STUDY ON THE EXPERIMENTAL THERMAL PARAMETERS OF BUILDING ENVELOPE COMPONENTS UNDER THE TROPICAL CLIMATIC CONDITIONS AND COMPARING THE RESULTANT BUILDING COOLING LOAD WITH THOSE OBTAINED FROM GLOBALLY AVAILABLE DIFFERENT SIMULATION TOOLS

SYNOPSIS OF THESIS

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Introduction

Buildings are designed to provide thermal comfort to the occupants all around the year despite variations in external climatic and other functional conditions. The building envelope refers to the external façade, which is composed of walls, roofs, glazing systems, doors and windows etc. From energy efficiency point of view, the envelope design must take into consideration both external and internal heat loads, as well as day lighting benefits. Unfortunately building design has not been a subject of study in India from the point of view of its electrical and thermal performance.

The building sector represents about 33% of the electricity consumption in India, with commercial sector and residential sector accounting for 9% and 24% respectively. Due to rapid income and population growth in India, the final energy demand of the Indian building sector will eventually grow over five times by the end of this century. Overall building sector plays a key role in the future energy demand as well as greenhouse gas emissions.

In tropical countries like India, heat transfer from the exterior environment to the conditioned internal environment through building components significantly adds to the cooling load of HVAC system. Several studies have found that residential air conditioning (AC) accounts for 20-40% of the annual electricity consumption of urban dwellings, and it is expected to triple by 2030. It is expected that the overall penetration of room air conditioners in the sector will increase from 8 percent in 2017-18 to 12 percent by 2022-23 and 21 percent by 2027-28, respectively. As per report by Central Electricity Authority's 'Year End Review 2012-13, HVAC accounts for about 52% of total energy consumption in commercial sector.

With the development of energy efficient building systems, it has become very important to characterise various components as well as materials used for construction of buildings at the design phase itself. To evaluate the thermal properties of materials for determining the energy efficiency, it is imperative to quantify the heat transfer rates through building materials. The most popular worldwide accepted standard procedure is to determine the overall heat transfer coefficient. which account all the modes of heat transfer i.e., conduction, convection and radiation. For experimental evaluation of overall heat transfer coefficient under different environmental conditions, Guarded Hot Box Test Facility is used in accordance to British Standards BS EN ISO 8990:1996.

Computer aided simulation programs are normally used to analyse the building in terms of energy efficiency, thermal comfort and hygro-thermal performance. Results from these simulation tools can be used to predict the thermal performance of buildings by studying the indoor comfort level of the rooms of the building. Moreover, one can also determine amount of heating/cooling loads that would be imposed on the HVAC system to be installed for the given building morphology. These simulation programs incorporate computation techniques such as finite difference, finite element, state space and transfer functions for building load and energy calculations.

Commercially available simulation engine includes TRANSYS, EnergyPlus based DesignBuilder, eQUEST, Environmental System Performance research (ESP-r). TRANSYS have a modular approach to solve systems. DesignBuilder uses dynamic simulation engine tool EnergyPlus which incorporates Finite difference method at its core. On the other hand, software such as ECOTECT uses Chartered Institute of Building Services Engineers (CIBSE) Steady State Method (ECOTECT). eQUEST uses Department of Energy (DOE-2) based simulation engine.

The thermos-physical properties of the building component material, the overall heat transfer coefficient of the building component play a key role in energy simulation. The typical thermal properties of common building and insulating materials as given in *ECBC 2017*, are ultimately derived from *ASHARE Handbook of Fundamentals*. Moreover, during the course of the simulation the interior and exterior air film resistance are calculated using either ASHARE standards or CIBSE guide or DOE 2 library. Therefore, using this method while evaluating the cooling load of a building situated in tropical climate such as India may not be a true representation of the actual climatic zone in which the building is located. It is felt that using the overall transfer coefficient of the building components obtained from Guarded Hot Box testing directly as input to the simulation software would result in more accurate and climate specific results pertaining to the local climatic zone.

Methodology of study:

In one scenario under the ambit of the present study, the thermos-physical properties of building materials were inherited into the simulation software from ASHRAE Handbook of fundamentals while in another scenario, the overall heat transfer as determined from guarded hot box testing was directly impregnated into to the simulation software. The rest of the input parameters such as weather data, latitude and longitude of location, plug loads, the HVAC schedules, the occupancy pattern etc. were kept constant in both the cases. The cooling load / cooling energy consumption was compared in both the cases for various orientation of the building.

For the purpose of testing of the samples, an in-house developed Guarded Hot box testing facility as per BS EN ISO 8990:1996 was extensively calibrated to quantify the various losses (Extraneous heat transfer, Flanking losses) associated with the system. The overall heat transfer coefficient of three masonry wall samples, roof sample and double glazing unit (warm-edge spacer based) were evaluated using Guarded Hot Box as per BS EN ISO 8990:1996 testing method for varying differential air temperature across the specimen. With the help of the regression plot, the U-value of these samples can be calculated for any differential air temperature suited to a particular climatic zone of India. The uncertainty analysis of the results was also performed for the test results.

The scope of research work involves the following:

(i) Identification of common building materials used for Energy Efficient Building construction.

(ii) Extensive Calibration of Guarded Hot box as per BS EN 8990-1996.

(iii) Study of the various boundary conditions applicable w.r.t. building components for measurement of U-value.

(iv) Determination of spectral properties of opaque coloured surfaces.

(v) Impact of varying air velocity on the overall heat transfer coefficient of the Masonry Wall surface.

(vi) Determination of U-value of Building envelop components like Masonry Wall, Reinforced Cement Concrete Roof and Window glazing unit using Guarded Hot Box, and Cooling load calculation for the enclosed space considered.

(vii) Identification of globally available building simulation tools, such as DesignBuilder, ECOTECT and eQUEST, which are recommended for Energy Conservation Building Code 2017 application.

(viii) Following ASHRAE 2017 Handbook, U-values of envelop components would be calculated by each of the above simulation tool, and resultant cooling load calculated thereof.

(ix) Comparison of the cooling load obtained from experimental parameter with those using DesignBuilder, ECOTECT & eQUEST. Effect of change in orientation on cooling load also studied by different simulation tools.

Results & Conclusions

In the present work, detailed calibration of the in-house developed guarded hot box was conducted to quantify the various losses associated with the test setup and later it was incorporated into the calculation procedure so that the overall heat transfer coefficient could be evaluated precisely. The thermal performance of roof and walls along with double glazing units were determined over the entire differential temperature range as experienced by the climatic zones of our country. The impact of varying air velocity on the overall heat transfer coefficient of walls were also evaluated. The overall heat transfer coefficient values were also computed numerically as per BS EN ISO 6946, and the results were compared with that obtained from testing results.

A simulation study was conducted to estimate the cooling energy consumption of single shell building using three different simulation tools. Two scenarios were considered. In one scenario, the thermos-physical properties of the building envelope components were given as input to the simulation software while in another scenario the U-values obtained experimentally were given as input to the software directly. The cooling energy consumption for both the scenarios were compared for various orientation of the building shell, such as North, East, West, South, North East, North West, South East and South West.

Following conclusions have been drawn the entire experimental and simulation work:

(a) Detailed calibration of the Guarded hot box has been conducted to quantify the various losses (extraneous heat transfer, flanking losses) associated with the testing setup which helped in accurate estimation of test results.

(b) The magnitude of extraneous heat transfer varied increased linearly with increase in differential air temperature while change in convection heat transfer coefficients seemed to have little impact on the extraneous heat transfer.

(c) The maximum fluctuation of air temperature in metering box and cold box when using 300m extruded polystyrene insulation were 0.049°C, 0.056°C and 0.076°C for δt_{air} = 40.10°C, 29.99°C and 20.16°C respectively. These values are within the prescribed limit of one percent of the air-to-air temperature difference across the specimen as per *BS EN ISO 8990:1996*.

(d) Overall heat transfer coefficients of masonry wall and roof samples made from locally available building materials were evaluated experimentally. The U-value of the samples decreased linearly with increase in differential air temperature for five-inch brick wall finished with cement plaster on both sides (Sample WI) and five-inch brick wall with cement plaster and finished with two coats of white cement primer on both sides (Sample WII). The plaster finished surface based wall has a higher absorptivity both in solar range (70.8%) and visible range (68.6%) as compared to white coloured wall (29.2% in solar range and 31.4% in visible range). Hence the U-value of Sample W1 was more than that of Sample WII. Overall heat transfer coefficient of Sample WII finished with white colour on one side and silicon based magenta coloured plastic paint (Sample WIII) was also evaluated experimentally. The U-value of the Sample WIII increased linearly with increase in differential air temperature across the specimen.

(e) Overall heat transfer coefficient of reinforced cement concrete with plaster finished with white cement primer on one side and bituminous layer on other side (Sample WIV) was evaluated experimentally. The U-value of the sample increased linearly with increase in differential air temperature across the specimen (similar to that of Sample WIII). Moreover, the U-value of the roof sample is almost double than that of the wall samples.

(f) From the regression plot of variation of overall heat transfer coefficient with respect to air temperature, the overall heat transfer coefficient of the samples can be evaluated experimentally for any particular differential air temperature as suited for any of the five climatic zones of our country.

(g) The impact of varying connective heat transfer coefficients on overall heat transfer coefficient of plastered brick wall sample.

(h) The overall heat transfer coefficient of an air-filled warm edge spacer based double glazing was evaluated experimentally and the results were compared to that of conventional aluminium spacer based double glazing system. The U-value of the sample increased linearly with increase in differential air temperature across the specimen in both the cases. A maximum reduction of 7.87% (at δt_{air} of 40ºC) and a minimum reduction of 7.06% (at δt_{air} of 20ºC) in U-value was observed while using warm-edge spacer based double glazing unit.

(i) The impact of impregnating experimentally obtained overall heat transfer coefficient values of common building components (such as wall, roof & glazings) directly into simulation software, and comparing the same with software-based results, based entirely on embedded library of materials, their properties and resultant U-value thereof have been explored. Three simulation software DesignBuilder, ECOTECT and eQUEST have been used. The cooling energy consumption in both the scenarios have been evaluated and compared. It was found that in case of DesignBuilder, the annual difference in cooling energy consumption with that of experimental one was found lowest, while it was highest in case of ECOTECT. In case of DesignBuilder, the maximum range of deviation occurs for West orientation from (-)0.30% to (+)4.03% and minimum range of deviation for South East 45°orientation from (-)0.06% to (+)1.69%. In case of ECOTECT, the maximum range of deviation occurs for South East 45° orientation from (-)9.31% to (-)5.13% and minimum range of deviation for South West 60°orientation from (-)5.96% to (-)4.81%, while ~~Lastly~~ for eQUEST, the maximum range of deviation occurs for North West 45° orientation from (+)12.70% to (+)36.63% and minimum range of deviation for South East 45° orientation from (+)03.08% to (-)02.67 %.

(j) It is therefore concluded that experimentally obtained U-values of building envelop components are preferred with DesignBuilder simulation software combination for better estimation of cooling energy requirement.

Signature of the Candidate

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