

Investigating Thermal Comfort for the Classroom Environment using IoT

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ABSTRACT

In this modern century where fine comfort is a necessity especially in buildings and occupied space, the study to satisfy one aspect of human comfort is a must. This study encompasses of exploring the physiological and environmental factors in achieving thermal comfort which specifically considering the clothing insulation and metabolic rate of students as well as the deployment of dry-bulb temperature, mean radiant temperature, humidity, and air movement in order to obtain the level of comfort students are experiencing in class. The level of comfort are detected by using ASHRAE 55 to determine the average thermal sensation response through the Predicted Mean Vote (PMV) value. An android application were developed to read input of recognizing clothing level (thickness of clothing) and capturing metabolic rate to cater the inputs for physiological factors, while radiant temperature, humidity and air movement are captured through static sensors set up in the classroom space. This paper analyses both the physiological and environmental factors in affecting students in class and further determine their comfort levels that is a major influencing factor of focus in learning. Through cross referencing collected data from IoT enabled nodes, it is found that both physiological and environmental factors, and the combination of them greatly influence in getting the most comfortable state with PMV value of 0.

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1. INTRODUCTION

Physiological and environmental factors plays a vital aspect in allowing humans to achieve comfort. Proper light, air, thermal, and acoustic makes up major basic parts of human comfort. Comfort is defined as the absence of discomfort. There are five main factors that influences human comfort, which are visual comfort, acoustical comfort, thermal comfort, indoor air comfort, and spatial comfort [1], [2]. Thermal comfort is one of the view in achieving human comfort [3]-[5].

In order to achieve thermal human comfort for students in classrooms, regulations such as Standard 55-2004, Thermal Environmental Conditions for Human Occupancy, by American Society of Heating, Refrigerating, and Air-Conditioning Engineers, ASHRAE American National Standards Institute, ANSI dictates that proper thermal comfort in occupied space must be adhered [3]. However, current thermal regulator instruments does not fully incorporates all aspects that has to be considered which contribute to thermal comfort. As a result, thermal comfort for all occupants in the classroom is not satisfied.

This study is conducted in a classroom of Faculty of Computer and Mathematical Sciences, Universiti Teknologi MARA (UiTM) Shah Alam, a small learning environment with air conditioning as a

test bed. To realize the aim of this research, an implementation of the IoT framework which consists of static node to be installed in the testing site. The node will be equipped with multiple sensors to acquire all the values of the environmental factors. This framework will also be established to function and communicate with mobile node framework which infers the values of physiological factors obtained. Finally, all these values are used in calculating the Predicted Mean Vote (PMV) to show the level of comfort in the classroom, henceforth introducing a new and enhanced way of regulating temperature in the classroom utilizing the IoT.

2. RESEARCH METHOD

This study embraces the advancement in IoT in achieving the accumulation of data as in many other research areas such as [6]-[8]. Particularly in this study, the accumulation of data from embedded sensor are of the purpose to calculate the PMV value. The rationale of using IoT is to implement network technologies which includes the use of high technology sensors to automate the process of data collection in a location, contextually a small learning environment and automatically generate the PMV value using algorithms programmed in the framework [8].

This implementation will allow a faster data collection, processing, and generation of results.

2.1. Predicted Mean Vote (PMV)

The PMV is a value on a Fanger Seven Point Scale [11], [10] or called thermal sensation scale [3] that consists of seven values from Cold (-3) to Hot (3) [12]. Figure 1 depicts the thermal sensation scale [10]. ASHRAE 55 recommends that the acceptable thermal comfort range for interior occupied space is in between -0.5 and +0.5 (-0.5 ; PMV ; +0.5) [3]. The PMV is obtained by equations produced by Fanger in 1970 [11].



Figure 1. Seven Point Scale / Thermal Sensation Scale

$$PMV = (0.303e^{-0.036M} + 0.028) \left\{ \begin{array}{l} (M - W) \\ -3.05 \times 10^{-3} [5733 - 6.99(M - W) - P_a] \\ -0.42[(M - W) - 58.15] \\ -1.7 \times 10^{-5} M(5867 - P_a) \\ -0.0014M(34 - t_a) \\ -3.96 \times 10^{-8} f_{cl} [(t_{cl} + 273)^4 - (t_r + 273)^4] \\ -f_{cl} h_c (t_{cl} - t_a) \end{array} \right\}$$

$$t_{cl} = 35.7 - 0.028(M - W) - I_{cl} \{ 3.96 \times 10^{-8} f_{cl} [(t_{cl} + 273)^4 - (t_r + 273)^4] + f_{cl} h_c (t_{cl} - t_a) \}$$

$$h_c = \begin{cases} 2.38(t_{cl} - t_a)^{0.25} & \text{for } 2.38(t_{cl} - t_a)^{0.25} > 12.1\sqrt{V_a} \\ 12.1\sqrt{V_a} & \text{for } 2.38(t_{cl} - t_a)^{0.25} \leq 12.1\sqrt{V_a} \end{cases}$$

$$f_{cl} = \begin{cases} 1.00 + 1.29I_{cl} & \text{for } I_{cl} \leq 0.078m^2C/W \\ 1.05 + 0.645I_{cl} & \text{for } I_{cl} > 0.078m^2C/W \end{cases}$$

Where,

M Metabolic rate, W/m²

W External work, W/m² (assumed zero for almost all of the activities) Pa

Partial water vapour pressure,

Pa fcl Ratio of clothed and nude surface area of the body

ta Air temperature, °C

tr Mean Radiant temperature, °C

hc Coefficient of convective heat transfer, W / (m² * K)

tcl Clothing surface temperature, °C

Icl Clothing thermal insulation, m² * K / W

ISO 7730 (2005) dictates that while this model is derived for a more stabilized conditions [13], the destabilization of one or more variables can be fixed with an approximation using average values of the previous hour [12] [2] emphasize that PMV value closest to zero (neutral) indicate better thermal comfort while zero PMV value shows that the most thermal comfort is fully achieved. Figure 2 [2] depicts the factors involved in obtaining thermal comfort and the relationship of PMV on the thermal sensation scale.

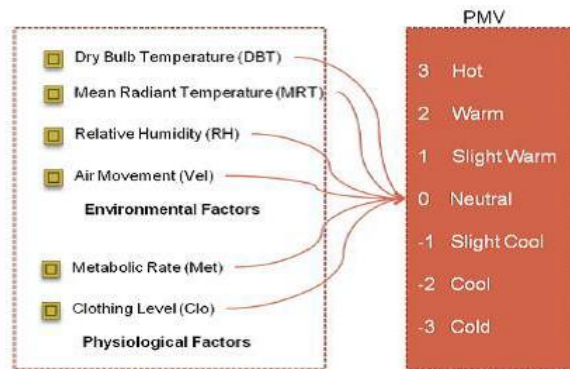


Figure 2. PMV on the thermal sensation scale [2]

3. ENVIRONMENTAL FACTORS INFORMATION GATHERING (STATIC NODES)

A test bed will be set up in a small classroom of about 10 x 10 meters. Each sensorpacked nodes will collect quantitative data in respect of each sensors and will send the collected data to the main node (sink) using wireless communication where the sink will calculate the PMV value using programmed algorithm and display the value on the display. Static nodes are assembled with Arduino Nano V3.1, SHT21/HTU21 temperature and humidity sensor, LM35 temperature sensor, HC-06 with JY-MCU carrier Bluetooth adapter, 16x2 1602A V2.0 LCD, 3.3V 5V Breadboard Power Supply, and 1K resistor which are attached to a breadboard for development purposes. The hardware programming is done through Arduino software v1.0.6 - a software for configuring Arduino based hardware such the Arduino Nano. All the sensors are calibrated using serial connection on 9600 baud for a stable serial transmission and high calibration accuracy. Figure 3 illustrates (a) the deployment of static nodes (orange half cylinder) on the ceiling and main node/sink (orange rectangle) in the test bed and (b) shows the actual assembly of a static node.

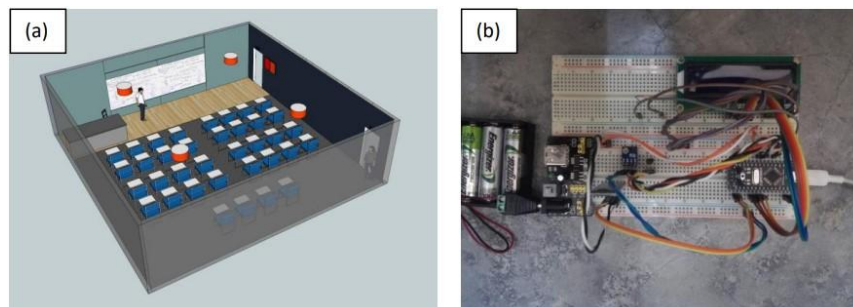


Figure 3. (a) Test bed layout and (b) static node components

In ensuring the accuracy of sensors, the outputs are compared with Windows Weather service as they provide a highly accurate reading of environment temperatures of an area. In comparison, the DBT and RH read by SHT21/HTU21 and LM35 are similar with what read by Windows Weather service and hence, shows accurate calibration and will provide accurate values to be used in calculating PMV value. In addition, the calibration process is conducted in a suitable environment that did not block or interfere with any natural outdoor temperature such as closed (no air flow) or air-conditioned room.

4. PHYSIOLOGICAL FACTORS INFORMATION GATHERING (MOBILE NODES)

In the physiological factors setup, this project requires the detection of the activity such as standing, walking, jumping, running and sitting and instance of the metabolic rate of the user or the subject in this experiment, the students. In order to achieve an accurate and precise PMV value, an accelerometer sensor from the mobile phone is to infer the metabolic rate of the user and an NFC tag is embedded within the clothing to define the clothing thickness worn by the user.

Clothing insulation is another primary determinant in achieving thermal comfort. While the main purpose of normal clothing is to protect from the cold, other types of clothing such as protective clothing is used to protect from heat as well. Clothing insulation is a standardized unit by ASHRAE 55 to measure thermal insulation on various clothing types [3]. A quantitative measure will be where 1 clo = 0.155 m² °C. Equally, 0 clo is when a person is not wearing anything (fully naked) while 1 clo is when a person is wearing a regular two-piece business suit [1]. Table 1 presents the clothing level based on standard (ISO 7730) that is used as the basis of reference in this experiment [13]. The metabolic rate that is based on the current activity of the user is obtained using the accelerometer sensor and the value of metabolic rate is referring the ANSI/ASHRAE Standard 55 which is also inferred through the mobile application. Table 2 presents the metabolic rate of selected activities relating to the project.

Table 1. The Clothing Level based on standard (ISO 7730)

Type of Clothes	Value of Clothing
Shirt	0.14
Sweater	0.26
Jacket	0.22
Dress and Skirt	0.23

Table 2. Metabolic Rate for Some Activity (Metabolic Rate)

Activity	Metabolic Rate
Sleeping	0.8
Sitting	1.0
Standing	1.2
Walking	1.9
Running	8.5

The setup is tested to perform connectivity between static and mobile node and able to perform data transmission. This experiment is done in collaboration with mobile node for data transmission and generation of PMV value by mobile node. Upon receiving the values from static node, the mobile node record the value in their respective field for users convenience apart to be used to generate PMV value. Figure 4 shows the return transmissions of two values of physiological factors together with calculated PMV value back to static node in which the static node display the received data on the LCD. The process of testing are repeated using similar steps at different locations with parameter variations to ensure full functionality of the setup. Figure 4 shows the setup flow in calibration of the static and mobile nodes readings in calculating the PMV.

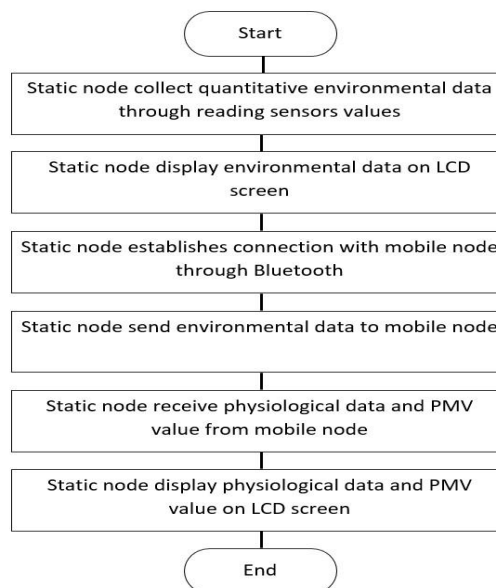


Figure 4. Working flow and calibration of static and mobile nodes

To evaluate the full functionality and accuracy, this framework is implemented as in scope to show the thermal comfort level in a typical classroom of 10x10 meters due to various contributing factors mainly DBT over a small period of time. This area is about the size of a small classroom that could fit 20-30 person and fitted with an air conditioner. Time slot used is in the morning in which it should have a lower external thermal impact on the test bed. The chosen scenario is to manipulate DBT as air temperature has the highest significance on thermal comfort, hence to achieve better effects, this experiment is tested without the utilization of the air-conditioner as slight changes in air temperature will affect human comfortability. The static node is placed in the middle of the class as an idea of a base reference that the data collected are similar throughout the whole classroom on average for the duration of 120 minutes.

5. RESULT AND DISCUSSION

Table 3 shows the collected values of both contributing environmental and physiological factors with calculated PMV being run in the duration of 120 minutes, which is the typical duration of a lesson in the classroom at University Teknologi MARA.

The air temperature increases in the classroom after the air-conditioner is turned off. The increment of temperature is deliberately slow over time due to the contained air in the classroom that trap the cold air to stay in the room. Similarly, there was also a steady climb of the MRT values over the time period. While the increment of MRT is almost proportional to the increment of DBT, the increment of MRT is slightly slower due to it takes time for MRT to adapt to new temperature changes as it consider the temperatures of its nearby surroundings into calculations (Figure 5).

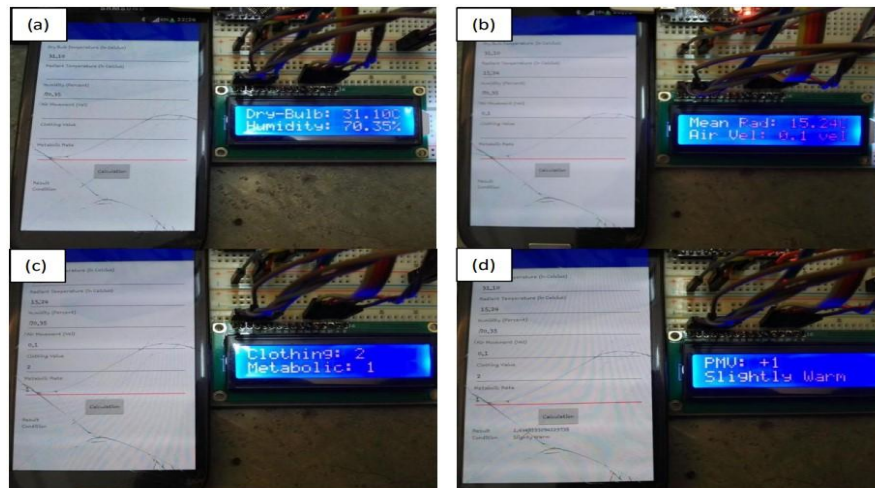


Figure 5. (a) Transmission of DBT and RH values (b) Transmission of MRT and Vel values (c) Transmission Clo and Met values (d) Transmission of PMV value

Table 3. Recorded Static and Mobile Nodes Readings with Calculated PMV

Time (min)	DBT (°C)	MRT (°C)	RH (%)	Vel	Met	Clo	PMV
10	20.69	19.28	78.06	0.1	1.0	0.7	-1.4
20	21.54	19.47	77.98	0.2	1.1	0.7	-1.1
30	22.03	19.95	77.68	0.2	1.3	0.7	-0.4
40	22.91	20.67	77.13	0.1	1.0	0.7	-0.8
50	23.86	20.83	76.85	0.1	1.5	0.7	0.4
60	24.37	21.42	76.31	0.1	1.7	1.0	1.0
70	25.72	22.39	76.02	0.1	2.2	0.7	1.4
80	26.03	23.08	75.62	0.2	1.0	1.0	0.5
90	26.67	23.81	75.52	0.2	2.3	1.0	1.8
100	26.99	24.55	75.12	0.3	1.6	0.7	1.1
110	27.01	25.23	74.88	0.1	1.0	0.7	0.6
120	27.32	25.64	74.47	0.3	1.2	0.4	0.2

Humidity otherwise records a decreasing rate in the classroom inversely to the increment of air temperature [5]. This is an expected behaviour as the amount of water vapour will decrease through evaporation when the air temperature increases. The changes of air velocity in the classroom is however random at time. While there are changes in air velocity, the changes are minor and barely noticeable by human according to its standardized table by ASHRAE [3]. This occurrence may be caused by the movement of human in the room or any other possible factors that caused air movement including the design of building that promotes air flow and not air-tight [8], [9], [14].

On the physiological factors data collection, there are constant changes observed in the reading of metabolic rate. This is due to the random activity the subject performs in the classroom as to observe the impact of metabolic rate on thermal comfort. As for the clothing level, the clothing values worn by the subject in the classroom during the time of testing. Several types of clothing types were tested in the entire duration of the experiment. There are three variations of clothing used which are shirt with shorts (0.4), shirt with trousers (0.7), and light business suit (1.0). Clothes worn will have an effect on thermal comfort as clothes provides insulation for human body. Figure 6 presents the PMV values for the duration of 120 minutes based on six contributing values of thermal comfort. The acceptable PMV values for thermal comfort in small occupied space is from -0.5 to +0.5 with 0 being most comfortable. After turning off the air-conditioner for ten minutes, the classroom is slightly cool for a sedentary person wearing a shirt and trousers (PMV: -1.4).

In the elapse of 20 minutes, the person with same clothing and metabolic activity is a bit more comfortable as the temperature of the room is increasing (PMV: -1.1). After 30 minutes, the person is doing some light activity such as arranging papers while still sitting down which induce thermal from body and allowing the person to be more comfortable in the cool environment (PMV: -0.4). At minute 40, the person feels a bit more uncomfortable due to the increase temperature over time although not doing any activity (PMV: -0.8). At minute 50, the person feels warmer as doing more activity such as walking in the classroom on top of the increasing air temperature (PMV: +0.4).

After the duration of 60 and 70 minutes, the person is doing more activity in a warmer place that contribute to a higher PMV value of +1.0 and +1.4 respectively. A nearer PMV value of +0.5 is achieved at minute 80 when the person goes back to sitting (sedentary) although wearing a light business suit and a more increased air temperature. The rest of the duration of this experiment indicate the thermal comfort of the person in the experiment with various metabolic activities and clothes worn in an increasing temperatures and decreasing humidity.

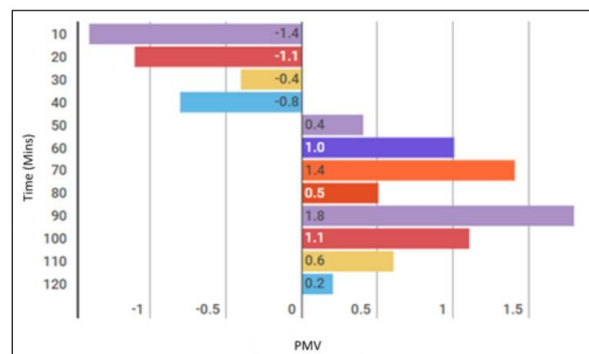


Figure 6. Generated PMV values based on environmental and physiological factors (Static and Mobile Nodes)

The combination of contributing factors affect thermal comfort and shows that multiple considerations have to be taken into accounts to achieve the most comfortable state which denoted with PMV value of 0. This experiment had proven the full functionality and accuracy of the framework not just through the logical inference by human brain but through cross referencing collected data with standardized tables and studies to confirm the integrity of generated PMV values.

6. CONCLUSION

This observatory study found that IoT enables automation of collection of quantitative values of the environment that affects human comfort thermally, and enables the generation of thermal comfort value to be implemented on thermal regulator devices, specifically air-conditioners in small learning environments. With the use of this technology, the achievement of thermal comfort will be easier and independent of human intervention. It is however recommended that thermal regulator devices especially air-conditioners for automatic thermal regulations that are better suited for thermal comfort are utilized towards regulating PMV of zero value in future research.

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