cooling effect of evaporation in the porous material. Evaporation rate also reached a maximum which was 22058.82 kg/m.m^2. The sample and control pots experienced the same situation for other days.

Due to its properties, each porous material had different evaporation mechanisms. The levels of evaporation from porous material differs considerably due to the changes in internal carriage mechanisms. According to Kelundapyan *et al*. (2020), pore properties and ambient conditions (humidity and air temperature) are the two factors which influence the evaporation rate of porous water-filled materials. In the meantime, during exposure to high ambient temperature, sweating will occur. When the body is overheated, sweat is secreted to the surface of the skin and evaporates by the heat on the surface of the skin.

From observations, the plaster and red clay had large capillary pores, which allowed for better flow of vapour in a short period of time and could not be compared to human sweat levels. From Table 4, which indicates that the plaster and red clay has a higher porosity, which is 8.5% and 7.59%. It was found that the higher the porosity of the substance, the higher the evaporation rate. This finding can be explained by the fact that the increase in porosity, increases the permeability of the porous material, allowing the liquid to permeate faster (Sellami *et al.,* 2019).

Similar studies were carried out by Kelundapyan *et al*. (2020) to determine the suitably of the porous material as the preliminary thermal comfort assessment by simulating human sweat evaporation rates in a similar method. In that experiment, the actual human sweat evaporation rate was determined by taking into account the difference in the individual nude body weight (kg) measured before and after each experiment in the electronic precision

Table 4: Comparison between minimum and maximum value for human sweat, red clay, white clay and plaster

Reference	**Material**	**Human Sweat Evaporation Rate (kg/m.m²)**		**Porosity (%)**
		Minimum	**Maximum**	
Rhubenthiraan Kelundapyan *et al*. (2020)	Human	0.00092	0.00496	-
	Red clay	14989.9	232920.1	7.6
	White clay	9253.9	92539.0	2.8
	Plaster	5477.7	115422.2	16.7
Current study	Red clay	0	30882.35	7.59
	White clay	0	22058.82	1.75
	Plaster	0	14285.71	8.5

balance scale (1 g accuracy). These studies were carried out in Universiti Teknologi Malaysia (UTM).

Besides that, as compared with the result from Kelundapyan *et al*. (2020), the style of the evaporation rate is comparable with the current study where the human sweat loss increases with time as the evaporation rate of pot samples at the beginning of the day reached its peak between 2.30 pm to 3.30 pm, the sweat loss value of human skin is lower than the pot samples (red clay, white clay and plaster), however, the style of the variation is comparable by showing the uniform deviation between sweat loss and evaporation rate of pot samples.

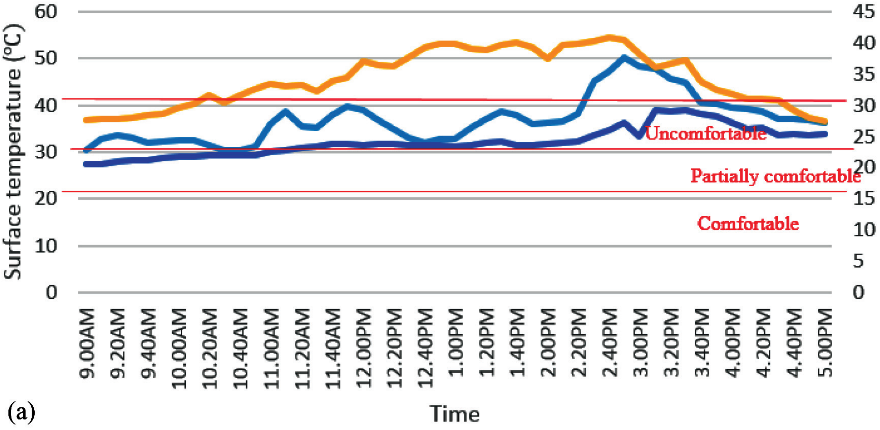
As a result, red clay and white clay have been found to be a more suitable porous material to use in simulating human sweating mechanism.

Characteristic of Porous Material with the Thermal Comfort Evaluation

In the analysis of thermal comfort evaluation, the Discomfort Index (DI) was used to determine the relationship of the porous materials with thermal comfort evaluation. Table 4 summarized the temperature range at each level of thermal comfort condition. The average of ambient temperature, surface temperatures, humidity and DI value were summarized.

DI is influenced by two major variables which are relative humidity and ambient temperature. Such variables may also influence the surface temperature and the evaporation rate of all samples at the same time. A surface temperature against time is then plotted and DI was calculated using Equation 1 to see the value of level of comfort.

Results of DI, average surface temperature red clay, white clay and plaster respectively against time is shown in Figure 5. It indicates a trend that the surface temperature also increased with the DI value. Some common patterns were observed as following: from sunrise to noon, the values increased due to gradual increase in the air temperature in contact with the heated surface and then decreased until the end of the day when surface cooling took place. DI could characterize and reflect the thermal conditions in the tropical countries like Malaysia. Based on the observation in this study, the estimated DI index from red clay, white clay and plaster may support the spatial patterns of DI over urban areas.



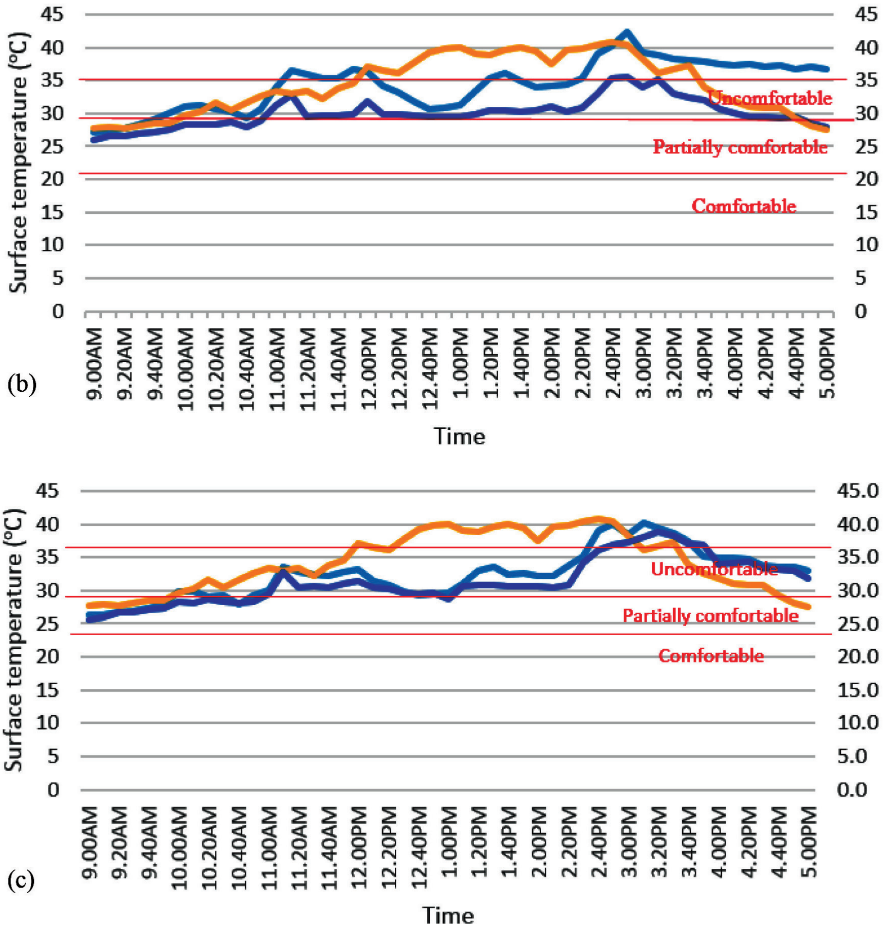


Figure 5: Surface temperature and DI evaluation for (a) red clay, (b) white clay and (c) plaster

Conclusion

UHI phenomenon caused the increase in air temperature to rise due to heat trapped by artificial built-up conditions in the surrounding city. As a result, it increases the level of discomfort among humans particularly among urban residents. Therefore, in order to assess the thermal comfort resulting from the thermal environmental, it is important to determine suitable materials for developing heat sensor integrated with related parameters like psychology and physiology factor based on local microclimate conditions. Porous materials such as red clay, white clay and plaster were used in this research to simulate the human sweating process by evaluating its evaporation rate, establishing correlation of the drying rate with the human sweating process and investigating the characteristics of porous materials with the thermal comfort evaluation.

Evaporation rate of porous materials result showed that white clay has the highest rate which is 22058.82 kg/m^2.m, red clay 13235.29 kg/m.m^2 and the lowest rate is plaster 10714.29 kg/m.m^2, respectively. Red clay and white clay have a close relationship and are thus capable of simulating the evaporation process of human sweating. The relative humidity and ambient temperature affected both DI and surface temperatures.

As the surface temperature as well as DI rises or gets uncomfortable, the level of thermal discomfort increases. This is indicative of the fact that the Discomfort Index can be used to assess the characteristics of the porous material. Based on the findings, the DI index can help to assess the spatial patterns of indices of discomfort over urban areas.

The rate of evaporation of porous material that simulates the human sweat loss as a first step or as a pre-assessment to indicate the influence of the outdoor impact. Sweating in human beings imply a step forward and has been considered the preliminary developmental analysis tool for calculating human thermal comfort levels as a physiological factor. Through this research study, porous material such as red clay and white clay may be suitable as a new generation of manikins that are fit for outdoor use and evaluation.

Therefore, the characteristics of porous materials like white and red clay can logically be used as part of a pilot study for future simulations of the human sweating mechanisms.

Acknowledgements

The authors would like to express their gratitude to the Ministry of Higher Education, Malaysia (Kementerian Pengajian Tinggi Malaysia) through Fundamental Research Grant Scheme of FRGS/1/2019/TK10/UNIMAS/02/4 and Universiti Malaysia Sarawak for their financial support and research facilities. The authors would like to thank Ms. Ruubhini Annahdurai for her contributions to the data collection used in this study.

References

Amran, M., Lee, Y. H., Vatin, N., Fediuk, R., Shek, P. N., Lee, Y. Y., & Murali, G. (2020). Design efficiency, characteristics and utilization of reinforced foamed concrete: A review. *Crystals*, *10*(10), 948. https://doi.org/10.3390/cryst10100948

Amran, M., Murali, G., Khalid, N. H. A., Fediuk, R., Ozbakkaloglu, T., Lee, Y. H., Haruna, S., & Lee, Y. Y. (2021). Slag uses in making an eco-friendly and sustainable concrete: A review. *Construction and Building Materials, 272*, 121942. https://doi.org/ 10.1016/j.conbuildmat.2020.121942

Burke, R. A., O'Neill, F. T., & Stricker, P. (1994). The development of a heat pipe driven manikin with variable flow irrigated skin. *The 6th International Conference on Environment Ergonomic*, Montebello, Canada, 25-30 September 1994.

Chao, K. N., Eisley, J. G., & Yang, W. J. (1979). Heat and water migration through normal skin: Part 1--steady state. *Medical & Biological Engineering & Computing, 17*(3), 301-310. https://doi.org/10.1007/bf02443814

Chen, L., & Ng, E. (2012). Outdoor thermal comfort and outdoor activities: A review of research in the past decade. *Cities, 29*(2), 118-125. https://doi.org/10.1016/j.cities. 2011.08.006

Din, M. F. M., Lee, Y. Y., Ponraj, M., Ossen, D. R., Iwao, K., & Chelliapan, S. (2014). Thermal comfort of various building layouts with a proposed discomfort index range for tropical climate. *Journal of Thermal Biology, 41*, 6-15. https://doi.org/10.1016/j.jtherbio.2014.01.004

Frankenberger, R. T., Nahim, W., & Konecny, E. (1997). Development of a premature baby simulator. *World Congress on Medical Physics and Biomedical Engineering: XVIII International Conference on Medical and Biological Engineering and XI International Conference on Medical Physics*, Nice, France.

Johansson, E., Thorsson, S., Emmanuel, R., & Kruger, E. (2014). Instruments and methods in outdoor thermal comfort studies-the need for standardization. *Urban Climate, 10*, 346-366. https://doi.org/10.1016/j.uclim.2013.12.002

Kelundapyan, R., Yong, L. Y., Zakaria, M. A., Nagapan, S., & Segaran, V. C. (2020). The suitability of porous material to simulate evaporation in human sweating mechanisms.

International Journal of Engineering and Advanced Technology, 9(3), 457-463. https://www.ijeat.org/wp-content/uploads/papers/v9i3/C4805029320.pdf

Lee, Y. H., Amran, M., Lee, Y. Y., Kueh, A. B. H., Kiew, S. F., Fediuk, R., Vain, N., & Vasilev, Y. (2021). Concrete thermal behaviors in the tropical climate. *Sustainability*, accepted for publication.

Lee, Y. H., Chua, N., Amran, M., Lee, Y. Y., Kueh, A. B. H., Fediuk, R., Vatin, N., & Vasilev, Y. (2021). Thermal performance of structural lightweight concrete composites for potential energy saving. *Crystals, 11*(5), 461. https://doi.org/10.3390/cryst11050461

Lee, Y. H., Lim, M. H., Lee, Y. L., Lee, Y. Y., Tan, C. S., Mohammad, S., & Ma, C. K. (2018). Compressive strength of lightweight foamed concrete with charcoal as a sand replacement. *Indian Journal of Engineering & Materials Sciences, 25*(1), 98-108. http://nopr.niscair.res.in/handle/123456789/44440

Lee, Y. Y., Din, M. F. M., Noor, Z. Z., Iwao, K., Tain, S. M., Singh, L., Khalid, N. H. A., Anting, N., & Aminudin, E. (2018). Surrogate human sensor for human skin surface temperature measurement in evaluating the impacts of thermal behaviour at outdoor environment. *Measurement, 118*, 61-72. https://doi.org/10.1016/j.measurement.2018.01.010

Lee, Y. Y., Lee, Y. H., Mohammad, S., Shek, P. N., & Ma, C. K. (2017). Thermal characteristics of a residential house in a new township in Johor Bahru. *IOP Conf. Series: Materials Science and Engineering, 271*, 012027. https://doi:10.1088/1757-899X/271/1/012027

Liu, P. S., & Chen, G. F. (2014). Chapter Five - Fabricating porous ceramics. In P. S. Liu, G. F. Chen (Eds.), *Porous materials* (pp. 221-302). Butterworth-Heinemann, https://doi.org/10.1016/B978-0-12-407788-1.00005-8

Mandal, S., Annaheim, S., Camenzind, M., & Rossi, R. M. (2017). Evaluation of thermo-physiological comfort of clothing using manikins. In *Manikins for textile evaluation* (pp. 115-140). Woodhead Publishing Series in Textiles. https://doi.org/10.1016/B978-0-08-100909-3.00005-4

Mendes, J. C. A. F., & Silva, M. C. G. (2004). On the use of porous materials to simulate evaporation in the human sweating process. *European Journal of Applied Physiology, 92*(6), 654-657. https://doi.org/10.1007/s00421-004-1131-4

Pang, T. Y., Subic, A., & Takla, M. (2014). Evaluation of thermal and evaporative resistances in cricket helmets using a sweating manikin. *Applied Ergonomics, 45*(2), Part B, 300-307. https://doi.org/10.1016/j.apergo.2013.04.011

Rose, D., Wu, H., & Beyers, M. (2010). Spatial and temporal computation of thermal comfort inputs in outdoor spaces. *The 5th International Symposium on Computational Wind Engineering*, Chapel Hill, North Carolina, USA May 23-27, 2010.

Rugh, J., & Lustbader, J. (2006). Application of a Sweating Manikin controlled by a Human Physiological Model and lessons learned. *The 6th International Thermal Manikin and Modeling Meeting*, Hong Kong, China, October 1-18, 2006.

Sellami, K., Feddaoui, M., Labsi, N., Najim, M., Oubella, M., & Benkahla, Y. K. (2019). Direct evaporative cooling performance of ambient air using a ceramic wet porous layer. *Chemical Engineering Research and Design, 142*, 225-236. https://doi.org/10.1016/j.cherd.2018.12.009

Tang, K. H. D., Foo, C. Y. H., & Tan, I. S. (2020). A review of the green building rating systems. *IOP Conf. Series: Materials Science and Engineering, 943*, 012060. https://doi:10.1088/1757-899X/943/1/012060

Tay, L. T., Lee, Y. Y., Lee, Y. H., & Kueh, A. B. H. (2021a). Compressive and flexural strengths of mortar with silica aerogel powder. In Mohammed, B. S., Shafiq, N., Rahman, M., Kutty, S., Mohamad, H., Balogun, A. L. (Eds.), *ICCOEE2020. ICCOEE 2021*. Lecture Notes in Civil Engineering, vol 132. Singapore: Springer. https://doi.org/10.1007/978-981-33-6311-3_57

Tay, L. T., Lee, Y. Y., Kueh, A. B. H., & Lee, Y. H. (2021b). Flatwise and edgewise compression strengths of sandwich panel with silica aerogel mat. *IOP Conf. Series: Materials Science and Engineering, 1101*, 012001. https://doi:10.1088/1757-899X/1101/1/012001

Thom, E. C. (1959). The discomfort index. *Weatherwise*, *12*, 57-61.

Wang, F. (2008). A comparative introduction on sweating thermal manikin "Newton" and "Walter". *The 7th International Thermal Manikin and Modelling Meeting*, University of Coimbra, Portugal, pp. 1-7.