Measurement 118 (2018) 61–72

Contents lists available at ScienceDirect

Measurement

journal homepage: www.elsevier.com/locate/measurement

Surrogate human sensor for human skin surface temperature measurement in evaluating the impacts of thermal behaviour at outdoor environment

Yee Yong Lee[a,*], Mohd Fadhil Md Din[b], Zainura Zainon Noor[b], Kenzo Iwao[c], Shazwin Mat Taib[b], Lakhveer Singh[d], Nur Hafizah Abd Khalid[e], Nickholas Anting[a], Eeydzah Aminudin[e]

[a] Jamilus Research Center, Faculty of Civil and Environmental Engineering, Universiti Tun Hussein Onn Malaysia, 86400 Parit Raja, Batu Pahat, Johor, Malaysia
[b] Center of Environmental Sustainability and Water Security (IPASA), Research Institute of Sustainable Environment (RISE), Universiti Teknologi Malaysia, 81310 UTM Johor Bahru, Malaysia
[c] Nagoya Institute of Technology, Incubation Center, Building 2, Room 622B, Gokiso-cho, Showa-ku, Nagoya-city, Aichi-Pref. 466-8555, Japan
[d] Faculty of Industrial Sciences & Technology, Universiti Malaysia Pahang (UMP), Lebuhraya Tun Razak, 26300 Pahang, Malaysia
[e] Department of Structure and Materials, Faculty of Civil Engineering, Universiti Teknologi Malaysia, 81310 Johor Bahru, Johor, Malaysia

ARTICLE INFO

Keywords:
Thermal environment
Ergonomics
Thermal comfort
Human skin surface measurement
Outdoor environment
Surrogate Human Sensor
Thermal behaviour

ABSTRACT

The world is experiencing high rates of urbanisation and it has slowly become an alarming social process, especially in developing countries. This has demanded an urgent investigation on human thermal comfort, especially in tropical climates. In this study, a surrogate human sensor (SHS) was developed to establish a linkage between human skin surface and SHS with the surrounding environments. Black plastic corrugated cardboard was used in the SHS fabrication as its thermal conductivity was close to the thermal conductivity and emissivity of the human epidermal skin layer. The SHS was designed to correlate with human skin surface temperature and a regression model was developed. The regression equation was obtained for the human skin temperature prediction (T_h) by using SHS. Statistical analysis of the ANOVA (F = 13,700; $\rho < 0.05$) was significantly tested to show its reliability. The predicted and measured human skin temperature was compared and the results revealed that both temperature variations was found in range ± 0.5 °C in temperature differences. The advantages of SHS as the sensor for the impact of thermal behaviour can be identified by observing the temperature difference as it can directly reflects the influences from the surrounding outdoor environment. Although it is proven valid statistically, however, SHS is only relevant as an initial indicator to investigate the impacts of thermal behaviour and discomfort level. It can further used to measure human thermal comfort by correlating surrounding environment condition with comfort sensation through SHS regression model.

1. Introduction

Thermal sensation was investigated initially by Fanger [1–2] in an indoor environment who focused on the correlation of the physical parameters, physiological parameters and human perception towards surrounded environment. His group introduced comfort index of Predicted Mean Vote (PMV) and Predicted Percentage of Dissatisfied (PPD), leading to other related indicators such as Heat Stress Indices [3]. Throughout the research development, adaptive thermal comfort has been concentrated [4–7]. In warm climates, it has been found behavioural adaptation is one of the overestimation of PMV index [8–9].

Outdoor thermal environment of urban spaces plays a great role on the quality of life in a city. It directly affects people's comfort or behaviour and usage of outdoor spaces. In the path of investigation, the thermal behaviour of urban environment has been documented by various researchers, both in anthropogenic factors [10–12] and 'albedo' effects of surface material [13–15] as well as the urban arrangement [16,17]. Evaluating the thermal environment, particularly when it concerns the human body and health, is important so as to improve our way of living. The level of human thermal comfort is highly dependent on the urban microclimate environment whereby thermal sensations and comfort in indoor and outdoor environments are expected to decrease along with changes in climatic conditions [18,19]. The significant consequences from the impacts of thermal behaviour of the surrounding built-up environment is known as Urban heat Island (UHI) phenomenon which may further affect human thermal comfort especially in urban outdoor conditions. Various new strategies for improving the state of ambient comfort have been outlined as they directly influence our energy consumption efficiency, which is mainly linked to sustainable development, and it also correlates closely with

* Corresponding author.
E-mail address: yylee@uthm.edu.my (Y.Y. Lee).

https://doi.org/10.1016/j.measurement.2018.01.010
Received 19 April 2016; Received in revised form 7 December 2017; Accepted 8 January 2018
Available online 09 January 2018
0263-2241/

human thermal comfort [20].

Logically, different parts of our bodies respond differently to local heat transfer and external heat impact of the thermal environment to keep our body temperature constant at 37 °C and this ability is generally termed as the human body thermoregulation system [21]. Besides this, the human skin temperature is also an important physiological parameter which reflects the state of heat exchange between the human body and its thermal environment [22]. The thermal heat balance of the human body is highly influenced by the external heat impact and its thermoregulation system. Therefore, it is essential to consider thermal comfort under continuous heat impact to accurately define the relationship between the human body and its surrounding environment. Some researchers have taken initiative to conduct human subject tests in controlled environmental chambers as to describe the predictive models of local and overall human thermal sensation and responses in a hot environment by calculating the heat exchange between the human body and the environment [23,24]. Besides that, some researcher carried out thermal comfort evaluation by employing an open networking technology and sensory devices in order to obtain the thermal characteristic of the environments for human as well as comfort measurement [25,26]. It is clear that thermal comfort research is essential to enhance the understanding of heat exchange occurring between the human body and the prevailing environmental conditions specifically through climatic variables such as, air temperature, humidity, radiant heat and wind speed [27,28]. The direct method such that exposing human body to direct sunlight or outdoor environment is discouraged due to induction of death and health problem consequently. Hence, one of the practical methods to evaluate human and thermal environmental interactions is via a kind of sensor namely, Surrogate Human Sensor (SHS). This is a simulating device or indicator alike the thermal manikin that is developed as the preliminary stage of study for establishing a linkage between human skin surface, devise and surrounding environments.

Previously, the thermal manikin has been used to study the interaction of human body with the thermal environment. The history and applications of thermal manikins have been discussed by [29,30]. The thermal manikin studies are mainly focus in indoor environment where it is installed in a climatic chamber and connected to a power supply with the computer-controlled system or using computational fluid dynamic methods (CFD) to investigate the parameters needed. The parameter was covered such as thermal radiation, resistance and evaporative resistance of clothing system; distribution of local and overall body segment's surface temperature; heat transfer coefficient, sweating mechanism and etc [31–42]. Less attention is given to the outdoor thermal comfort evaluation due to the impacts of thermal behaviour, which now has increased interest especially in the urban cities. Therefore, in this study, a simplified form of manikins which are categorized as simplified Surrogate Human Sensor (SHS) have been consider by using simple and readily available material for fabrication so that it is easily applicable to the public, unlike the existing manikin which is complex and heavy, causing complications for transportation. The term simplified Surrogate Human Sensor (SHS) is used as this SHS is not yet a thermal manikin but acts as a sensor or tool for correlation as the preliminary stage of the new manikin development. This SHS was initially developed to determine its thermal interaction with the surrounding environmental conditions for predicting the impact of thermal behaviour in outdoor environments, as well as establishing a human skin surface correlation to examine its relationship with human skin surface. This SHS is simulated for observing the heat transfer reaction from the ambient to the manipulated human skin temperature.

Hence, in this study, SHS was developed and can also be used to investigate the heat envelop throughout the city environment as it can directly reflect the impact of the thermal behaviour based on the influence from the climatic variables. This study was initiated with the SHS design and investigate its interaction with the human skin surface in outdoor thermal environment. A regression model can be developed from SHS by integrating the influence of the climatic variables and human skin temperature. As a result, the prediction towards the temperature variation of human skin surface could be obtained in relation to the outdoor thermal environmental condition. The impact of thermal behaviour is usually determined based on the different types of built-up environments where two types of built-up environment such as green area and city center been investigated for application of SHS regression model. The SHS regression model was examined to ensure the usability of the regression model by the SHS. By this examination, the impact of thermal behaviour from the surrounding built-up environments on human health and comfort can be identified using a simple prediction model, i.e. a simplified Surrogate Human Sensor (SHS) which can directly measured and reflected the impacts of thermal behaviour to human skin temperature as well as thermal comfort through the regression model. Throughout this study and paper presentation, it could promote environmental awareness and can be considered by individuals, groups or the local authorities responsible for planning and managing townships in urban cities for mitigation purposes to achieve sustainable development.

2. Materials and method

SHS was initially fabricated as an indicator to receive the impact of thermal load from the surroundings built up environemnts. It can be used to study the interaction of human skin surface with the surrounding outdoor environment in terms of temperature, as well as establishing a human skin surface correlation to examine its relationship with human skin surface. Fig. 1 shows the flow chart for the research activities.

2.1. Surrogate human sensor design

A "Surrogate Human Sensor (SHS)" is alike to the thermal manikin, but their functions were different throughout the study. SHS, while similar in design with a head, face and body, is not the thermal manikin; it acts like a sensor, or indicator, to determine the impacts of thermal behaviour from the surrounding environments. This SHS was fabricated to simulate only the sensible heat process. The advantages of this technique included speed and ease of measurements as well as lower cost per measurement. The 2D black SHS was fabricated using black plastic corrugated cardboard made of polypropylene with a stand at the back to support the measuring plate of the head, face and body, as shown in Fig. 2. The black in colour in thermodynamic equilibrium can absorb the solar heat from all surfaces that strike on it where the 2D geometry is enough to present the surface temperature of the SHS. The SHS was formed by horizontal and vertical flat plate with the total surface area of the SHS was 0.52 m^2, as shown in Fig. 2. The orientation of the three measuring plate are based on the position of human body where there is a horizontal head plate, a vertical face and body plate; even though this SHS does not act like a human body or a thermal manikin. This SHS was initially fabricated to replace the thermal manikin in measuring the heat distribution at each surface zone by using new material.

A thermocouple wire type-T was attached to its head, face and body to measure the surface temperature of the SHS independently in this case study. The thermocouples were attached to the stated positions with epoxy that can resist damages from raining day and take the related surface temperatures when connected to the data logger. The points of measurement were selected at the head, face and body because these parts received the strongest thermal heat, similar to that of an actual human body, as the head is the topmost part of the SHS and is directly exposed to sunlight and heat. The face and body represents the vertical surface of the SHS that received heat so that the SHS received heat from both the vertical and horizontal surface while the black colour also encourage the absorption of heat from the surrounding environment. The body makes up the largest surface area where it may