Abstract

In the residential and commercial buildings, most of the energy is used to provide the thermal comfort environment to the occupants. The recent research towards Green Buildings is focusing on reduction of energy consumption by air-conditioners and fans used for producing the thermal comfort environment. The thermal comfort is defined as the condition of mind which expresses human satisfaction with the thermal environment. The human body is continuously producing metabolic heat and it should be maintained within the narrow range of core temperature. The heat generated inside the body should be lost to the environment to maintain the thermal equilibrium with each other. The heat loss from the body is taking place in different modes such as conduction, convection, radiation and evaporation through the skin and respiration. These heat losses are influenced by the environmental factors (air temperature, air velocity, relative humidity and mean radiant temperature), physiological factors (activity level, posture and sweat rate) and clothing factors (thermal insulation value, evaporative resistance and microenvironment volume). When the body is in thermally equilibrium with its surrounding environment, the heat production should be equal to heat loss to maintain the thermal comfort. The level of thermal comfort can be measured by the different indices which combine many parameters. Of these, the Fanger's *PMV* (Predicted Mean Vote) – *PPD* (Percentage of People Dissatisfied) index was universally suggested by ASHRAE and ISO. The *PMV* – *PPD* index was derived based on the experiment conducted on acclimated European and American subjects. Many researchers have criticized that the *PMV* – *PPD* index is not valid for tropical regions and some researchers have well agreed with this index for the same region. The validation of *PMV* – *PPD* index for thermal comfort Indians has not yet been examined.

The validation of PMV – PPD index can be done by the human heat balance experiment and the individual heat losses have to be calculated from the measured parameters. In the human heat balance, the convective heat transfer plays the major role when the air movement exists around the human body. The convective heat loss is dependent on the convective heat transfer coefficient which is the function of the driving force of the convection. Using Computational Fluid Dynamics techniques, an attempt has been made in this work to determine the convective heat transfer coefficient of the human body at standing posture in natural convection. The CFD technique has been used to analyze the heat and fluid flow around the human body as follows:

The anthropometric digital human manikin was modeled in GAMBIT with a test room. This model was meshed by tetrahedral elements and exported to FLUENT software to perform the analysis. The simulation was done at different ambient temperatures (16 ^{o}C to 32 ^{o}C with increment of 2 ^{o}C). The Boussinesq approximation was used to simulate the natural convection and the Surface to Surface model was used to simulate the radiation. The surrounding wall temperature was assigned equal to the ambient temperature. The sum of convective and radiative heat losses calculated based on the ASHRAE model was set as heat flux from the manikin's surface. From the simulation, the local skin temperatures have been taken, and the temperature and velocity distributions analyzed. The result shows that the skin temperature is increasing with an increase in ambient temperature and the thickness of the hydrodynamic and thermodynamic boundary layers is increasing with height of the manikin. From the Nusselt number analogy, the convective heat transfer coefficients of the individual manikin's segments have been calculated and the relation with respect to the temperature differences has been derived by the regression analysis. The relation obtained for the convective heat transfer coefficient has been validated with previous experimental results cited in literature for the same conditions. The result shows that the present relation agrees well with the previous experimental relations. The characteristics of the human thermal plume have been studied and the velocity of this plume is found to increase with the ambient temperature. Using the Grashof number, the flow around the human manikin has been examined and it is observed to be laminar up to abdomen level and turbulent from shoulder level. In between these two levels, the flow is found to be in transition.

The validation of *PMV* model for tropical countries, especially for Indians, was done by heat balance experiment on Indian subjects. The experiment was conducted on forty male subjects at different ambient temperatures in a closed room in which low air movement exists. The local skin temperature, relative humidity, air velocity and globe temperature were measured. The sensation vote was received from all the subjects at all the conditions. The convective heat loss was calculated from its coefficient obtained from the present computational simulation. The radiation heat loss was calculated for two cases: In case one, the mean radiant temperature was taken equal to the ambient temperature and in case two, the mean radiant temperature was calculated from the globe temperature. The other heat losses were calculated from the basic formulae and the relations given by ASHRAE based on Fanger's assumption. From these calculations, the validity of the Fanger's assumption was examined. The collected sensation votes and the calculated *PMV* were compared to validate the *PMV* – *PPD* index for Indians. The experimental results show that there was much variation in the calculated comfort level using the measured parameters and the Fanger's assumption. For the case of mean radiant temperature equal to the ambient temperature for indoor condition, the comfort level was varying more than the actual. In addition, the calculated comfort level from the globe temperature agreed well with the comfort level from the collected sensation votes. So it was concluded that the ASHRAE model is valid for Indians if the radiation was measured exactly.

Using the ASHRAE model, the required wall emissivity of the surrounding wall at different ambient temperatures was determined from the CFD simulation. In the ASHRAE model, the surrounding wall emissivity plays the major role in the radiative heat loss from the human body. Hence in recent years, research on low emissive wall paints is focused. The computational study was done to determine the required wall emissivity to obtain the thermal comfort of the occupant at low energy consumption. The simulation was done with the different ambient temperatures (16 ^{o}C to 40 ^{o}C with increment of 4 ^{o}C) with the different surrounding wall emissivity (0.0 to 1.0 with increment of 0.2). From this simulation, the change in mean skin temperature with respect to wall emissivity was obtained for all ambient temperature conditions. The required mean skin temperature for a particular activity level was compared with the simulation results and from that, the required wall emissivity at the different ambient conditions was determined. If the surrounding walls are having the required emissivity, it leads to decrease in heat/cold strain on the human body, and the thermal comfort can be obtained with low energy consumption.