PERFORMANCE OF EVAPORATIVE COOLING SYSTEMS WITH CHILLED WATER

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Abstract

Many climatic records indicate that the average temperature of many countries have increased at least by one degree and also have changed the rainfall pattern to a certain extent. These have made the conditions in warm humid tropical countries somewhat undesirable. With improved economic conditions in many countries in the Asian region, a shift to air conditioning can be seen in office buildings, factories and houses. An energy efficient alternative to air conditioning is the use of evaporative cooling. However, its performance in months with higher moisture content that results in higher relative humidity cannot be efficient and hence there is a barrier for its popularization. One option available is the use of chilled water for improved performance. This research highlights the thermal performance that can be achieved with chilled water and the responses that have been obtained from the workers of a large factory complex located in Sri Lanka where the humidity ratio can reach 0.018 during some months.

Key words: *Evaporative cooling, humidity ratio, thermal performance, chilled water*

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1. Introduction

The warm humid climates of the tropics would be characterized by low changes in diurnal temperature thus giving a prevalence of a relatively high humidity. The humidity can vary from about 55-60% at the day time where the peak temperature occurs and could rise to about 85-90% during the night time (Anh et al, 2012). The reason for this is the prevalence of relatively high moisture content (a humidity ratio) in the range of 15g to 18g per kg of air. However, people who have lived in the tropics have adapted very well to these conditions by wearing light clothes especially with cotton as the main material due to its ability to absorb perspiration (Mendoza and Griffin, 2010). They have also used many trees around their houses and buildings, so that a better micro-climate could be created. Thus, the energy usage in many houses and buildings have remained relatively low since either natural ventilation or forced circulation with fans was sufficient to have the air movement needed for thermal comfort. The primary energy use has been for the lighting during the night time.

However, this favorable scenario has changed gradually in the recent times due to many factors and the shift is severe in tropics. With urbanization, there has been a trend to move to cities where the property values in cities and suburbs have become significantly high. One solution to this has been the use of smaller plats land such as 6 perch (150 m^2) for construction of houses. The houses in such small lands would not allow the growth of larger and shady trees and hence the urban environment has been affected by the heat island to certain extent where the temperature would be about 1^0 C-2 ^{0}C higher than the wooded areas (Simon, 2008). The Google map of Figure 1 indicates this situation in an area about 5 km away from the city of Colombo, the capital of Sri Lanka.

In environments covered primarily with roofs of houses and buildings, some adverse effects of urban heat island would be inevitable. This would create warmer day times and also warmer night times. With a per capita income of about 2,500 USD per annum (wikipedia.org/wiki/List of countries by GDP, 2011) the affordability of active means of thermal comfort such as air conditioning would be high and this would be undesirable from the global point of view with respect to CO_2 emissions associated with electricity generation. The ideal solution is to promote houses designed with passive features that could provide adequate thermal comfort either with natural ventilation or forced ventilation achieved with low energy consuming means such as fans. However, the existing buildings and houses that form the majority of the building stock could pose a major challenge to keep the carbon foot print per person at a relatively low level such as 1000 kg per person per annum. An alarming trend is the fixing of air conditioners at least for the bed room if the whole house would not be air conditioned. Thus, the use of relatively low energy consuming evaporative cooling would be desirable if its effectiveness can be ensured throughout the year once installed.

This paper presents improved performance of evaporative cooling with chilled water and validation of the same through the responses of occupants of a building located in Sri Lanka where the humidity ratio can reach 0.018 during some months.

2. Objectives

There are two main objectives of this research and those are given below:

I. To evaluate the improved performance of Evaporative cooling system connected to chilled water supply.

II. To find out the profile of Thermal Sensation Votes (TSV) cast on the ASHRAE scale based on the responses of user of the factory building which is cooled by evaporative cooling connected to chilled water supply.

3. Methodology

In order to achieve the above objectives, the following methodology was adopted:

i. The temperatures of supply air of evaporative coolers with and without chilled water were measured and evaluated.

ii. The responses of occupants who engage with light works in the building operated by evaporative cooling with and without chilled water and performance data pertaining to the same boundaries were captured and analysed.

4. Evaporative cooling

4.1 History of Evaporative cooling

Originally, this process was firstly applied by humankind in Near East, where the dry and hot climate was favorable to its application. Thus, in paintings from Ancient Egypt it can be seen how slaves fanned big vessels filled with water, which were porous enough to permit this water to pass through the ceramic wall and maintain the surface humid, evaporating into the air (Zhiyin et al, 2012). Moreover, old buildings from Iran were regularly cooled by this process, as they were partially built underground to avoid solar radiation, while the upper terraces were provided with pools of water cooled in a kind of cooling towers.

The first rigorous analysis of the direct and indirect evaporative systems, considering both the advantages and disadvantages and indicating and establishing some basis about their design, was developed by Dr. John R. Watt, who worked for the Research Laboratory of the U.S. Navy. He built and studied four prototypes of plate evaporative coolers, one of them constituted of two stages; as well as a cooling tower and coil, determining their efficiency and cooling capacity (John R Watt, 1986).

Later, the work developed by Dr. Donald Pescod gathered different studies about plate evaporative coolers, being the pioneers in using plastic materials for the plates, and in creating artificial turbulences to minimize the stillness of the air film, reaching really high heat-transfer areas in compact distributions (San et al, 1998).

4.2 The Technology

Evaporative cooling is a method of converting hot air into a cool breeze using the process of evaporating water (Wu et al, 2009). It is similar to the cool refreshing effect one would feel when one would immediately step out of a pool. Evaporative coolers utilize the natural process of water evaporation along with an air-moving system to create effective cooling. Fresh outside air is pulled through wetted filters that cool the air through water evaporation. A blower wheel then circulates the cool air throughout the space which is to be air conditioned.

Evaporation is the conversion of a liquid substance into the gaseous state. When water evaporates from the surface of something, that surface becomes much cooler because it requires heat to change the liquid into a vapour. Evaporative cooling on a hot day cools space because the current of air makes perspiration to evaporate quickly. The heat needed for this evaporation is taken from occupants' bodies and a cooling effect is perceived by the occupants. When air moves over a surface of water, it causes some of the water to evaporate (Wiki.naturalfrequency.com, 2012). This evaporation results in a reduced temperature and an increased vapour content in the air. The bigger the area of contact between the air and water the more evaporation occurs, resulting in more cooling and the addition of moisture.

4.2 Effectiveness of evaporative cooling in warm humid

Thermal comfort in a built environment will depend on the indoor air temperature, the relative humidity, the indoor air velocity and the presence of solar radiation. In a well-planned indoor environment, it is possible to keep the direct solar radiation effect to a minimum with the proper planning of openings and opaque walls. Therefore, two governing parameters will be the indoor air temperature and the relative humidity. The reasonable values for a tropical climate can be presented as shown in Figure 2 as a comfort zone on a Psychrometric chart. In this figure, it is possible to select a band of $\pm 2\ ^{0}C$ (Szokolay, 1991) or $\pm 3.5\ ^{0}C$ (De Dear & Brager, 2002). It has been shown that this band width of $\pm 3.5\ ^{0}C$ would be of greater degree of relevance to free running buildings. The band of $\pm 2\ ^{0}C$ would be better for conditioned buildings where thermal comfort is provided with active means. This clearly shows that for tropical climates, due to the prevalence of high humidity ratios such as 0.018 in some months, achieving a reasonable thermal comfort level in indoor will not be feasible since line AB marked on Figure 2 does not go across the comfort zone.

However, when air movement is available with the indoors environment, it can create a physiological cooling effect. This can be presented as an enlarged zone on the Psychrometric chart. An example is shown in Figure 3 where relatively low indoor air velocities of up to 1.0 m/s are represented. Line CD indicates humidity ratio of 0.018. This is the value likely in Sri Lanka during April and May. Even with such high humidity ratios, still the line CD can be within the extended comfort zone. This indicates that evaporative cooling would work only with sufficient indoor air velocity that is maintained using suitable type of fans.

Another important aspect is the effect of evaporative cooling. It is an adiabatic process. Hence, it would move parallel to the lines indicating wet bulb temperature as indicated in Figure 4. The drop in temperature usually achieved is only about 2^0C - 3^0C under warm humid conditions. It can be more in warm dry conditions.

However, the drop in temperature could be improved if cooler water is used for generating cool air in the evaporative cooler. However, this will be a challenge since the cooler water used would also need energy. One option is the use of a chiller that will produce chilled water where the temperature of the water would be dropped to about 24^0C. The other option is the use of natural means such as storing water in clay pots.

During April, the outdoor air temperature could reach about 32^0C during daytime. If such outdoor air used with chilled water, it would be possible to have an air with 27^0C-28^0C using evaporative coolers. If such air is circulated indoors with the humidity ratio as 0.018, still it will lie within the comfort zone. The effectiveness can be further enhanced if the indoor air velocity is increased up to or above 0.6 m/s. This shows that there is a good possibility for using evaporative cooling throughout the year if there is a possibility for providing chilled water to the evaporative coolers.

5. Enhanced thermal comfort by evaporative cooling with chilled water

In order to check whether this theoretical model can be used in practice, a thermal comfort survey was carried out in one of the factories that were fitted with such a system.

5.1 Personal Parameters

The method for estimating the personal parameters was based on the ASHRAE Standard 55 (ASHRAE 55, 2004). The clothing and metabolic rate were estimated based on the observations made during the survey. It was observed that all the occupants' clothing is similar and it consisted of their uniforms which were short sleeve T-shirts and straight trousers for male and skirts or straight trousers for female. The clothing that the occupants dressed could be categorized as light summer clothing (tropics) which the clothing insulation value is 0.5 Clo. Metabolic rate could be close to

1.2 met (69.8 W/m^2) which corresponds to the sedentary activity in all locations. The activities of the occupants in the building were light work at seated positions.

5.2 Subjective Parameter Assessments

On the same day, a questionnaire survey was conducted with the building occupants in order to get a feedback on their thermal sensation as an average of the day. This subjective assessment was based on the occupants' vote on the thermal sensation (Yufeng & Rongyi, 2008) and ASHRAE scale was used. The survey was conducted from 9.00 a.m. to 5.00 p.m. Temperature measurements are shown in Graphs 1 and 2.

5.3. Results and Discussion

5.3.1 Respondents

A full day subjective study was carried out on the same day (an average representative day) with a total of 45 respondents for each zone A & B of the selected floor. All the respondents were within the age group of 19 – 36 years old. Demographic data of respondents is shown in Table 1. Both Zones A & B are provided with evaporative cooling. For Zone A, Chilled water was used. For Zone B, normal water was used.

5.3.2 Analysis of Votes

The summary of responses of occupants in both zones A & B are presented under this section. The equation that relates thermal conditions to seven point ASHRAE thermal sensation scale of, -3 (cold), -2 (cool), -1 (slightly cool), 0 (neutral), 1 (slightly warm), 2 (warm) and 3 (hot) was applied to collect the Thermal Sensation Votes (TSV) cast on the ASHRAE scale and the calculated TSV percentages can be seen in Graphs 3 & 4 relevant to zones A & B, respectively. The results are presented only for the time with highest indoor temperature.

The Thermal Sensation Vote for Zone B indicates that only about 6% of the occupants have found it warm whereas all the other have found it slightly warm, neutral or slightly cool. This gives an indication that in this building, evaporative cooling was effective during this warm day that the outdoor has reached 30.8^{0}C. The indoor temperature was about 29.2^{0}Cwith evaporative cooling. The indoor average air velocity was about 0.4 m/s in this particular building with ducted air distributed using diffusers. There is a remarkable improvement TSV when the indoor air circulated was chilled water. The indoor maximum temperature was maintained at about 28.3^{0}C.

This clearly shows that the use of chilled water where the temperature of water was dropped to about 24^{0}C from a normal temperature of pipe water of about 29^{0}C, could make a significant different.

It should be noted that in evaporative cooling is expected to give a reasonable thermal comfort with a much lower energy consumption. Therefore, it is not possible to directly compare the Thermal Sensation with air conditioning. Nevertheless, the ability to make it almost like a free running system with a significant level of fresh air will make it an ideal tool even in warm humid climates. The main key to success will be the indoor air velocity. It can be further improved with chilled water.

6. Conclusions

It is shown that with the high level of moisture present in the outdoor air, it is possible to have a humidity ratio values such as 0.018 at least in few months every year in tropical climates. Therefore, it is not possible to make evaporative cooling to be effective unless adequate indoor air velocity is maintained. The performance can be further improved by using chilled water instead of normal water since it could give an additional drop 0.5^0C – 1.0^0C to the circulated air. Since evaporative cooling is low energy consuming system, even such a marginal improvement could be important.

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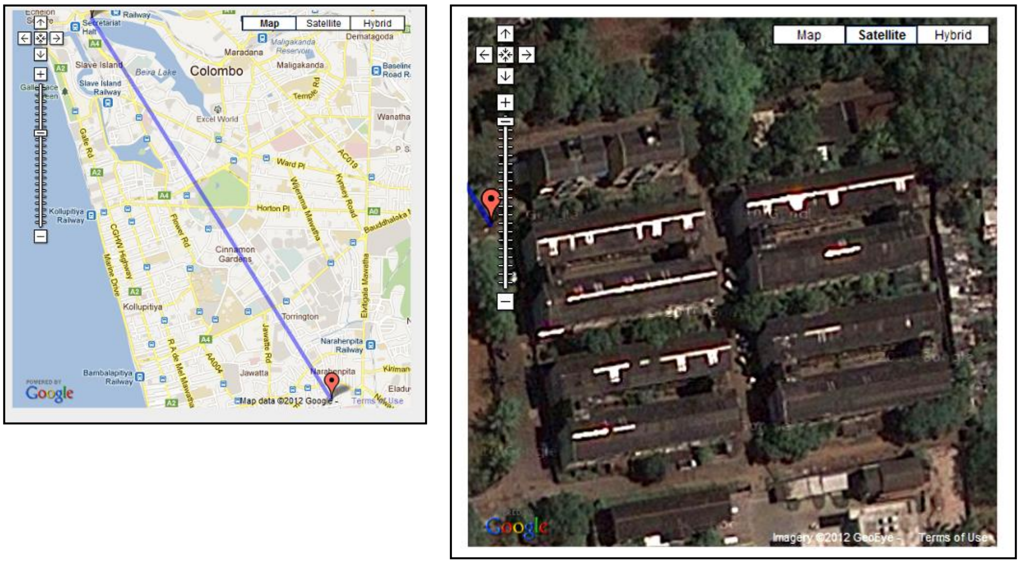


Figure 1: A city about 5 km away from the city of Colombo, the capital of Sri Lanka

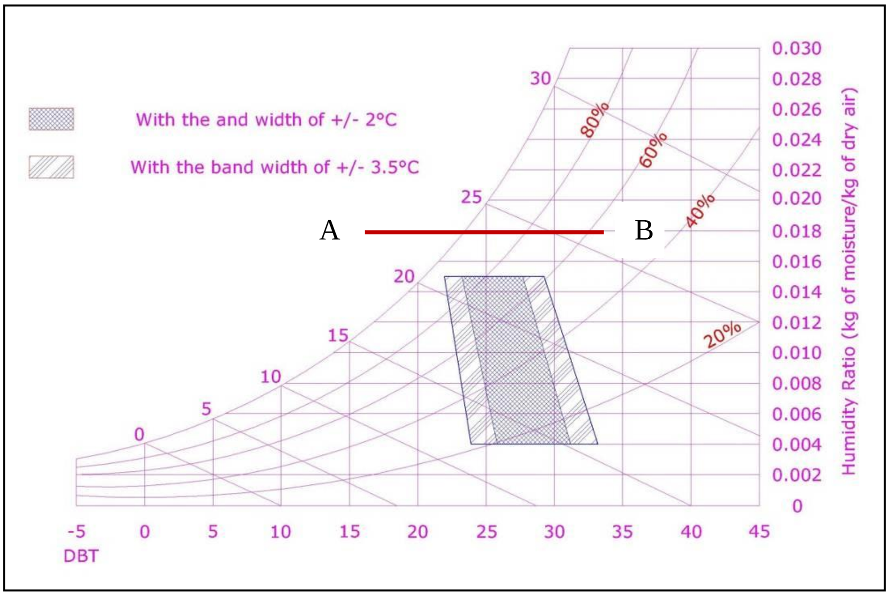


Figure 2: The comfort zone developed using a neutrality temperature of 26.5 ^{0}C (With both ± 2^{0}C and ± 3.5 ^{0}C band widths)

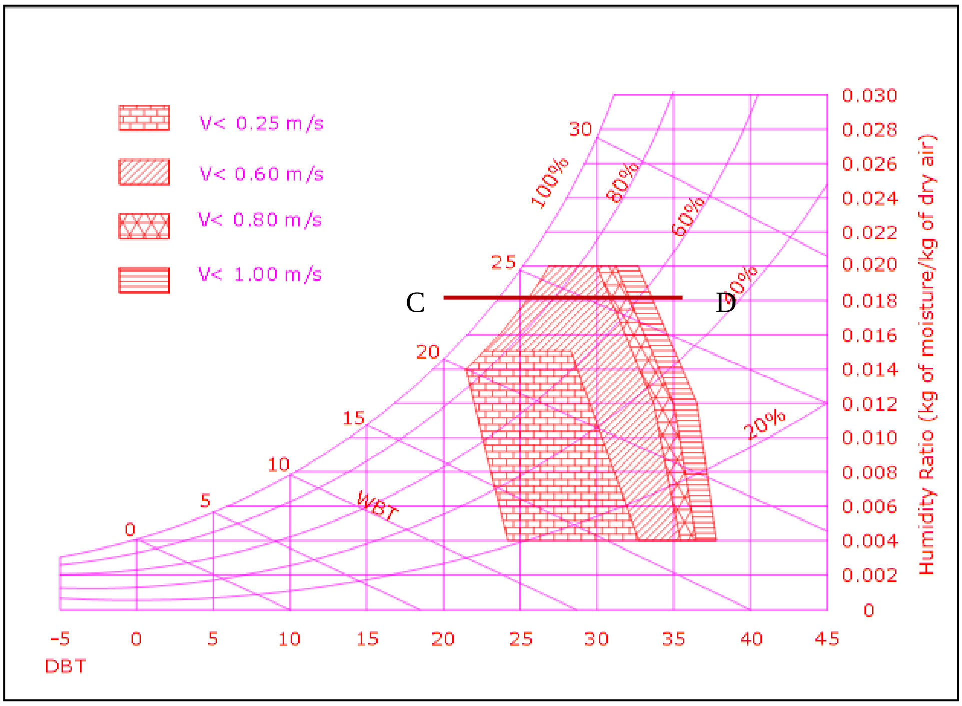


Figure 3: The extended comfort zone for different air velocities (Band width is ± 3.5 ^{0}C)

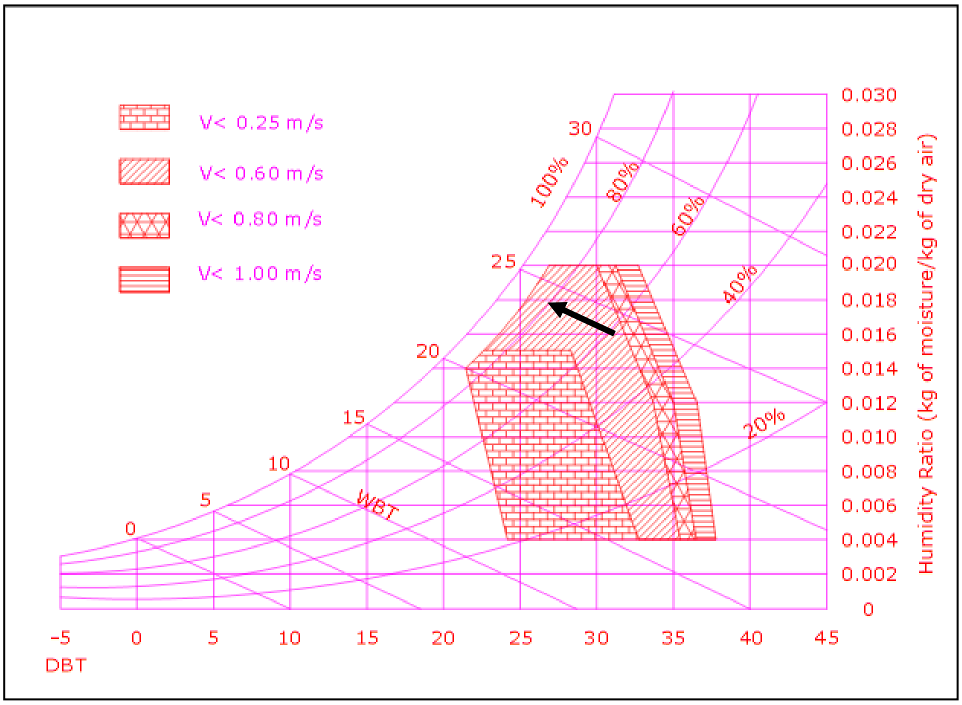


Figure 4: Evaporative cooling as an adiabatic process on the extended comfort zone

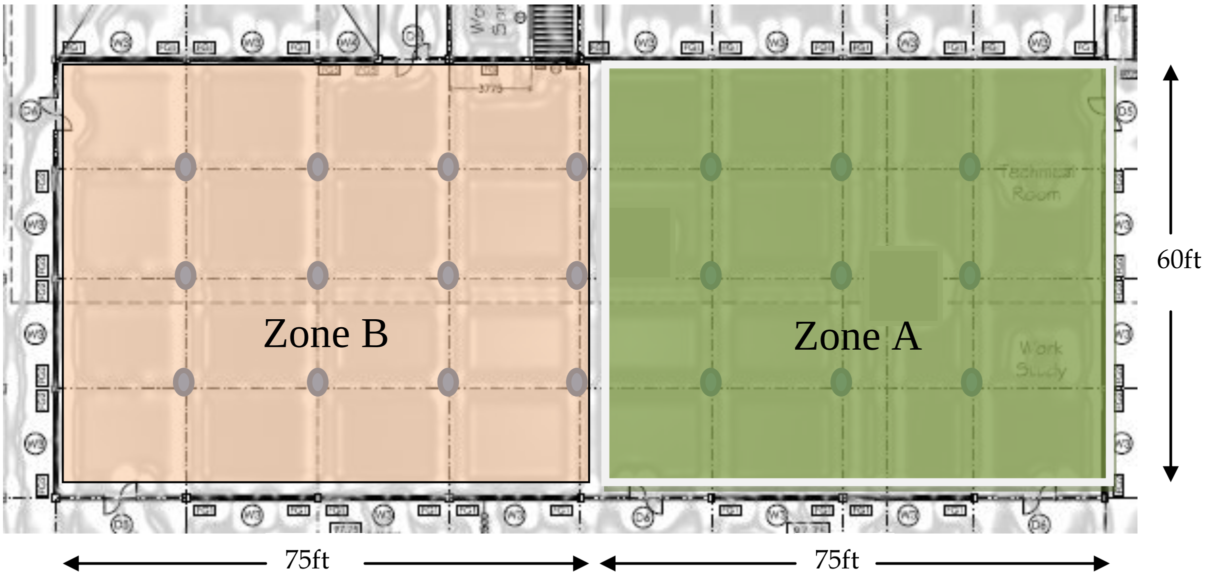
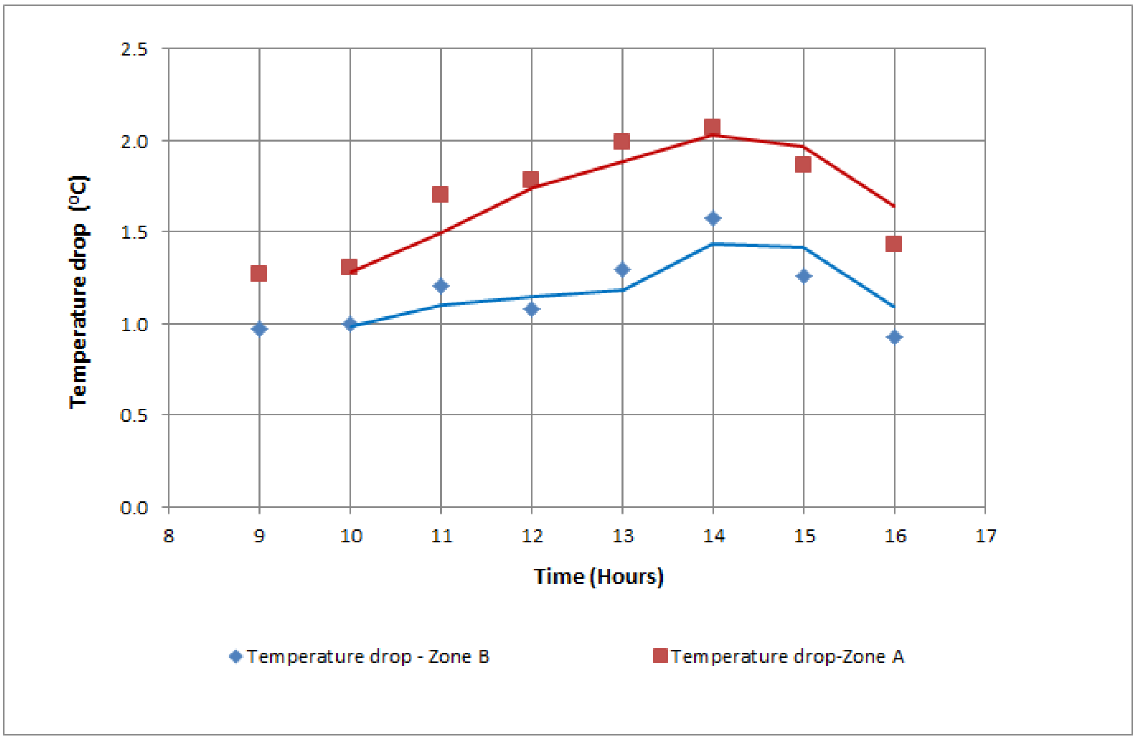
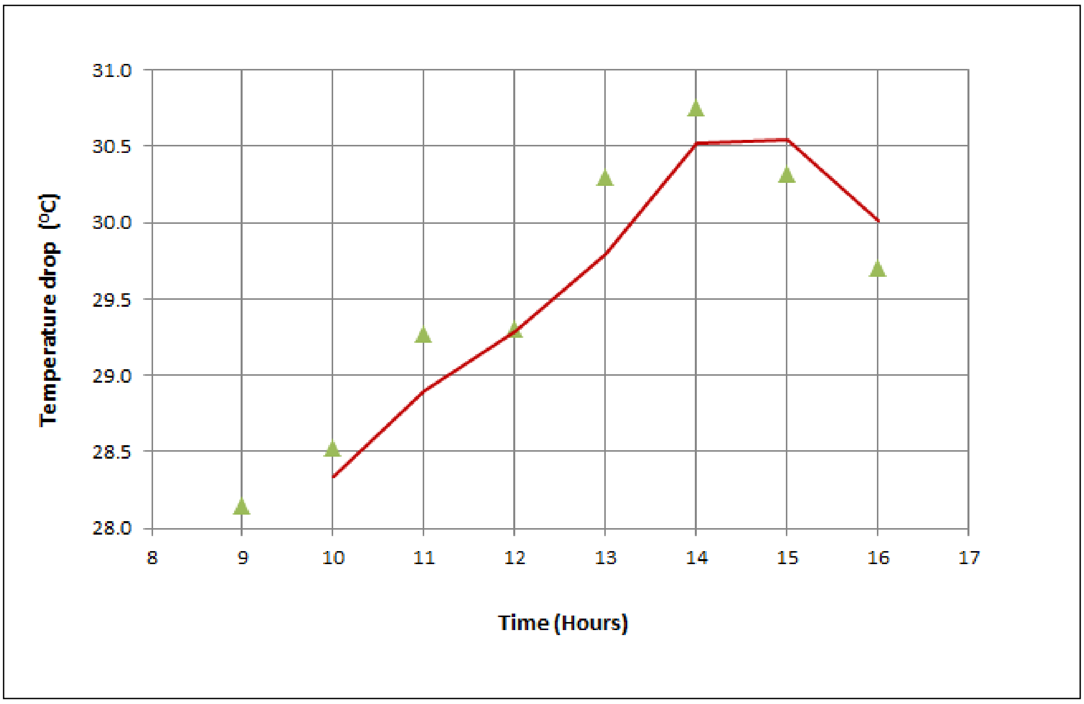


Figure 5: Two zones of demarcated for the experiments



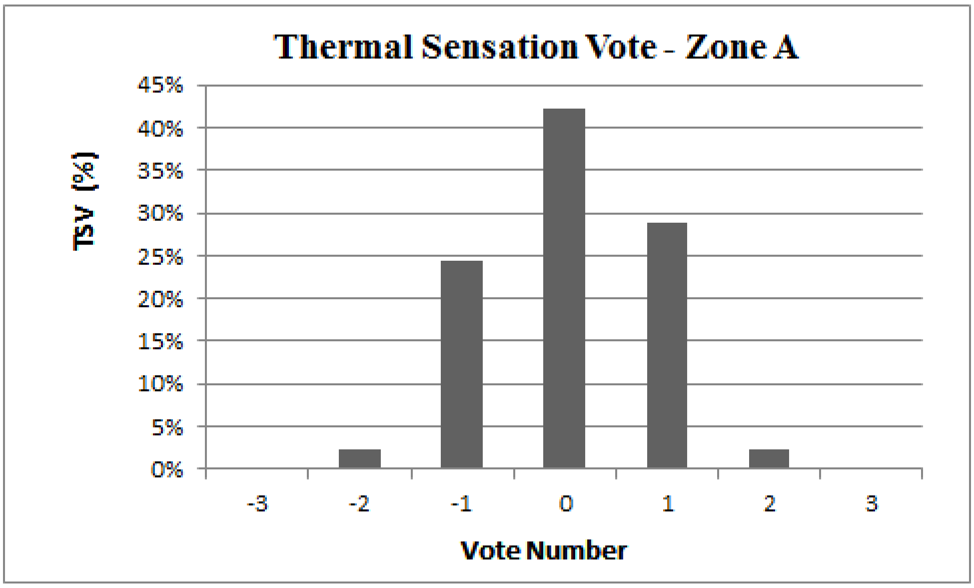
Graph 1: Temperature drop in Zones A & B



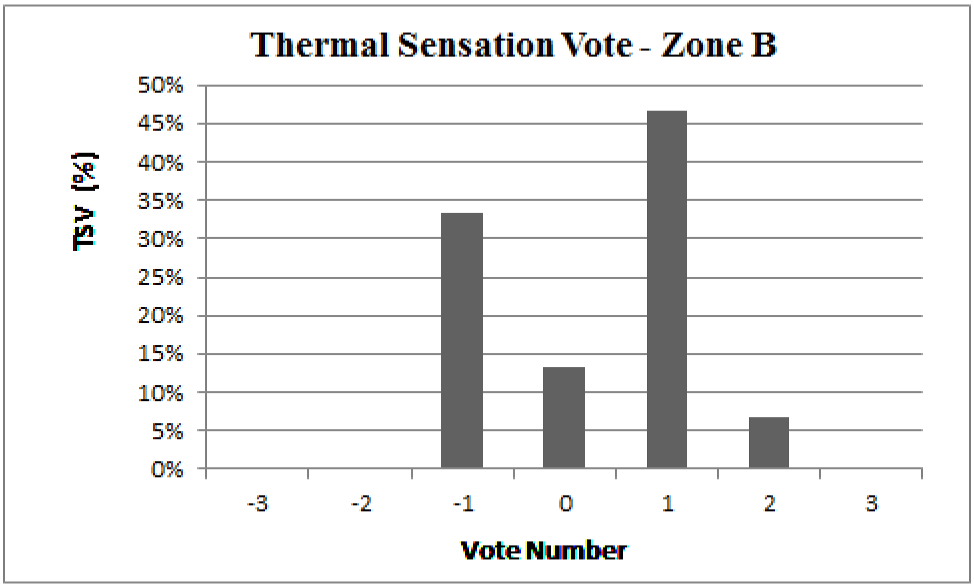
Graph 2: Variation of the Outdoor temperature with the time

Table 1: Demographic data of responds

	Zone A			Zone B		
Age group	**Male**	**Female**	**Total**	**Male**	**Female**	**Total**
18-24	3	22	25	4	19	23
24-30	2	13	15	2	16	18
30-36	0	5	5	0	4	4
Total			45			45



Graph 2: The profile of Thermal Sensation Vote (TSV) - Zone A



Graph 3: The profile of Thermal Sensation Vote (TSV) – Zone B