To Investigate the Influence of Building Envelope and Natural Ventilation on Thermal Heat Balance in Office Buildings in Warm and Humid Climate

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Abstract. India’s commercial building sector is witnessing robust growth. India continues to be a key growth market among global corporates and this is reflective in the steady growth in demand for prime office space. A recent trend that has been noted is the increase in demand for office spaces not just in major cities but also in smaller tier II and Tier III cities. Growth in the commercial building sector projects a rising trend of energy intensive mechanical systems in office buildings in India. The air conditioning market in India is growing at 25\% annually. This is due to the ever increasing demand to maintain thermal comfort in tropical regions. Air conditioning is one of the most energy intensive technologies which are used in buildings. As a result India is witnessing significant spike in energy demand and further widening the demand supply gap. Challenge in India is to identify passive measures in building envelope design in office buildings to reduce the cooling loads and conserve energy. This paper investigates the overall heat gain through building envelope components and natural ventilation in warm and humid climate region through experimental and simulation methods towards improved thermal environmental performance.

1. Introduction
The building sector during its construction and operations consume more than 40\% of the total energy end use worldwide [1]. The commercial building sector is expected to increase fivefold between now and 2030 in India. It is estimated that about 70\% of the commercial floor space that will exist in India in 2030 is yet to be constructed [2]. It is important for India to promote research in energy conservation during the early stages of growth in the building sector [3]. The building envelope contributes to a large extent in heat transfer in to a building and makes the indoor uncomfortable in the naturally ventilated buildings and adds to energy load in the conditioned buildings. The thermal performance of building depends on the design variables such as the dimensions of building elements and their orientation, the thermo physical properties of the building materials and also the climatic data of the reference site location. Out of the total solar radiation incident on the external layer of the roof, a part of it is absorbed by the roof and some of it is reflected back to the environment. Heat is also lost to the environment through convection and radiation from the roof’s external surface. The remaining heat is conducted into the roof raising the roof surface temperature. The inner surface of the roof transfers heat by convection and radiation to the room air, raising its temperature. Heat exchanges like
these take place through opaque building elements such as walls and roofs. Such heat transfer processes affect the indoor comfort temperature experienced by its occupants.

Providing a comfortable environment for occupants in office buildings should be a high priority without which the building will have decreased worker productivity. It is important to understand the contribution of building envelope components on thermal heat gain in buildings so that appropriate building envelope strategies can be undertaken to meet the adaptive comfort standards. Air-conditioning systems consumes the most energy of all building services, which comprises 55% of the total energy consumption in commercial buildings and has the largest potential in energy savings [2]. This paper investigates the contribution of thermal heat gain of various building envelope components and natural ventilation for an office space during a peak summer day in warm and humid climate towards prioritizing the passive strategies to be adopted. The paper also investigates the effectiveness of ventilation and its effect on cooling the thermal mass during the day. The research objectives are to use simulation methods to analyze the contribution of building envelope design and natural ventilation towards thermal heat balance in office buildings in warm and humid climate.

2. Methodology
A study was carried out in 2012-2013 on office buildings in Coastal Karnataka to understand the construction practices adopted and energy consumption scenarios. The study revealed that the majority of the buildings surveyed the building roof consisted of RCC slab and concrete block was used for masonry walls. The mean radiant temperatures remains very high during the day because of heat gains through the building envelope and to maintain thermal comfort the air conditioning systems were extensively used by the occupants. To understand heat gain through the building envelope, an office building in coastal Karnataka, India is taken for detailed analysis and demonstration. The building is six floors high and consists of various naturally ventilated and air conditioned office spaces. The study area falls under identified warm and humid region and the location of the case study is a broad representative sample of this region. The building has a narrow floor plate of 11m and the effects of natural cross ventilation can be better understood in a narrow layout. The longer axis of the building is exposed to the east and west incident solar radiation. This layout can help to determine the thermal heat gain during the heat gain conditions on a peak summer day. The reference baseline model was modelled as per the as built documentation of the reference building. Simulation software design builder has been used for the study as it has the Energyplus simulation engine developed by department of energy, USA [4], [5]. Energyplus has been validated under the comparative standard method of test for the evaluation of building energy analysis computer program BESTEST and ASHRAE Std 140.A thermal comfort survey was conducted in the reference building. As per the survey, the occupants of the fifth floor office space were found to have the maximum thermal discomfort and that office space was chosen as the baseline case to analyse thermal heat gains. Climatic analysis of warm and humid climate along coastal Karnataka revealed that March, April, and May to be warmest months. May being the most critical month in terms of percentage of office hours outside the thermal comfort zone, detailed simulations were carried on the peak summer day of that month. The results of field studies and simulation results have been analysed to study the impacts of building envelope and natural ventilation on thermal heat gain.

3. Climate Study
Coastal Karnataka has warm and humid climate with intense radiation on clear days. In summer, temperatures can reach as high as 30-35°C during the day and 25-30°C at night. In winter, the maximum temperature is between 25°C to 30°C during the day and 20°C to 25°C at night. The relative humidity is generally very high, about 70-90% throughout the year. Precipitation is also high, being about 1200 mm per year [6]. The wind is generally along southwest to northeast direction with speeds ranging from extremely low to very high. The typical Meteorological weather data for the reference site location is shown in Fig. 1.
Figure 1. Climate Data of the reference site location

4. Reference Building Data
The reference building is located in Manipal in Coastal Karnataka, India as indicated in Fig.2. The details of the reference building details and also the building envelope details is listed in Table 1 and Table 2. The Building floor to floor height is 3.2 m height The window wall ratio of the simulated fifth floor office space is 40% on east side, 22.5% on south, 30% on the west side. The north side of the office space is blocked because of another office space. The window sill height is 0.9m from the floor.

Table 1. Reference building details & operation schedule

| Building Information | Details                          |
|----------------------|----------------------------------|
| Location             | 13°20'58.5"N 74°47'14.8"E        |
| Building Floor Plate | 40m long, 11m wide               |
| Building Orientation | East                             |
| Office Schedule      | 8 AM to 6 PM (6 days a week)     |
| Occupancy            | 1 person per 9 m²                |
| Lighting Power Density | 9.5 W/m²                        |

Table 2. Building Envelope Details

| Building Component | Details                                                                 |
|--------------------|-------------------------------------------------------------------------|
| Wall               | 200mm thick masonry wall + 15mm cement plaster on the internal and external surfaces |
| Roof               | 150mm thick reinforced concrete slab                                     |
| Floor              | 150mm thick reinforced concrete slab                                     |
Surface | Cream color interior paint, light brown color exterior paint  
Window type | Clear Glass with 4 mm thickness  
Window Frames | 100 mm steel  

5. Simulation and Data Analysis
The roof of the buildings is constructed using 150 mm Reinforced cement concrete roof with 12mm plaster on both sides. The calculated u-value from the thermo physical properties of the roof is listed in table 3. The Masonry wall is 200mm concrete block with 15mm cement plaster on both sides. These data as per the as built documentation has been used as a input condition for the energyplus model.

| Description of the roof | Conductivity W/mK | Density K/m³ | Specific heat J/Kg°K | U Value W/m²K |
|-------------------------|------------------|-------------|----------------------|--------------|
| Baseline Case 1 : 150 mm RCC slab with 12mm plaster on both sides | 2.864 |
| 1. 12 mm Cement Plaster | 0.721 | 1762 | 0.84 |
| 2. 150mm RC slab | 1.580 | 2288 | 0.88 |
| 3. 12 mm Cement Plaster | 0.721 | 1762 | 0.84 |

The heat balance through the roofs and walls is shown in Fig. 3. The surface temperature of the inside and the outside surface of the roof is shown in Fig. 4. Solar heat gains through the windows and heat losses due to natural ventilation are shown in Fig. 5.
6. Discussions on simulation results

The simulation results show that the heat gain through the roof increases the most between 2pm and 6 pm during office hours due to the high U value of 2.864 W/m²K of the widely used roof construction practices in the region. For the reference office space the heat balance through the roof is 4.97 KW at 2pm and 6.83 KW at 6 pm during the peak summer day. Heat gain through the roof elevates ceiling surface temperature and causes radiant heat load on the occupants. The solar gains through the exterior windows are the most during the morning hours because of exposed east openings. The solar gains through the window openings is 9.33 kW at 8 AM, reduces to 3.26 kW during noon and increases again to 5.95 kW at 4 PM due to west openings. The day time ventilation has a beneficial cooling effect during the office hours. The walls do not contribute significantly to heat gain during the office hours because of the time lag and the thermal mass providing a heat sink during the working day. In the conventional roof the temperature amplitude ratio of the outside surface temperature and the
inside surface temperature is low contributing to internal heat gains. The roof is the most exposed to impacts of solar radiation, as it receives sunlight for practically the whole of the day and in the tropics the angle of incidence is close to the normal in the hotter parts of the day. The results can be summarized as follows:

- The roof contributes the most to heat gain through the building envelope due to exposed solar radiation. It is very essential to construct roof with good insulation and layers of different thermo physical properties.
- The opaque parts of the building envelope should be constructed with an improved temperature amplitude ratio which specifies the time it takes for a temperature rise on the outside of the building component to pass on the inside.
- A building envelope optimized with low U-value and openings to allow natural ventilation provides good protection against overheating in summer.

7. Conclusions
India’s commercial building sector is expected to grow fivefold between now and 2030. To reduce the dependence on fossil fuels it is essential to reduce the use of energy intensive systems in the building sector. Analysis of the building thermal performance is investigated in this paper with simulation approach to understand the source of the most significant heat gain in warm and humid climatic region which contributes to energy loads in buildings. This can help in developing specific strategies in the design of building envelope components to improve heat balance in buildings, conserve energy and contribute towards mitigation of climate change. Further research can be conducted on the various types roof and wall construction assemblies to optimize thermal heat balance in warm and humid climatic regions.

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