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Assessment of Thermal Comfort in Institutional Building based on Theoretical and Experimental Analysis

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Abstract **- Energy Management in buildings is a sound and respected engineering course. Careful use of energy and resources represents a technical, economical and ecological challenge as well as being one which is important for survival and which can only be mastered by highly qualified engineers. The main focus lies on the interaction between the building as a structure and the technical facilities. The main aim of my work is to utilize the natural thermal condition that exist presently in the building structure to a maximum by reducing the use of artificial thermal sources such as heaters, air conditioners etc. In this paper, I have considered 9 factors that influence the building structure as main factors. By analyzing these factors several possible solutions can be arrived for the utilization of natural energy instead of using artificial sources.**
Keywords**: Apparent Temperature, Heat Index, Temperature Humidity Index, Thermal comfort, Thermal Resistance**

I. INTRODUCTION

In each sector of Indian economy including agriculture, domestic, industry, transport and commercial, the consumption of energy in all forms has been steadily rising all over the country. Energy conservation facilitates the replacement of non-renewable resources with renewable energy. It is often the most economical solution to energy shortage. Energy conservation is the practice of decreasing the quantity of energy used while achieving a similar outcome. This practice may result in increase of financial capital, environmental value and human comfort. Treatment of building with thermal insulation may help in reducing domestic energy consumption. Buildings consume 50% of total human energy use, it is clear today that the building sector contributes significantly to global warming [1].

There are a number of energy simulation studies available in many countries, where internal heating is required to achieve thermal comfort in buildings. Thermal comfort is defined as the state in which the body adapts itself to the environment by spending the least amount of energy. It is possible to divide the thermal comfort factors into two groups as objective and subjective. Objective factors are air temperature, relative humidity which depends upon dry bulb and wet bulb temperature, air velocity and radiation. Subjective factors are the activity level, metabolic rate, thermal insulation of clothing, dieting habits, sex, age, shape of the body and acclimatization. Thermal comfort indices are the measures of thermal comfort. Normal body temperature is 37ºC [2]. In winter the temperature control is in range of 68 -76ºF and humidity is 20 -60% but in summer the temperature control is in range of 74 -78ºF and humidity is 30 -60% [3].

In a building, energy management is considered to be an important factor for the people. Some of the factors related to energy are considered while constructing the structure in order to provide comfort condition inside the building. Certain features are not considered while constructing which lead to the discomfort inside the building. The main aim is to identify these factors and analyze their effects. In a building, energy management is required to minimize the use of artificial energy systems and to provide the best comfort level. The role of the building energy management is mainly to implement continuous energy management and Therefore to the achievement of the possible energy savings in the building. The energy diagnosis aims at determining the current conditions of the facility, from the point of view of energy use, identifying problems and recommending possible solutions. With the consideration of the necessity of energy management in buildings, this work investigates about the condition in existing building and gives solutions for the problem of energy demands in the Institutional Building by utilizing the natural thermal condition to the maximum by reducing the use of artificial systems (air conditioner, heater, etc) in order to achieve possible energy savings in the building.

II. METHODOLOGY

A.The Building of Study

It is predicted that the earth's average temperature could rise by 1.4–5.8 ºC by year 2100, if the nations around the world do not act to control greenhouse pollution [4]. The method is based on determining the thermal comfort in buildings based on the theoretical and experimental analysis case. The analysis is carried out in the Engineering College building having four floors, which is located at Nagercoil, Kanyakumari district, Tamilnadu state, in Southern tip of India. The latitude and longitude of the building are 8.1971546ºN and 77.3848522ºE. The class rooms of the facade are facing the east and west direction. The size of the class rooms are 9m x 9m and 9m x 6m, utilized by under graduate and Post Graduate students respectively, having floor height of 3.6m. For the measurement of heat, thermo hydro clock were used, and the measurements were carried out at desk level.

B.Factors to be considered for thermal effects

1. Temperature Humidity Index (THI)
2. Heat Index (HI)
3. Heat Transfer Co-efficient (HTC)
4. Tropical Summer Index (TSI)
5. Apparent Temperature (AT)
6. Wet Bulb Globe Temperature (WBGT)
7. R-value and U-value
8. Questionnaire Survey
9. Thermal Comfort
    a. Indoor adaptive comfort temperature
    b. Floor wise variation of temperature
    c. Variation of Indoor Temperature with WWR

1.Temperature Humidity Index (THI)

Temperature-Humidity Index (THI) is the combination of temperature and humidity that is a measure of the degree of discomfort. Temperature Humidity Index (THI) also known as Discomfort Index (DI) [5]. It is measured inside the room. By empirically testing the THI values on human objects, the comfort limits are defined as: $21 \leq THI \leq 24$ = 100% of the subjects will feel comfortable, $24 < THI \leq 26$ = 50% of the subjects will feel comfortable and $THI > 26$ = 100% of the subjects will feel uncomfortably hot [5].

$$THI = 0.8T + (RH \times T/500)$$

Where, T - Air Temperature (ºC), RH - Relative Humidity (%)

2.Heat Index (HI)

The Heat Index (HI) is an index that combines air temperature and relative humidity in an attempt to determine the human-perceived equivalent temperature [6]. When the heat gain is great than the level of heat which can be removed by the body. The body temperature will be increased which results in illness and disorders.

3.Heat Transfer Co-efficient (HTC)

The amount of heat which passes through a unit area of a medium or system in a unit time when the temperature difference between the boundaries of the system is 1 degree. It ranges from 6 to 8 W/m^2K [1]. The heat transfer coefficient is also known as thermal admittance. It helps to design the most efficient heat flow path.

$$h = 5.7 + 3.8\,Ws$$

Where, h - heat transfer co-efficient (W/m^2K), Ws - wind speed (m/s)

4. Tropical Summer Index (TSI)

Tropical Summer Index is the temperature of calm air at 50% relative humidity which imparts the same thermal sensation as the given environment [7]. TSI evaluates indoor thermal comfort level [8].

$$TSI = 0.745DB + 0.308WB - 2.060V$$

Where, DB - Dry Bulb Temperature, WB - Wet Bulb Temperature, V - Wind Speed (m/s)

5. Apparent Temperature (AT)

Apparent Temperature is defined as the temperature, at the reference humidity level, producing the same amount of discomfort as that experienced under the current ambient temperature and humidity. Using the Steadman Table the apparent temperature is calculated [6].

$$AT = T_a + 0.33xe - 0.70X\ w_s - 4\text{ , here }AT > T$$

6. Wet Bulb Globe Temperature (WBGT)

The wet-bulb temperature is a type of temperature measurement that reflects the physical properties of a system with a mixture of a gas and a vapor, usually air and water vapor. Wet bulb temperature is the lowest temperature that can be reached by the evaporation of water only. It is the temperature one feels when his skin is wet and is exposed to moving air and it should not be greater than 29˚ C [7]. Unlike dry bulb temperature, wet bulb temperature is an indication of the amount of moisture in the air. To estimate the effect of temperature, humidity, wind speed and solar radiation on humans.

$$WBGT = 0.567 \times T_a + 0.393 \times e + 3.94$$

Where, T_a - Dry Bulb Temperature (ºC), e - Water Vapor Pressure (hPa).

7. R-Value and U-Value

Thermal Resistance is the ratio of the temperature difference across an insulator and the heat flux (heat transfer per unit area). The R-value being discussed as the unit thermal resistance. This is used for a unit value of any particular material. It is expressed as the thickness of the material divided by the thermal conductivity. It gives good building insulation. The R-value depends on the type of insulation, including the material, thickness, and density. When calculating the total R-value of a multilayered wall, all R-values of the individual layers must be added. The effectiveness of the insulation's resistance to heat flow also depends on how and where the insulation is installed [9].

Thermal transmission per unit time through unit area of the given building unit divided by the temperature different between the air and some other fluid on either side of the building unit in 'Steady State'. To choose best window (process of heat transmission). U-value of single glazed wooden window frame realizes 4.5 W/m^2 K for windows [10].

$$U = 1/\ \sum R\ (W/m^2\ K)\ [11]$$

8.Questionaire Survey

A questionnaire was prepared and circulated among the 200 participants of the college, in two seasons, both in summer and in winter in the year 2016. The participants comprised are mainly of graduate students, faculty members, administrative support staff, research staff, technicians, and undergraduate students. It comprises conditions like Satisfaction, Neutral and Dissatisfaction. Among this, Neutral indicates that, at some occasion they were not fully satisfied but they were able to manage without daylight.

9.Thermal Comfort

Thermal comfort refers specifically to our thermal perception of our surroundings [12]. Human thermal comfort is defined by ASHRAE as the state of mind that expresses satisfaction with the surrounding environment [13,14]. Acceptable thermal environment is an environment, which at least 80% of the occupants would find thermally acceptable [15,16]. Maintaining thermal comfort for occupants is one of the very important aspects for building designers.

$$T_c = 19.7 + 0.30\ T_o\quad [17]$$

In India, thermal comfort of a person lies between 25˚C and 30˚C, with optimum condition at 27.5 ˚C [7]. In a situation where there was no possibility of changing clothing or activity and where air movement cannot be used, the comfort zone may be as narrow as 2˚C [18]. The normal skin temperature is 31 to 34^{0}C [19].

III. RESULTS AND DISCUSSIONS

A.Temperature Humidity Index (THI)

The temperature humidity index is found for four different days in a month at one week interval. It is measured from 10.00am to 4.00pm. From the figure [1] it is found that there is an increase in the value from morning to evening. Temperature humidity index exceeds the limit and the people felt uncomfortable.

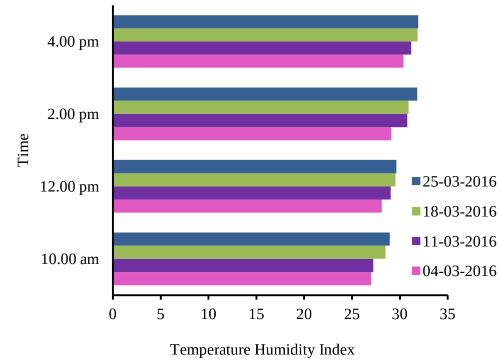

Fig.1 Variation of THI with time.

B.Heat Index (HI)

For the same days, heat index is found with which 32 – 41ºC, the category is extreme caution. That leads to sunstroke, muscle cramps and/or heat exhaustion possible with prolonged exposure and/or physical activity. Here the condition of extreme caution exists as the heat index value exceeds the limit which is represented in the figure[2]. On 4th March, heat index remains constant. But on 11th and 18th March it increases when the time passes.

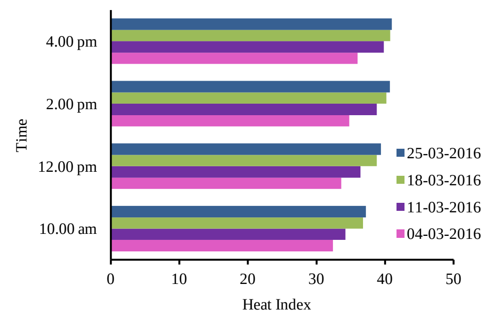

Fig.2 Variation of Heat Index with time.

C.Heat Transfer Co-efficient (HTC)

In figure[3] it is clearly shown that as the time passes there is an increase in the heat transfer value and it is not up to the limit for the four days, it is found to be high which causes discomfort condition for the people.

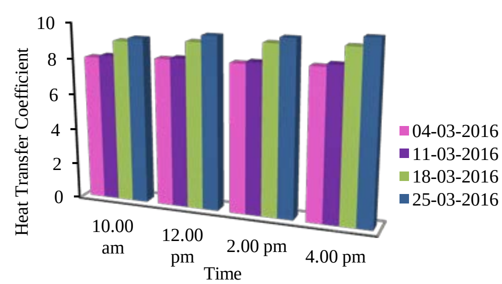

Fig.3 Variation of HTC with time.

D.Tropical Summer Index (TSI)

For the same month for five different days Tropical Summer Index is calculated and it is represented in the figure[4]. It is found that the values go on increasing gradually. There is an uncomfortable condition with the tropical summer index.

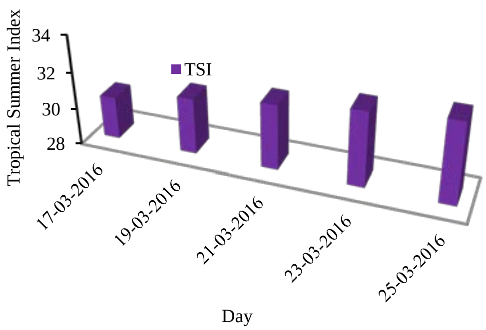

Fig.4 Variation of TSI with day.

E.Apparent Temperature (AT)

The apparent temperature is calculated for the same month and it is found from the figure[5] that there is an increase in the apparent temperature on the passage of time for all the four days.

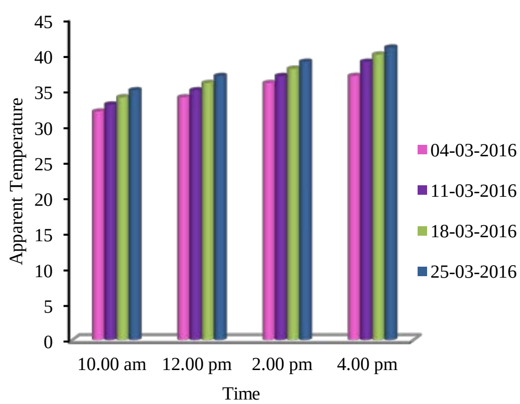

Fig.5 Variation of Apparent Temperature with time.

F.Wet Bulb Globe Temperature (WBGT)

The wet bulb globe temperature is taken for the four days and a comparison is made between the measured value and the value that has been obtained from the table. From the figure [6,7,8,9] it is found that for the four days, there is an increase in the Wet Bulb Globe Temperature on the passage of time. The calculated values of WBGT are within the limiting range while the values obtained from the table slightly exceed the limiting range.

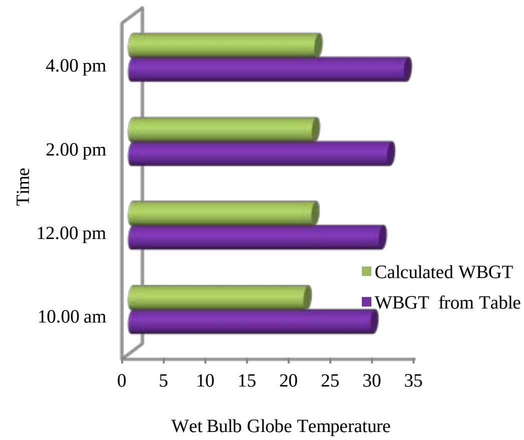

Fig. 6 Variation of WBGT with time on 4/3/2016**.**

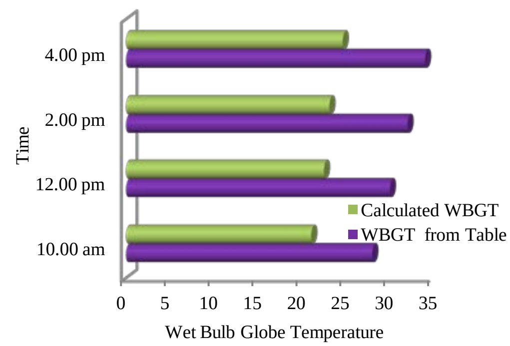

Fig.7 Variation of WBGT with time on 11/3/2016**.**

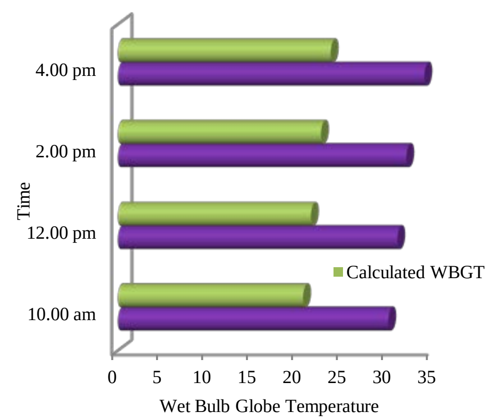

Fig.8 Variation of WBGT with time on 18/3/2016

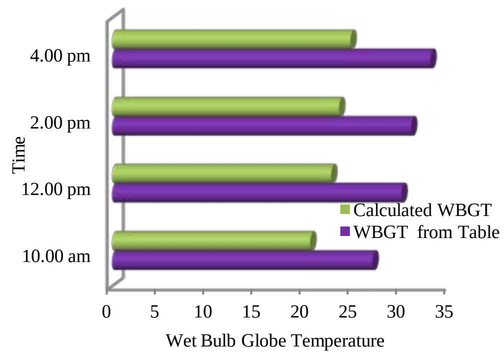

Fig.9 Variation of WBGT with time on 25/3/2016.

G. R-Value and U-value

The thermal resistance value is mentioned as R-Value and it depends on several factors and it is calculated as 5.416 m²k/W. The thermal transmittance value was found to be 0.185 W/m^2 K and generally for concrete it is about 1.7 W/m^2 k.

H.Questionaire Survey

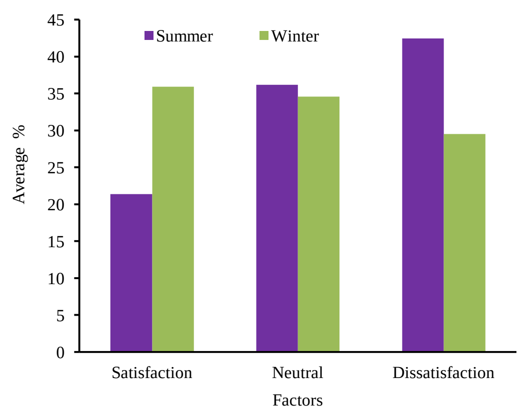

Fig.10 Variation of average percentage with factors.

By the survey that has been taken among the people of the institution by considering several factors that influence existing climatic condition into account, the calculated average value from the figure [10] during summer, clearly shows that the students are not highly satisfied with the existing thermal condition. But during winter, students are highly satisfied with the thermal condition that provides adequate amount of heat to withstand the coolness.

I.Thermal Comfort

By considering all the factors related to thermal, even though there is a fluctuation in the values we found that the year 2016 has a good comfort condition by satisfying the limiting range of 25˚C and 30˚C. In figure [11] it is found that from January to May, thermal effect increases which make people a little discomfort with the environmental condition but from June to November the value goes on decreasing so that it gives a good comfort level for the people. Then from December again it increases.

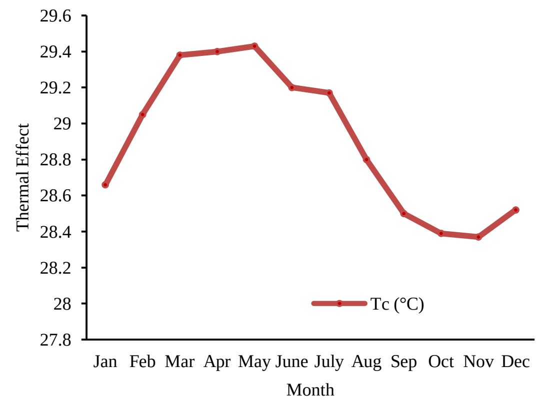

Fig.11 Variation of thermal effect in different months.

1.Indoor Adaptive Comfort Temperature

Indoor Adaptive Comfort Temperature used for the present study is plotted as graph for three months in summer. From the figure [12,13,14], we have obtain a comfort zone as 2.29ºC for January, 2.4ºC for February and 2.54ºC for March.

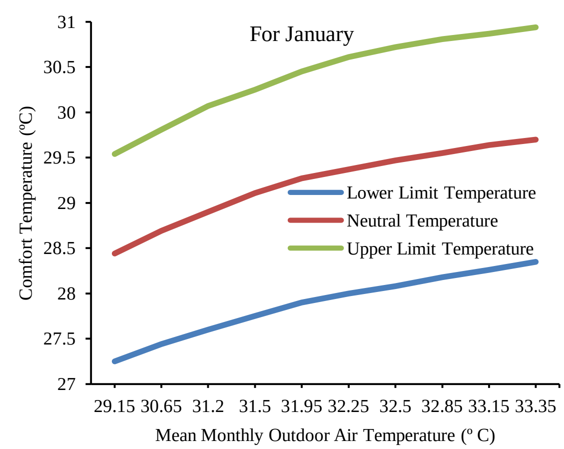

Fig.12 IAC temperature for January.

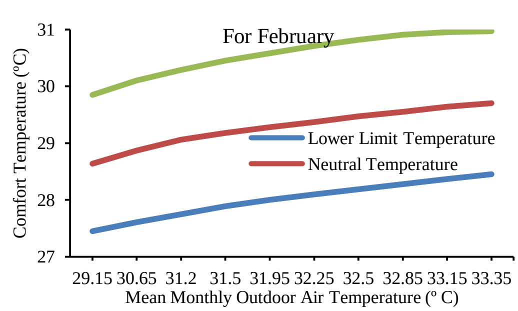

Fig.13 IAC temperature for February.

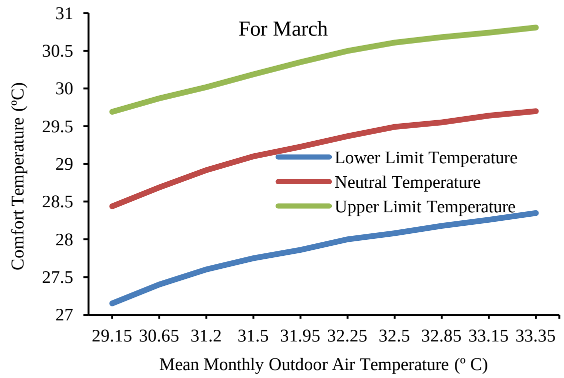

Fig.14 IAC temperature for March.

2.Floor wise Variation of Temperature

For the floor wise variation with the temperature, we found that the inside temperature and outside temperature goes on increasing for the succeeding floors.

3.Indoor Temperature with WWR

The indoor temperature of the room is plotted against the Window-to Wall Ratio and we have obtain the linear equation as $y=28.295x +28.324$ by using MS Excel.

IV. CONCLUSION

Energy Management is the sum of measures planned and carried out to achieve the objective of using minimum possible energy while the comfort levels (in offices/dwellings) and the production rates (in factories) are maintained. The main objective of energy management is to minimize the use of artificial energy systems and to provide the best comfort level to the buildings.

1. Some of the factors of thermal such as Temperature Humidity Index and Tropical Summer Index (TSI) are not up to the limiting value.
2. By Questionnaire survey, we found that in winter, people are satisfied with the natural thermal conditions that exist inside the building. But in summer they are dissatisfied with the existing condition.

Some of the ways to reduce energy use

a. Install heating controls including thermostatic radiator valves.
b. Avoid overheating and use thermostats to control the room temperature rather than opening windows to let heat out.
c. Change incandescent lamps to energy-efficient versions.
d. Increased planting of spreading trees.
e. Using different heat absorbing materials such as coconut shell, thylam sheet, mat, etc.

It is concluded that the comfort level was unsatisfactory during most of the days in summer whereas indoor thermal comfort condition remained within satisfactory limits during most of the days for the same season.

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