SMART THERMAL COMFORT SYSTEM: A DEVELOPMENT OF THE FUNDAMENTAL CONTROL ALGORITHM

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To my parents, Abdul Shukor Shamsuddin and Hamidah Mohd. Yusop,
to my sister, Suriati Akmal, and my fiancé, Afdzan Rizal Abdul Razak.
You are my inspiration.

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ABSTRACT

This paper reports on the development of the fundamental algorithm for a smart thermal comfort system. Using Predictive Mean Vote (PMV) as a means of measuring thermal comfort, this system would able the user to define their own expression towards the surroundings, from slightly warm to slightly cold. Here, the operator only needs to insert its respective value of PMV (ranging from –1 to +1) and the system will generate the compressor and fan of the air conditioning system so that it will create a thermally comfortable environment, based on the operator's desires. This differentiates the system with the conventional air conditioning system where the operator needs to set separately fan speed and degree of cooling. The PMV value here will be calculated as input instead of the normal PMV equation where these values depend on the air temperature, relative humidity and air velocity. All these parameters values are set from the standard range allowed by the ISO 7730 of thermal comfort at a workplace for sedentary activity. Since previous researches use PMV as the output value, the help of Microsoft Excel is used to obtain air temperature and air velocity for respective values of PMV. Finally, the fundamental stage for experimentation step is implemented by building a working region in allowing the PID (Proportional, Integrative, Derivative) controller to control its duty cycle.

ABSTRAK

Laporan ini menyentuh tentang pembangunan algoritma asas bagi sebuah sistem keselesaan haba yang pintar. Dengan menggunakan 'Predictive Mean Vote (PMV)' sebagai cara untuk mengukur peringkat keselesaan haba, sistem ini berupaya untuk membenarkan pengguna mendefinisikan tahap keselesaan masing-masing terhadap persekitaran. Dengan cara ini, pengguna hanya perlu memasukkan nilai 'PMV' mereka (dari –1 ke +1) dan berpandukan nilai ini, sistem akan mengawal kompressor dan kipas sistem penghawa dingin mengikut kehendak pengguna. Ini dapat menghasilkan situasi selesa kepada pengguna. Kaedah ini berbeza dengan sistem penghawa dingin yang sedia ada memandangkan sistem yang ada sekarang hanya membenarkan pengguna mengawal keselesaan bilik dengan mengatur nilai suhu bilik dan kelajuan kipas secara manual. Dalam projek ini, nilai 'PMV' akan digunakan sebagai input, berbeza dengan kajian dan projek yang sedia ada yang menggunakan 'PMV' sebagai keluaran. Di sini, nilai 'PMV' bergantung kepada suhu angin, kelembapan dan kelajuan angin. Kesemua parameter ini dikira berdasarkan standard yang dikeluarkan oleh ISO 7730 bagi keselesaan haba. Memandangkan hampir kesemua kajian terdahulu menggunakan 'PMV' sebagai nilai keluaran, bantuan daripada 'Microsoft Excel' digunakan untuk mendapatkan suhu dan kelajuan angin mengikut 'PMV'. Kaedah terakhir yang digunakan di dalam projek ini adalah dengan membina kawasan kerja bagi suhu dan kelajuan angin untuk membenarkan pengawal 'PID (Proportional, Integrative, Derivative)' mengawal kitar tugas sistem pintar ini kelak.

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LIST OF SYMBOLS

C_{res}	-	Respiratory convective heat exchange
DR	-	Draught Rate
E_c	-	Evaporative heat exchange at the skin
E_{res}	-	Respiratory evaporative heat exchange
f_{cl}	-	Clothing area factor
h_c	-	Convective heat transfer coefficient
H	-	Dry heat loss
I_{cl}	-	Clothing insulation
M	-	Metabolic rate
p_a	-	Humidity
PMV	-	Predicted Mean Vote
PPD	-	Predicted Percentage of Dissatisfied
RH	-	Relative Humidity
T, t_a	-	Air temperature
t_{cl}	-	Clothing surface temperature
t_r, MRT	-	Mean Radiant Temperature
t_{sk}	-	Mean skin temperature
Tu	-	Turbulence intensity
v	-	Air velocity
v_{ar}	-	Relative Mean Air Velocity
W	-	Effective mechanical power

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CHAPTER I

INTRODUCTION

1.1 Introduction

Thermal comfort has always been very important in human life, as it contributes towards health and welfare of human beings. People can work, play and do whatever activity they intended with ease when the surroundings have achieved its thermal comfort. History and recent situation show that man has always attempted very hard to create a thermally comfortable environment.

Thermal comfort is being defined as a condition of mind that expresses satisfaction with the thermal ambience. The physical basis of comfort lies in the thermal balance of the body. The heat produced by the body's metabolism must be dissipated to the environment; otherwise, the body would overheat. In other words, if the rate of heat transfer is higher than the rate of heat production, the body cools down and we feel cold; if the rate is lower, we feel hot [1].

There are several parameters that contribute towards room climate, which are physiological conditions like clothing and activity of humans as well as on physical parameters like room temperature, air velocity and relative humidity. The physical factors are usually measured by the electronic control of comfort climate conditions. When the parameters are measured properly, the HVAC system could be used to regulate the room's air draft to generate a thermally comfortable situation in the room.

In summer or for tropical countries like Malaysia, the use of air conditioners and fans are very essential in creating thermal comfort inside a room. The recent situation of the air conditioning system only allows the operator to manually control the cooling compressor and the ventilation fan by controlling the temperature switch. But, in this situation, the humidity content of the air is neither detected nor regulated. Here, the occupants would set the degree of cooling and the fan speed according to his/her choice intention and they tend to set to maximum cooling, which yield to uncomfortable climate problem according to the standard as well as consuming extra energy.

From the above problem, therefore it is important to develop a smart thermal comfort system for air-conditioned rooms, which allows the climate control system to consider not only the temperature but also other parameters as well.

1.2 Research Background

1.2.1 Thermal Comfort

Human has always work hard in creating a thermally comfortable environment. It is very important to establish and maintain appropriate conditions for thermal comfort as it contributes towards positive effect on health and quality of life.

But then, till now, there is still no system that is capable to convert control system from temperature regulations to thermal comfort regulations. The current air conditioning system, for example, only allows the operator to control it through the temperature switching. This seldom yields the operator to set the temperature with maximum cooling. Nevertheless, this usually does not create thermally comfortable surroundings, but it can produce an unhealthy effect towards human, such as colds and stiff neck.

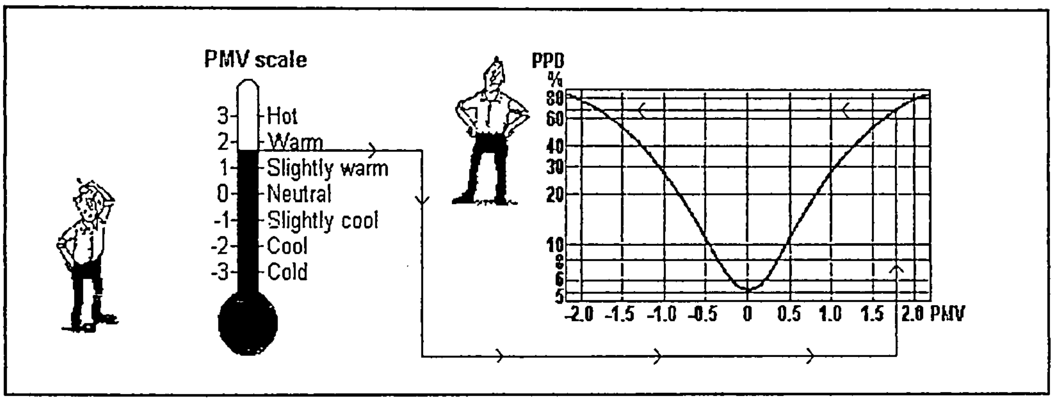
In a thermal comfort measurement, the system monitors on six variables – four physical parameters and two physiological conditions – like air temperature, relative humidity, air velocity, mean radiant temperature, clothing insulation and human's level of activity. All the physical parameters are expected to be measured and calculated using electronic devices, such as sensor.

One of the methods to determine thermal comfort, in fact is going to be used in this study, is through the Predictive Mean Vote (PMV) index. The PMV-index predicts the mean value of the subjective ratings of a group of people in a given environment [2].

The PMV scale is a seven-point thermal-sensation scale ranging from -3 (cold) to +3 (hot), where 0 represents the thermally neutral sensation. Even when the PMV-index is 0, there will still be some individuals who are dissatisfied with the temperature level, regardless of the fact that they are all dressed similarly and have the same level of activity – as comfort evaluation differs a little from person to person.

To predict how many people are dissatisfied in a given thermal environment, the PPD-index (Predicted Percentage of Dissatisfied) has been introduced. In the PPD-index people who vote -3, -2, +2, +3 on the PMV scale are regarded as thermally dissatisfied. Notice that the curve showing the relationship between PMV and PPD never gets below 5% dissatisfied. Figure below shows on how the relationship works.

Figure 1.1: The relationship between PMV and PPD



1.3 Problem Statement

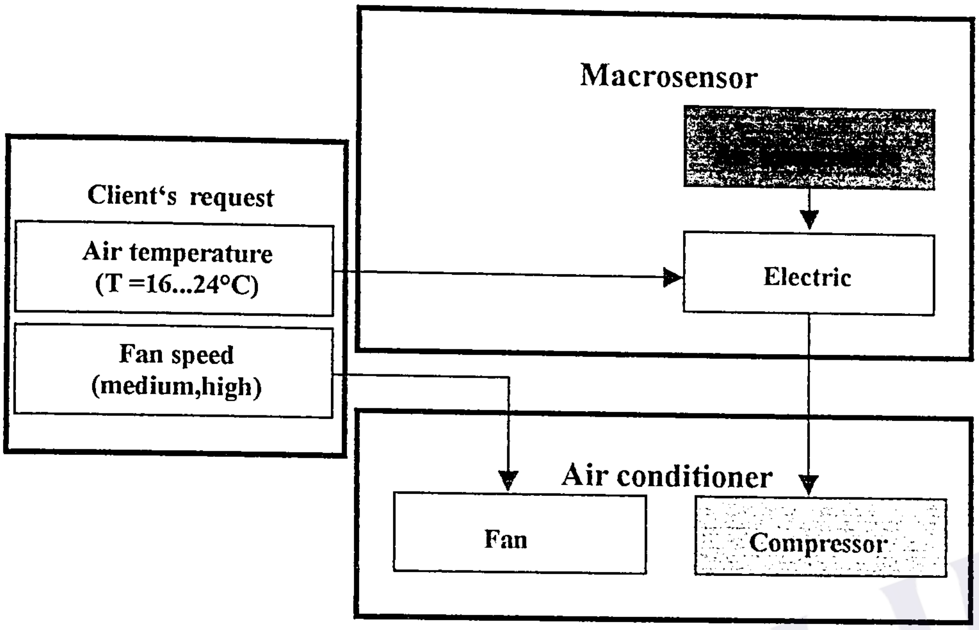
In the present type of air conditioning systems the room's occupants are allowed to control the system as they needed. Thus, as they feel hot and uncomfortable with the room's climate, they tend to control the system into maximum cooling. This yields to uncomfortable climate – too cold environment would bring diseases such as cold, fever and stiff neck – as well as energy consuming. Actually, the cooling method used by the system can be replaced by blowing for better consumption of energy, since it allows the creation of thermally comfortable environment through higher air velocity and higher air temperature compared to before (as air temperature controls the air conditioning's compressor and air velocity controls the fan).

Most of the commercial system and sensor to measure thermal comfort available in the market at the moment is constructed by a macroscopic system, which is not suitable to be implemented. Therefore, by using MEMS technology, it is possible to build a system to measure the thermal comfort in the room. Microsystem is being preferred due to:

- High accuracy and sensitivity
- Capable to facilitate measurement of air velocity
- Lower power consumption

Figure below summarize the operation of the present type of air conditioning system. The macrosensor part would obtain user's value of air temperature and fan speed. It then will control the compressor and fan to meet the user's demand.

Figure 1.2: Recent air conditioning system



1.4 Objectives

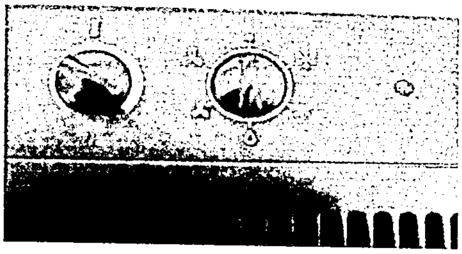
The objectives of this project are:

- To study the concept of thermal comfort
- To understand on the parameters that determine thermal comfort
- To evaluate thermal comfort through PMV
- To define the calculations, graphs and equations needed in a thermal comfort system

1.5 Aim / Scope of Research

The scope of this study is to develop a control algorithm, which can be used in a smart thermal comfort system. This will able the user to define their own thermal comfortability by themselves, from slightly cold to slightly warm. This system would also provides with advantages – lower energy consumption at lower cost and able to prevent any uncomfortable feelings towards operators.

Figure 1.3: The air conditioning system control knob. Users tend to misuse it – thus produce an unhealthy environment and consume extra energy



CHAPTER II

LITERATURE REVIEW

It is important to obtain enough information on thermal comfort before proceeds with the development of the algorithm. Therefore, readings and studies were conducted from various sources to achieve necessary background on the project before developing it. Since this area of research is building up rapidly, there are several numbers of researches that need to be considered. All the researches are mainly using PMV as the mean of determining human thermal comfort.

2.1 Thermal Comfort [2]

All the required backgrounds for this project were obtained from the booklet by Innova AirTech Instruments. This essential information is mainly on the parameters and necessary definitions and procedures in defining thermal comfort.

2.1.1 Physical Parameters

The physical factors, or also being called as the environmental parameters, are the important one in determining thermal comfort in a room. Furthermore, in this project, the physical parameters are the main factors that play the major role.

2.1.1.1 Air Temperature

Air temperature is usually can be understood by people. It is the dry-bulb temperature of the air surrounding the occupant. As one of the important parameters to evaluate thermal comfort, it can be directly measured with a calibrated mercury or digital thermometer. To estimate the air temperature of a room this should be taken at a central location and at about face level (avoiding bright sunlight or other asymmetrical heat sources).

Different research suggests different optimum air temperature ranges. The recent recommended range for internal air temperature is between 19 °C and 23 °C in winter and less than 27 °C in summer. However, different occasions mean that people need different indoor temperatures. For instance, 21°C may be considerably too warm for people exercising in their own house, but the same conditions perhaps are a bit cold for a person sedentary in a dwelling. Comfortable air temperature requirements also vary from day to day for the same individual. There is no scientifically exact temperature to please everyone. The best temperature is the temperature that most people find comfortable. If at all possible, mechanical systems such as heaters or air conditioners can have indoor temperature control for each room to meet the needs of occupants, since comfort requirement can vary with age (older people generally prefer warmer temperatures), sex (very little), clothing worn, and level of physical activity. Table show the air temperature for respective activity.

Table 2.1: Suitable temperature for different human activity

Temperature [°C]	Activity
25	Optimal for bathing, showering
24	Sleep is disturbed People feel warm, lethargic and sleepy
22	Optimal for unclothed people
21	Most comfortable year-round indoor temperature for sedentary people. Optimum for performance of mental work.
18	Physically inactive people begin to shiver. Active people are comfortable.

However, most of the recommendations above are only suitable and applicable for four-season countries, like Europe, United States of America and Canada. For a tropical country like Malaysia, the temperature range is usually higher, since we have higher relative humidity.

2.1.1.2 Air Velocity

Air velocity is a measure of movement of air in a space. Low velocity random air movements usually are measured by the Kata-thermometer or a hot-type anemometer. The rate of air movement has an important bearing on the sensation of freshness and comfort. Air velocity is proportional with air temperature. When temperatures are low, even moderate rates of air movement indoors may be felt as cold draughts. It is possible to overcome draught discomfort to a certain extent by raising air temperatures.

The contribution of air movement to thermal comfort is to remove the moisture and heat surrounding the human body. People begin to perceive air movement at about 0.2 m/s, when air movement less than 0.1 meters per second will create a feeling of stuffiness. At higher air temperatures, increasing the air speed will help the evaporation of sweat thus leading to a cooling effect to achieve comfort for an occupant, particularly if loose clothing is worn, but when the temperature or humidity is too high it will be quite difficult to compensate the dissatisfaction by air speed. For sedentary people, a sense of draughtiness will be caused by too high air speed. Even though air speed does not play a crucial role in thermal environment, it is still essential for a person to avoid draughts, which are an unwanted local cooling of the body caused by air movement. In hot conditions air movement can be increased by the use of active measures such as fans to relieve thermal discomfort.

The table below describes how human occupants react to various conditions of room air motion.

Table 2.2: Occupants reaction to room air motion

Air Velocity	Typical Evaluation
0 – 0.5 m/s	Complaints about stagnant air
0.5 – 2.5 m/s	Generally favourable (manufactures of air outlet devices, e.g., base performance on 50 fpm air velocity in occupied zone)
2.5 – 5 m/s	Awareness of air motion, but can be comfortable (e.g., some retail shops and stores) when temperature of moving air is above room air temperature.
5 –10 m/s	Constant awareness of air motion, but can be acceptable (e.g., some factories) if air supply is intermittent and above room air temperature.
10 m/s and above	Increasingly draft conditions with complaints about "wind" in disrupting a task, activity, etc

2.1.1.3 Relative Humidity

Air is capable of holding a certain amount of moisture at a given temperature, and the actual amount of moisture in air at any time is called its humidity. The higher the temperature is, the more amount of moisture air can hold relatively. Humidity can be ascertained in terms of RH, Relative humidity (RH) in % is the amount of moisture in air compared to the maximum amount that can exist at a given temperature without condensation.

Humidity is measured from the Wet Bulb Temperature (WBT), which is the temperature at which water, by evaporating into air, can bring the air to saturation adiabatically at the same temperature. RH is measured using a sling psychrometer (whirling hygrometer) or a hygrometer. From the temperature difference between the dry bulb temperature and wet bulb temperature, the percentage relative humidity can be found. In this way, RH can be measured quickly and accurately.

According to ASHRAE standards, the humidity of a zone occupied by people doing light or primarily sedentary activity shall fall approximately within a range between 30% to 60% relative humidity. The percentage of humidity necessary for thermal comfort depends upon all other parameters. If the relative humidity is very high, the heat loss by evaporation will be much greater, so raising the temperature is one practical way to compensate for the extra loss by evaporation. When temperatures are within the comfort range (19-23 °C) the RH has little effect on comfort provided that it is within the range 40-70%. Influence of humidity is not great for a person with very light or sedentary activities as well. Higher humidity will make a person feel warmer particularly in a ventilated area where the air speed is low. In areas of very low humidity people may experience discomfort from dry eyes, nose and throat. Generally people are much more sensitive to extremes of temperature than extremes of humidity.

In Chapter IV, one will find the relationship between relative humidity in % and air temperature together with air velocity. The changing of both factors when the relative humidity changes would highlights on its importance towards determining thermal comfort.

2.1.1.4 Mean Radiant Temperature

Mean radiant temperature, which has the same importance as air temperature in thermal comfort is defined as the uniform surface temperature of an imaginary black enclosure in which an occupant would exchange the same amount of radiant heat as in the actual non-uniform space.

MRT (mean radiant temperature) can be determined in two ways:

- By calculation which is dependent on surface temperatures of all areas in a space and the location of a person.
- Directly measured by GT (globe temperature).

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