A STUDY ON COMFORT TEMPERATURE AND THERMAL EFFICIENCY OF BULDINGS

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Abstract: Indoor temperature of a building is based on the thermal performance of the building's roof and wall temperatures. The quantity of heat transmitted by the roof and walls is radiated into the inside of the building. The heat transmitted to the indoor is directly proportional to the inside temperature of the roof and walls. The indoor temperature varies with respect to the R Values of the materials used. The expectation of the inmates is to get thermal neutrality or comfort level. Buildings which are not able to provide comfort are thermally inefficient. If the indoor of the building gains more and more thermal energy from outdoor, above the comfort level then, it becomes a hyper thermic building. If the indoor of a building loses more and more thermal energy to the outdoor below the comfort level then it becomes a hypo thermic building. The hyper or hypo thermic states further lead to mega thermic and meso - thermic states. Too high or low indoor temperatures of any building result in non-living conditions of the occupants. This study likes to find out a relationship between the indoor temperature and thermal efficiency of a building in relation to comfort temperature. A building which provides comfort temperature is supposed to possess the maximum thermal efficiency (100%). A building's indoor when reaches the human body temperature is supposed to possess zero thermal efficiency. In the same way, when it reach a low temperature to the same extent from the comfort level its efficiency becomes zero. The efficiency lies between comfort and mega or meso - thermic states of indoor temperatures.

KEY WORDS: Thermal comfort, thermal efficiency, indoor temperature, outdoor temperature, hyper - thermal, hypo - thermal

I. INTRODUCTION AND BACKGROUND OF THE STUDY

The sun is the most important star which influences living and non- living things of Earth, and is the primary thermal source to the earth. The habitats of human beings are influenced by the solar insolation. The major building elements, roof and walls are irradiated by the Sun. Radiations from the sun decides the outdoor temperature of the habitats. The different parts of the earth are affected either by cold or heat. The people in the cold region heat their indoor and the people in the hot region cool their indoor to fetch the comfort. Too hot or cold indoor temperature is unpleasant and every one dislikes it. So a temperature at which a person feels better thermal sensation that is neither hot nor cold is defined as comfort temperature. If the indoor temperature of the building is within the specified limits for comfort, then the building is said to be comfortable and is considered to be energy efficient. When the solar radiation fall on the surface of the envelope, it reflects a part and the remaining part is absorbed by envelope and is retained as heat energy. The retained heat energy by the roof and walls is radiated into the indoor. The temperature existing inside the building is the indoor temperature. Whenever there is a variation in the outdoor temperature that affects the indoor temperature. In a building the indoor temperature may vary from room to room (bed room, dining hall, kitchen, reading room and rest room).

Thermal comfort is one of the most essential aspects of user satisfaction and energy consumption in buildings [1]. According to ASHRAE thermal comfort is defined as that condition of mind that expresses satisfaction with the thermal environment [2]. Thermal comfort is a result of a combination of adaptation of parameters of both the environment and the human body itself. The first heat balance thermal comfort model Fanger, states that the skin temperature and sweat secretion lies within narrow limits for the thermal comfort condition. From climate chamber experiments, sweat rate and skin temperature were measured on people who judged their thermal sensation as comfort. The sensation experienced by a person is a function of the physiological strain imposed on him by the environment. The thermal environment is taken into account by the air temperature, the mean radiant temperature, the partial pressure of water vapour in ambient air and the air velocity. The heat balance model analyses thermal physiology in detail by assuming controlled steady-state conditions and high accuracy for all analysed variables such as activity level, thermal resistance of clothing, air temperature, mean radiant temperature, relative air velocity, and water vapour pressure in ambient air [3].

The adaptive model investigates the dynamic relationship between occupants and their general environments based on the principle that people tend to react to changes that produce discomfort by seeking methods of restoring their comfort levels [4]. Such adaptation encompasses physiological, psychological, and behavioural adjustments simultaneously [5]. Therefore, the adaptive model provides greater flexibility in matching optimal indoor temperatures with outdoor climate, particularly in naturally ventilated buildings [6]. Adaptive standards are thus considered more appropriate for supporting comfort in low-energy buildings [7].At thermal equilibrium condition, normal temperature of a human body possesses 37˚C or 98.6˚F. To attain thermal comfort, 50% relative humidity, 18˚C– 27˚C temperature range and less than 0.15 m/s airflow speed are required [8]. A field study on the basis of adaptive approach was conducted in the Naturally Ventilated apartments of Hyderabad, during summer and monsoon, in 2008. The analysis resumed a comfort temperature of 29.23°C and the comfort band of 26 -32.5°C, and the relative humidity range of 17% - 78% [9].

The heat produced by the human body is exchanged with the environment by means of evaporation of body fluids. During normal rest or exercise the body temperature is maintained to be near 37 ˚C. Whenever there is a thermal disturbance, the temperature control system tries to maintain a constant temperature. There are two types of Thermoregulatory systems. One is autonomic and the other is behavioural. Autonomic system is more complicated and incorporates control principles than any other actual technical control system. It behaves in a highly non-linear manner and contains multiple sensors, feedback loops and outputs. Behavioural thermoregulation is based on active movement and adjustment of clothing. Temperature sensation is expressed in terms of cold or warm. But thermal comfort is expressed in terms of pleasant or unpleasant. The temperature sensation is due to thermo receptors in the skin whereas thermal comfort or discomfort reflects a general state of the thermoregulatory system [10].

The meaning of words "pleasant" and "comfortable" do not have an absolute value, but will be relative to experience and expectation. It is conventional to treat overall thermal discomfort (a subjective condition) in terms of thermal sensation (an objective quantity). This may be justifiable in case of steady-state conditions however probably not when transient conditions have to be judged [11].

The difference between thermal comfort and temperature sensation during changing environmental conditions was clearly demonstrated. The subjects were exposed for one hour to neutral thermal conditions(29˚C), then a step change to a much colder (17.5 ˚C) or warmer (48 ˚C) environment for a two hour exposure, which was followed by a step change back to neutral conditions. On entering the cold conditions there were immediate reports of cold sensations and discomfort. On returning to the neutral environment discomfort almost immediately disappeared, while temperature sensations lagged considerably behind the comfort reports and did not return to neutral for all subjects during the one hour post exposure period. The transient exposures to the hot environment showed much the same responses. On entering the hot conditions there were immediate reports on warm sensations and discomfort. On re-entering the neutral conditions discomfort disappeared rapidly however more slowly than in the case of the cold to neutral step. The temperature sensations showed an overshoot with some initial reports of slightly cools [12].

Table.1 Shows the Comfort Temperature ascertained by different authors in different places of Hot and Humid Climate and composite climate.

Table.1. shows the comfort temperature determined by different studies.

Researcher	Country	Comfort temperature˚C
J. F. Busch	Thailand	24.5
R.J. De Dear, K.G. Leow et al.	Singapore	24.2
R.J. De Dear, M.E. Fountain	Townsville, Australia	24.6
T.H. Karyono	Jakarta, Indonesia	26.7
W.T. Chan et al.	Hong Kong	23.5
Ruey Lung Hwang	Taiwan	25.6
Madhavi Indra ganti	Hyderabad, India	29.23
Stanley R. Kurvers	Surakarta, Indonesia	32.5

This study aims to find out the thermal efficiency of different types of buildings on the above basis. For this purpose, six different modules with different roof and walls are considered.

II. RESEARCH DESCRIPTION

The size of the modules is 3mx 3m x 3m. The galvanized sheets used in the modules have the same thickness of 0.21 mm. The walls have a thickness of 230 mm made up of brick and cement mortar. Two angles are used as purlins. It is a low sloped roof and is maintained to be 2˚. Walls of the modules are white washed and the flooring is done with cement mortar. The indoor temperature and the relative humidity of the module were recorded through hygro thermometer. Single channel data logger has been utilised for this recording. The outdoor temperature is obtained from the local meteorological records. The alternate aim of this study is to find out a thermal efficient and comfort providing module through passive approach.

A. First Module (SID):

First module is Single Decker, in which Galvanized sheets are used as roof element, where the walls are made by bricks with cement mortar. When the solar radiation falls on the roof, the sheets are very easily heated even by early hours of the day due to conduction and it continues for the whole day up to the sun shine. During the peak hour, the amount of heat transmitted into the building is massive.

Fig.1. SID module

B. Second Module (PUD):

The second module is constructed with Polyurethane panels of length 3660 mm and breadth 1000 mm is used as roof, which is an industrial product. The thickness of the Poly Urethane Decker is 35 mm and the thickness of the sheets is 0.35 mm. This roof material is not popular among the common people. The number of industries is very less. The cost of the material is also high. The panels should not be punched are damaged. If the punching necessitates it should be carefully protected. Water leak in or moisture absorption will lessen the insulation property of the panel. The panels should be overlapped perfectly. These panels serve as a good roof panels in the aesthetic sense and its performance.

Fig.2. PUD Module

C. *Third Module (DOD):*

The roof is modelled to have an acceptable indoor temperature rather than the aesthetic sense. Third module roof is newly designed. The materials required are galvanized sheets, wooden reapers mineral wool of required length and breadth. The design is carried out in four steps. In the first step, first roof is made using galvanised sheets. In the second step wooden reapers of size 3000 mm X 50 mm X 25 mm were arranged over the roof. The spacing between the reapers is 200 mm. In the third step packed mineral wool roll was spread. Thickness of the mineral wool is 50 mm. In the fourth step galvanized sheets were set over it as second roof. The two roofs are separated by 100 mm to 122 mm. Since light roofing system have two light roofs enclosing the wooden reaper and mineral wool is named as Double Decker. Since the sheets are trapezoidal, air gap of 11 mm above and below the mineral wool pack and wooden reapers is formed. This assembly possesses three insulators wooden reapers, mineral wool and air gap. Mineral wool has a low thermal conductivity among the building materials used (K= 0.04 W/m K). The mineral wool is also not so popular. But it is available in the market.

Fig.3 DOD module

D. *Fourth Module (OAS):*

The fourth module is constructed by using trapezoidal Asbestos sheets for the roof and wall. Asbestos has been banned by developed countries but it is used still in India. This type of roof too allows the solar radiation into the occupant zone through the roof and walls. As long as the sun shines it receives heat and passes it into the indoor. So the indoor temperature during the summer day hours is enormous. The indoor exists with a large amount of heat and unbearable by the occupants. The cheapness of the material attracts the consumers tempts to use. Asbestos is banned by most of the developed countries. Still some of the developing and underdeveloped countries are keeping it in use.

Fig.4 OAS module

E. *Fifth Module (OGS):*

The roof and wall of the fifth module OGS is constructed with Trapezoidal shape Galvanized sheets. This roofing is adopted by the industries, workshops, warehouses and is also followed by the Low economy Group community because of its light weight, easiness in construction and low cost. Being a conductor the sheets easily permit solar radiation into the occupant zone not only through the roof but also via walls. In the winter season except the peak day hours it performance is somewhat better. In the summer season its heat transmission is tremendous. It behaves like a source of heat.

Fig.5 OGS module

F. *Sixth Module (RCC):*

The sixth module is a RCC roof. A room of size 3m x 3m x 3m of a one storey building has been considered for this experiment. The roof consists of concrete, weathering course and Mangalore Tile is used over the weathering course.

Fig.6 RCC Module

III. RESULTS AND DISCUSSION

A new type of scale is proposed to find out the thermal efficiency. It is proposed on the basis of the human body temperature and comfort temperature. The building with comfort temperature is strongly believed to have the maximum thermal efficiency (100%). If the indoor temperature attains the human body temperature then the building attains zero thermal efficiency. On the above two set points the efficiency of a building is determined. It is noticeable that comfort temperature so far established by different researches has a lower temperature than that of the body temperature. So the human body needs a lower indoor temperature than the body temperature for comfort. The comfort temperature value is 29.2˚C according to the Indra ganti study, at Hyderabad. The mega thermal state possesses a temperature of 37˚C and above. The meso thermal state possess a temperature of 21.4˚Cand below.

Table.2 shows the indoor temperature at peak hours of the day for the monitoring period, from September 2013 to August 2014. During the month of June maximum indoor temperatures have been recorded, and during December minimum indoor temperatures has been observed. The highest indoor temperatures were provided by OGS from 30.22 ˚C to 37.99 ˚C and OAS provided 29.64 ˚C to 37.01 ˚C. These two modules can be recognised as mega thermic during summer. From March to september they are least efficient.

Table.2 The indoor temperature of the six modules for the monitoring period

Months	T_i SID	T_i PUD	T_i DOD	T_i OAS	T_i OGS	RCC
Sept.13	32.60	29.81	29.32	33.54	34.92	33.20
Oct-13	31.45	28.60	28.82	32.73	33.67	32.57
Nov-13	29.26	27.81	28.19	30.96	31.62	30.99
Dec-13	26.86	27.22	27.85	29.64	30.22	28.75
Jan-14	27.85	27.91	28.22	30.38	30.96	29.18
Feb-14	28.87	28.45	29.12	30.62	31.75	30.10
Mar-14	32.88	31.50	30.50	32.78	34.06	32.35
Apr-14	34.29	33.69	32.43	35.64	35.85	35.04
May-14	34.78	33.88	32.65	36.55	37.64	36.35
Jun-14	35.22	34.55	32.88	37.01	37.99	36.4
Jul-14	34.88	33.91	32.58	36.52	36.99	34.99
Aug-14	34.58	33.22	32.42	35.84	36.15	33.75

The graph has drawn Fig.7 between the indoor temperatures of the six modules and the monitoring period shows that the indoor temperatures are high for the months from April to September. For the other periods the indoor temperatures are low. The maximum variation is found in December and January. The indoor temperature of the DOD module is neither too low nor too high than the other modules.

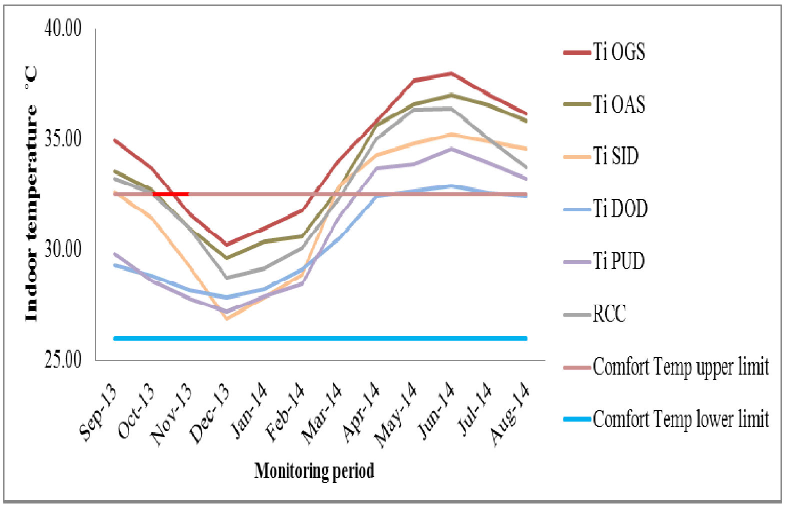

Fig.7 the monitoring period and the indoor temperature

A. *Thermal behaviour of the building*

Thermal behaviour of a building can be understood if its indoor temperature is keenly observed and analysed. Five different temperatures of the indoor are considered to understand the performance of a building.

Case (i): when the indoor and the comfort temperatures are equal ($T_i = T_c$), the indoor provides thermal delight to the occupants. It needs no energy for cooling or heating. Or this can be a free running building. This type of building can be considered as an ideal building.

Case (ii): As the indoor temperature increases above comfort temperature, the building provides discomfort. The discomfort increases with the increase of indoor temperature and the occupant begins to feel sultry and sweat. If it increases more and more, hyper thermal state will prevail. Then the occupant begins to minimize the wearing.

If the indoor temperature increases up to or beyond the human body temperature (T_b), the building is totally unfit to reside, and the building is said to be a mega thermic building. The isothermal condition between the indoor and the body causes maximum discomfort. In other words, the building is said to reach maximum inefficient thermal state, or zero thermal efficient state. Here $Ti \gg Tc$, or $Ti \geq Tb$. The occupant is forced to wear less clothing. Now the building needs to be cooled to a large level by means of electro mechanical systems such as ceiling fans or pedestal fans or air coolers or air conditioners. The diseases caused due to hyper thermal state are headache, nausea or vomiting, dizziness, weakness, irritability, thirst, and heavy sweating and cluster of red bumps on skin fig.8.

Fig.8. Problems due to hyper thermal state of the indoor

Case (iii): On the other hand, if the indoor temperature decreases than the comfort temperature of the building, it certainly provides discomfort. The discomfort increases with more and more decrease of indoor temperature. Now the building attains the hypo thermal state ($Ti< Tc$). The occupant feels chillness and begins to increase his wearing. As the temperature goes down the occupant adds special dresses to keep safe. If the indoor temperature is decreased to a lower level, it will be unsuitable to reside.

If the indoor temperature $Ti \ll Tc$ or $Ti \leq Tc - 7.8$, and the building is said to be a meso thermic building. The building reaches thermal inefficient state. Or it attains zero thermal efficient state. Now the building needs to be heated. The diseases caused due to low temperature are cold sensation; shiver can be mild to severe and numbness and results in frost bite, etc.

Now the indoor temperature of the building should be raised. Now the building attains the maximum thermal inefficient state. To raise the indoor temperature, equal to or nearby comfort value, the indoor should be heated.

B. Energy Efficiency Triangle

Thermal efficiency of a building is the ability of a building to keep its indoor temperature between the comfort temperature and the mega - thermic state or the meso - thermic state. The thermal efficiency is maximized when the building provides comfort temperature. The thermal efficiency is minimized or becomes zero when the indoor temperature reaches mega thermic state or the meso - thermic state. Thermal efficiency of a building oscillates between mega thermic to meso - thermic states in different seasons. Thermal efficiency decides either to heat or cool the building. The amount of heating or cooling level also can be obtained. And it also provides knowledge to understand in what type of building the occupant resides. This triangle provides a new way to find the thermal efficiency of any building depending on the indoor temperature. The determination of thermal efficiency provides the knowledge about the building. It announces the behaviour of the building. The consumer is able to know the level to which it should be heated or cooled. Figure.9 is the thermal efficiency triangle. This is an isosceles triangle. Two of the vortex of the triangle has the values 37˚C, 21.4˚C which denote the mega and meso thermic states. Otherwise these points represent the minimum efficiency. Third vortex represents the maximum efficiency 100%, which corresponds to comfort temperature 29.2˚C. The lines which are drawn from the maximum efficiency to minimum efficiencies form the two sides of the efficiency triangle. The base of the triangle represents the indoor temperatures from mega state to meso- state. The bisector of the triangle denotes the thermal efficiency. Hence the Y – axis represents the efficiency in percentage. This triangle is used to find out the efficiency of the module for every decimal of indoor temperature.

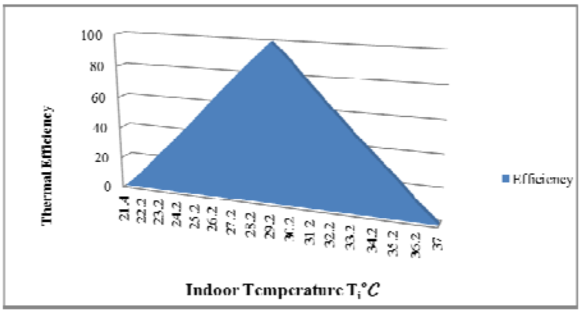

Fig.9 The indoor temperature Verses thermal efficiency

Fig.10 shows the relationship between the indoor temperatures of the different modules considered for the study. From the figure it is clear that the indoor temperature of all the modules are within the comfort limits in the winter season. But for the summer season the indoor temperature of all the modules are away from the upper comfort limit.The indoor temperature of the DOD is very close to the upper limit of the comfort band. The upper limit of comfort indicated in the study[9] is 32.5 ˚C and the lower limit indicated is 26 ˚C. The upper and lower limits of the comfort band possess the thermal efficiency of 59.5%. The upper and lower limits are fixed depending on the voting during survey. It can be understood that the occupants are stisfied to reside in a building which possess an efficiency of 59.5%.Table.3 shows the indoor temperature of the experimental modules in the winter and summer seasons.

S.No	Modules	Winter Dec Ti	Summer June Ti
1	SID	27.12	35.22
2	PUD	27.22	34.55
3	DOD	27.85	32.88
4	OAS	29.64	37.01
5	OGS	30.22	37.99
6	RCC	28.75	36.4

Table.3 shows the Indoor Temperture of the modules in the two extreme seasons

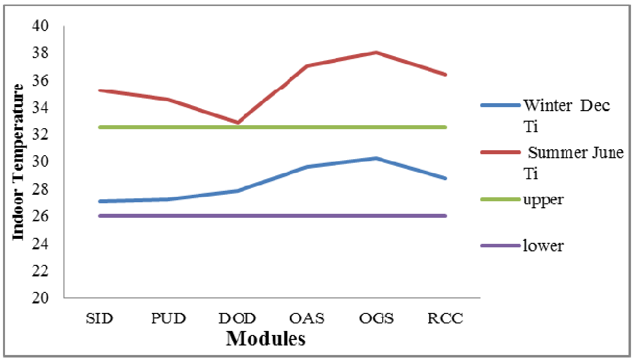

Fig.10 The indoor temperature of two extreme seasons verses the different modules

Table.4 shows the efficiency calculated through the efficiency triangle for the experimental modules in the winter and summer seasons.

Table.4 Thermal Efficiency in two extreme seasons verses different modules.

S.No	Modules	Winter Efficiency %	summer Efficiency %
1	SID	71.5	23.5
2	PUD	74	36
3	DOD	82.5	54.5
4	OAS	95	0
5	OGS	87.5	0
6	RCC	94	8.25

The thermal efficiency of the modules varies from 71.5 to 95% in the winter season. Among all the modules considered for this study DOD module has the highest efficiency in winter. But all the modules provide a desirable efficiency in the winter. But in summer the efficiency lies from 0% to 54.5%. The maximum efficiency is exhibited by the DOD module and the minimum efficiency is exhibited by the OAS and OGS module.

Comfort band has the maximum and minimum temperatures within which a person feels a good thermal sensation. Comfort temperature is a special case of indoor temperature where the pleasant sensation of the thermal condition is felt by the occupant. Otherwise it can be taken as the critical temperature of indoor temperature**.** Above or below this comfort temperature the efficiency decreases. The thermal efficiency of the module has uniform variation for both heat gain or heat loss**.** In comparison, the thermal efficiency determined for the upper and lower limits of comfort should be the same. But there is a variation found in the efficiency values. The difference between comfort and upper comfort band temperatures (29.2˚C and 32.5˚C) is 3.3˚C whereas the difference between comfort and lower comfort band (29.2˚C and 26˚C) is 3.2˚C. The upper and lower limit of comfort band has a small variation by 0.1˚C. Thermal efficiency values for the lower and upper comfort bands, does not coincide exactly due to this variation. Either the upper limit or the lower limit should be adjusted to have the same efficiency. Same thermal efficiency of 59.5% is obtained for the upper limit of 32.4˚C and for the lower limit of 26˚C.

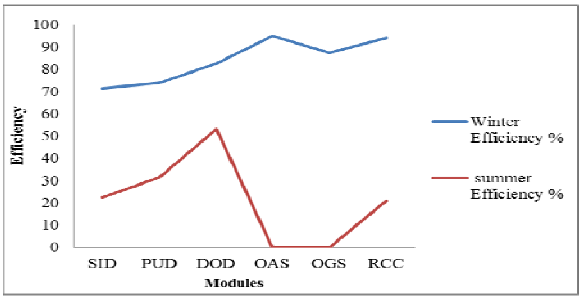

Fig.11 Thermal efficiency and different modules

IV. CONCLUSION

Thermal efficiency has been defined on a new approach. The innate thermal efficiency determination is based on the temperatures of the comfort, mega and meso thermic states. The mega and meso thermic states are placed symmetrically on either side of the comfort temperature. Thermal efficiency triangle is useful in categorizing the building. Among the considered modules no module falls in the category of meso thermic state. Two modules OAS and OGS attain the mega thermic state in the summer. Different modules are having different efficiencies. Thermal efficiency of the newly designed roof DOD provides a better efficiency than the other modules. The heating and cooling requirement of a building can be easily determined. The occupants are able to identify the nature of the building in which they reside.

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