Internet-of-Things (IoT) for Human Thermal Comfort: A Simulative Investigation

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***Abstract*—Human thermal comfort is very important especially in an indoor environment as it can influence human's health and welfare. In tropical countries like Malaysia, air conditioning system has become a necessary tool in creating a thermally comfortable ambience in an indoor environment. However, the current control mechanism of the system would allow the user to set into maximum cooling – at minimum temperature with maximum fan speed – which not only consumes more energy, but is not creating a thermally comfortable environment as well, as extreme coolness could also bring negative effect towards the human. Therefore, it is essential to integrate human thermal comfort factor into air conditioning system control as well. This paper will highlight the possibility of integrating thermal comfort control into air conditioning system in creating a comfortable indoor environment. It adopts an enhanced version of Predictive Mean Vote (PMV) approach, specifically in creating thermal comfort ambience for a small sedentary work-based indoor space, in tropical countries. As the Internet-of-Things has become a trend in the smart home application, its element is also integrated here, where an Android-based application is developed and tested towards controlling a hardware simulative model which represents an air conditioning system based on the user-defined PMV value. It is shown that the application is able to control the fan speed and temperature through the LED brightness as demanded by the user. It is not only expected to work with a real air conditioning system in the future to create a thermally comfortable environment, but could also allow the system to be operated in energy and cost-efficient manner.**

***Index Terms*—Air Conditioning System Control; Android-Based Application; Human Thermal Comfort; Internet-Of-Things; Predictive Mean Vote (PMV).**

I. INTRODUCTION

Thermal comfort is very important especially in a closed, indoor space. It can be defined as the condition of mind that expresses satisfaction towards the thermal environment [1]. It is often that the air conditioning (a/c) system be utilized to create a thermally comfortable ambience indoor, especially in tropical countries like Malaysia. However, existing control features of the system do not allow it to be operated to create a thermally comfortable environment for human. Even worse, users have the tendency to set the a/c system into maximum cooling, i.e. at minimum temperature with maximum fan speed, which could bring negative effect towards human's health and welfare.

Existing commercial a/c system only focused on energy savings and temperature regulations, but not human thermal comfort [2]. Other features like power saving, motion detection and fast cooling have been used in the commercial a/c system, but none of them has integrated the thermal comfort features. Thus, it is very important to have a control mechanism that will allow users to operate the a/c system to create a thermal comfort environment.

Due to the above importance, researchers have come out with several mechanisms to integrate thermal comfort in the a/c system. Feldmeier and Paradiso [2] for example, have developed a personal Heating, Ventilating, Air Conditioning (HVAC) thermal comfort, but it only deals with hot, cold and neutral feelings, which sometimes are not adequate for human comfortability. Some researchers developed control system integrated with user comfortability, but have only been developed and tested for a desktop fan/heater [3] and domestic heaters [4], which may not be effective for an a/c system. As web services, cloud computing and Internet-of-Things (IoT) has become a trend, more and more researchers are integrating these features to control a/c system, but thermal comfort element is still not considered [5, 6].

This project will concentrate on the simulative results of integrating IoT with the a/c system control for human thermal comfort development. It is focused on small indoor spaces (usually fit for one or two people) where sedentary work is normally performed. An enhanced version of PMV approach is adapted here [7], as it has been analyzed and evaluated towards human subjects [8]. A web-based application via Android is developed to control the air temperature and velocity of the a/c system as defined by users. The developed application is tested simultaneously by using LED and motorized fan to show its workability.

This paper is organized as follows – Section II will cover the methodology, from the background of the selected enhanced PMV model chosen, to the Android-based application and prototype development. Some results and discussion on the investigation of the mobile application is covered in Section III, and will end with a conclusion and recommendations for future work.

II. METHODOLOGY

A. The Enhanced PMV

The Predictive Mean Vote (PMV) approach is developed by P.O. Fanger [9] as an approach to determine human comfort towards his / her ambience. According to Fanger, there are six parameters that can influence human thermal comfort – air temperature, relative humidity, air velocity, mean radiant temperature, clothing insulation and human's metabolic rate, as defined by Equation (1):

$$PMV = \{(0.303e^{-0.036M} + 0.028)[(M - W) - H - E_c - C_{res} - E_{res}]\} \quad (1)$$

where:
- M = Metabolic rate
- W = Effective mechanical power
- H = Dry heat loss
- E_c = Evaporative heat exchange at the skin
- C_{res} = Respiratory convective heat exchange
- E_{res} = Respiratory evaporative heat exchange

PMV works on a scale ranging from -3 (cold) to +3 (hot), as shown in Table 1, to assist users in defining their comfortability towards the ambience. An accompanying index has also been developed named the Predicted Percentage of Dissatisfied (PPD), which represents the relationship of PMV with the percentage of occupants who may not satisfy with the defined scale. However, this PPD index is not applicable here as the adapted model is designed solely for the small indoor area of a small number of occupants.

Table 1
The PMV thermal sensation scale

Scale	Comfortability
-3	Cold
-2	Cool
-1	Slightly cool
0	Neutral
+1	Slightly warm
+2	Warm
+3	Hot

PMV has been adopted by many in developing thermal comfort indoors, but in this project, an enhanced version of the PMV developed by [7] is used. The enhanced model has predefined parameters as stated in Table 2, due to the reasons and assumptions that it is developed for tropical countries / summer time applications and occupants with sedentary work. All of these parameters are set as according to the standards defined by the International Organization of Standardization (ISO) Geneva [1] and the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) [10]. Figure 1 shows the enhanced model that is being adopted here in this project. From here, occupants can just choose the respective PMV scale as desired and the model will set the appropriate value of air temperature and air velocity (or fan speed) of the a/c system.

Table 2
Parameters as defined by [7]

Parameters	Value
Mean radiant temperature, t_r	25ºC
Clothing level, I_{cl}	0.155 m^2ºC/W
Person's activity, M	58.15 W/m^2
Effective mechanical power, W	0 W/m^2
Turbulence, Tu	0%

A. Android-based Application

The Android-based application was designed using Android Studio. It is an open source Integrated Development Environment (IDE) specifically for Android platform development, developed by Google Inc. It uses JAVA programming language as the primary coding language.

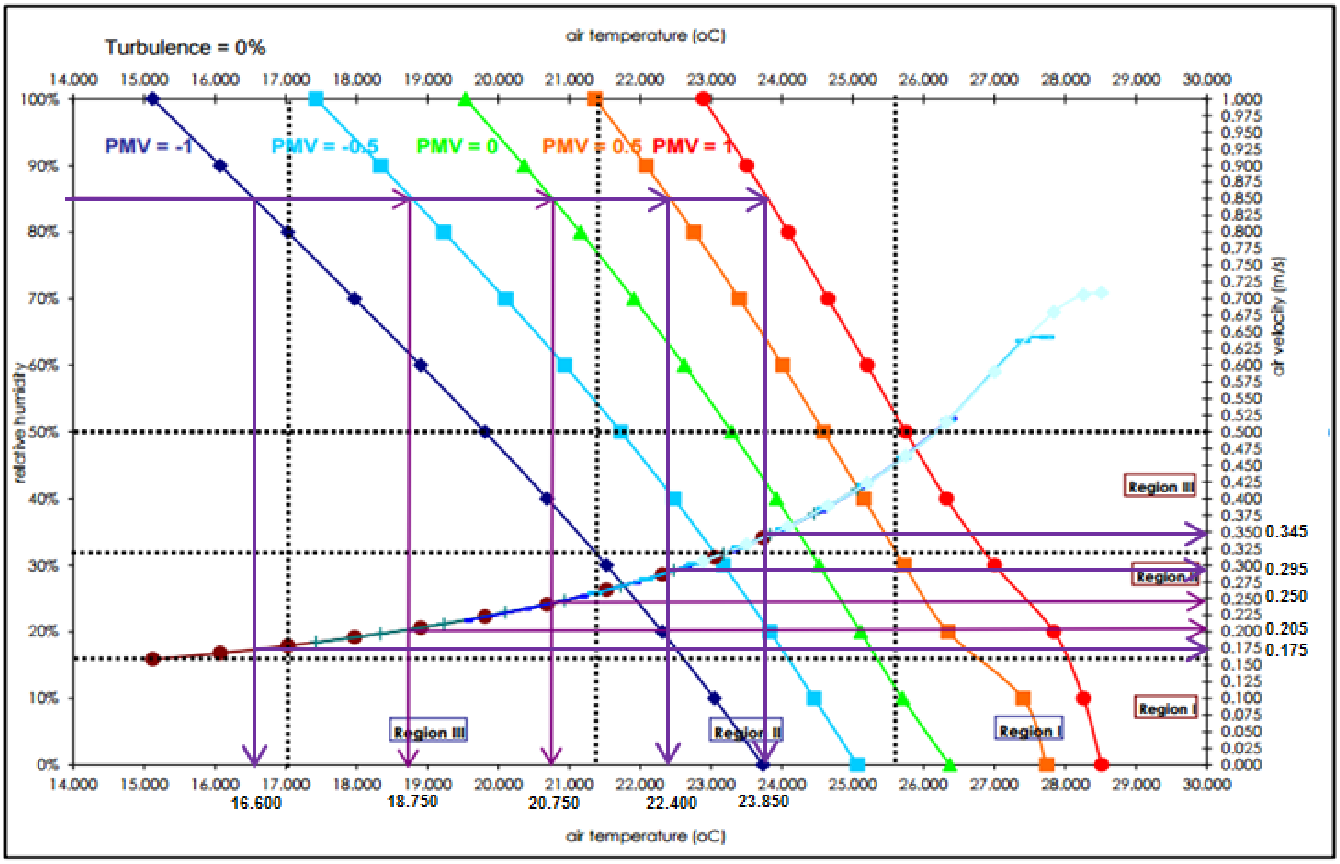
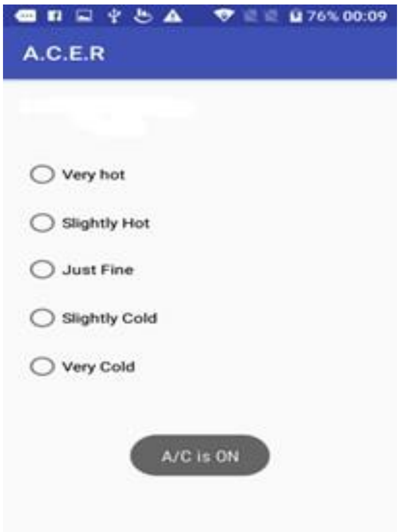


Figure 1: The enhanced model of PMV as defined by [7] used in this study, with the application at relative humidity, RH = 84%

The development kit offers a few features which are one of a kind compared to other development software. It also offers simplified and convenient Graphical User Interface (GUI) layout editor for the developers.

From here, a mobile application is developed to act as the controller which the occupants can use to control the a/c system in developing a thermally comfortable ambience. The GUI layout design of the application, named A.C.E. R (Air Conditioner Environment Regulator) can be seen in Figure 2. The selection of comfortability used here is representing the PMV index ranging from -1 (very cold) to +1 (very hot), with the increment of 0.5. This is preferred compared to the original PMV index, as the maximum index value will not be desired by occupants in tropical countries.

(a)



(b)

Figure 2: Layout of the Android-based application

B. *Network Communication*

The communication that occurs between the hardware and the mobile application can be achieved using HTTP Request protocol. There are two types of HTTP request methods – GET and POST. In this project, the GET method is used. A GET method is a type of HTTP request protocol, commonly used by the browser to search for an URL or link from the Internet. The operation flow of the network communication during HTTP GET method request is illustrated in Figure 3.

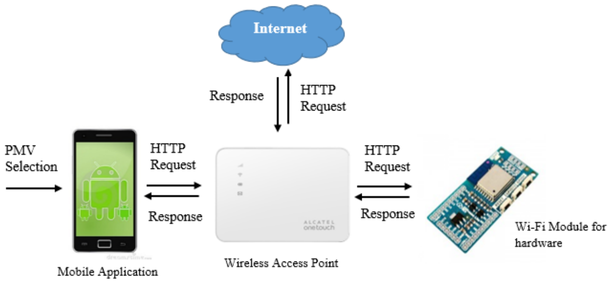


Figure 3: Request and Response flow of the network communication

C. *Hardware*

To perform the simulative investigation, a prototype was designed which consists of the equipment as listed in Table 3. Their specifications and functions are also listed to justify their importance in this investigation. Figure 4 shows the connection of the prototype as used in this project.

Table 3
Components used for hardware prototype

Component	Specification	Function
	ESPresso Lite V2.0: - Wi-Fi module with 4Mb flash - Support Arduino boards and libraries - Operating Voltage: 3.3 VDC	To allow the mobile application to pair and communicate with the model
	Arduino Uno: - Digital I/O Pins: 14, 6 with PWM output. - Analog Pins: 6 - Operating Voltage: 5V - Flash Memory: 32 KB - EEPROM: 1 KB	To process the data transmitted from the mobile application and produce the desired output
	3mm LED: - Forward Voltage: 3 to 3.4 VDC	To simulate the air temperature using the brightness as the coolness level. (brightest = highest temperature; dimmest = lowest temperature)
	DC Brushless Fan: - Operating Voltage: 5VDC - Maximum Speed: 9000rpm - Power: 1.60W	To simulate the air velocity of the AC system
	L293D Motor Shield: - Up to 4 bi-directional DC motors with individual 8-bit speed selection. - 2-pin terminal block to connect external power, for separate logic/motor supplies	To control the speed of the fan
	Liquid Crystal Display(LCD): - A 16x2 data display	To display the air temperature and air velocity after user select their PMV index

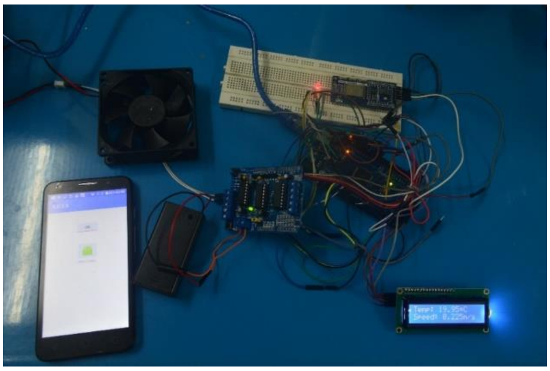


Figure 4: The prototype used to perform the simulative investigation

III. Results and Discussion

The simulative investigation was conducted on May 2017. As the relative humidity is among the important parameters, its value was taken from the Malaysian Meteorological Department website, and it was noted that the average readings were 84%. Therefore, during the investigation, the relative humidity was set to 84% and the respective values of air temperature and air velocity can be obtained from Figure 1.

During the investigation, the user was asked about what he / she desires from the ambience. A 'Slightly Hot' index (PMV = +0.5) was requested, and by referring to Figure 1 before, the value of the appropriate air temperature should be at 22.4ºC and air velocity of 0.295 m/s. From the network point of view, when this is being chosen, a 'GET /Hot' request is sent from the application to the server and if the response is received, the mobile application will display 'Increasing Temperature'. From the prototype, after the Arduino detected the 'GET /Hot' request within the server, it will produce a response by adjusting the air temperature and air velocity values respectively, as according to the operating model. The simulation as well as the results shown by the display and the mobile application upon this selection can be seen from Figure 5, 6 and 7 respectively.

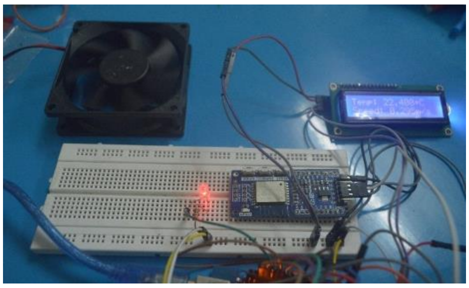


Figure 5: Simulation of air temperature and air velocity for PMV index of +0.5

Figure 6: Display of the air temperature and air velocity when PMV index of +0.5 is selected

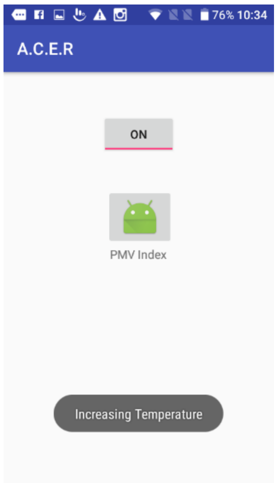


Figure 7: Response showed by the application after the user selects "Slightly Hot"

On the other hand, when a 'Very Cold' index is desired and selected, a 'GET /Cold' request indicating PMV index of -1 is sent to the server. When the response is received, the mobile application will display a 'Chill Out' message as shown in Figure 8. After the Arduino detected the 'GET /Cold' request within the server, it will produce a response and adjusting the air temperature and air velocity to 16.6ºC and 0.175 m/s, respectively. The results of the prototype as well as displayed by the LCD can be seen from Figure 9 and 10.

Figure 8: Response obtained after the user selects "Very Cold"

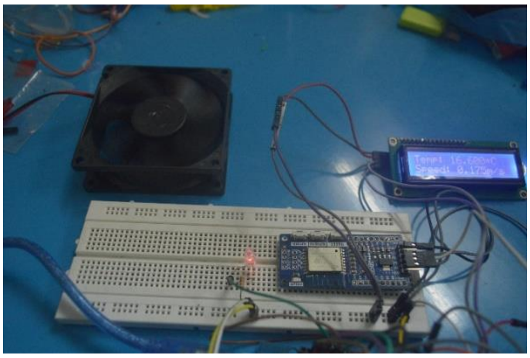


Figure 9: Simulation of air temperature and air velocity for PMV index of 1

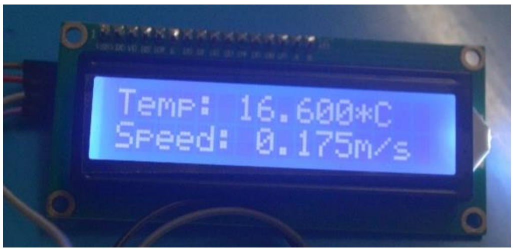
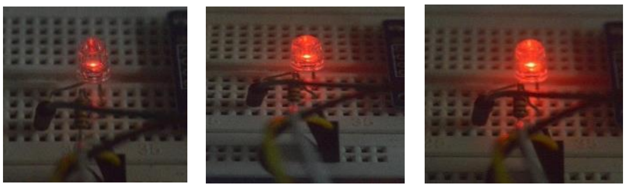


Figure 10: Display of the air temperature and air velocity when PMV index of -1 is selected.

As mentioned previously, the role of the LED is to indicate the changes of air temperature that has been performed once different indexes were chosen, i.e. the brighter the LED, the higher the air temperature will be. Figure 11 shows the different brightness of the LED as the air temperature value changes. The same setting could also be found in Figure 5 and 9 previously.



(a) (b) (c)

Figure 11: Different temperature represented by different LED brightness: (a) Very cold (PMV = −1), temperature set at 16.6ºC; (b) Just fine (PMV = 0), temperature set at 20.75ºC; (c) Very hot (PMV = +1), temperature set at 23.85ºC

In the meantime, the speed of the fan can be used to observe the changes in air velocity. In here, the value of the fan speed can be calculated from Equation (2), given that 1 rad/s = 60/2π rpm:

$$v = r\omega \tag{2}$$

where: v = air velocity in m/s
r = radial distance
ω = angular velocity in rad/s

Thus, for air velocity of 0.295 m/s for example at PMV index of 0.5, the DC fan motor has to rotate at a speed of 71 rpm.

By assuming that the a/c system will operate at 100% power at maximum cooling (lowest temperature and maximum speed), it can be deduced that the system will function at a lower cost and energy consumption at higher temperature and minimal speed, by implementing the above model in controlling the a/c system.

IV. Conclusion

Based from the performance of the Android-based application in this simulative investigation, it is shown that it is possible to control the a/c system via IoT-based approach by integrating the selected enhanced PMV-based model to create a thermally comfortable ambience. Due to its importance, to have such tool that integrates IoT in aiding human to control the a/c system would be very beneficial, as it is not only capable of creating a thermally comfortable ambience, but could also allow the system to be operated in energy and cost-efficient manner. However, more work is needed, especially to carry out testing and experiments towards the real a/c system to ensure its effectiveness.

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