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Exploring impact of opaque building envelope components on thermal and energy performance of houses in lower western Himalayans for optimal selection

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ABSTRACT

The building envelope plays crucial role of both protecting its occupants from external environment and controlling indoor environment to maintain indoor thermal comfort condition and energy-efficiency. The main aim of present day building design should be eliminating the need for mechanical heating and cooling equipment wherever possible. A novel approach is applied in this study to find empirical data through field experimentation conducted in the study area to derive the proposal suitable for the buildings of that location. Field studies of naturally ventilated residential buildings were conducted at Mandi town, located in western Himalayan Indian state of Himachal Pradesh with composite climate, during winter and summer months of 2013 and 2014 to assess the impact of opaque building envelope materials on indoor thermal condition. Further, energy performance of residential buildings is analyzed using e-QUEST building-energy simulation tool to find the potential annual energy consumption and energy savings during the functioning of buildings. The study found that the use of thermal mass in wall and roof construction can maintain indoor thermal comfort during winter and summer months in composite climate. The study also found that the application of wall and roof insulation can maintain indoor thermal comfort condition in modern houses during winters and summers and can also improve energy-efficiency of partially and fully air-conditioned buildings significantly – the heating, cooling and mechanical ventilation load can be reduced up to 60%, 40% and 40% respectively; the peak energy demand during summer and winter can also be reduced. Further research area is also identified.

1. Introduction

The use of materials and construction technique in building envelope widely differs between developed countries like Europe, USA, and developing tropical countries like India [1]. In almost all parts of the world including India, buildings used to be constructed using local materials to maximize comfort considering local climate. In warm-humid areas larger openings were provided in the buildings for natural ventilation to result convective cooling. Buildings were constructed with heavy walls and roofs having high thermal mass in hot-dry areas and the construction practice is still being used in many parts of the world as well as in hot-dry climate of India. Thermal mass of the building envelope materials was also utilized in cold and moderate climate for their capacitive insulation. But, due to modernization and faster urbanization rate, the force of market economy and electronic media along with a change in socio-cultural outlook have made people accepting the gradual change in the building design and construction materials even in remote rural and semi-urban places [2]. Also, the advancement in building science has brought in new construction materials and technology in the market, and has made mechanical heating and cooling of buildings much easier. Present day construction practices utilize modern standardized building materials and construction methods that dominate the market in the country [2,3].

The building envelope, also called building enclosure, shell or fabric, is the boundary or physical separator between un-conditioned or conditioned interior of a building and the outdoor environment. Building envelope, consisting of external walls, roofs, ceilings, floors, windows, and doors, regulates the flow of energy between exterior and interior of the building and plays a crucial role of both protecting building occupants from external environment by providing them comfort and by enhancing their productivity. Building envelope also plays a critical role in determining the amount of energy a building will use during its operation. The energy costs associated with the production and transportation and overall environmental life-cycle impacts of

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different envelope materials vary greatly [1].

Local climate and function of the building are the two foremost important parameters affecting building envelope design. The thermal loads of residential buildings are primarily external (from sun). The efficiency of building envelope design is significantly affected by the building configuration and footprint also. India is divided into five major climatic zones as per the *National Building Code of India 2005* (NBC) namely: 1) hot-dry; 2) warm-humid; 3) temperate; 4) composite; and 5) cold climates – all of which suggest different design strategies. Acknowledging this, the *Bureau of Indian Standards* (BIS) has published a series of codes [5,6] addressing thermal performance and energy efficiency issues of buildings and recommended broad design guidelines for different climatic regions in India. Further, to mitigate the implication of growth in building sector on energy resources of India, Government of India (GOI) has introduced the *Energy Conservation Building Code* (ECBC) in 2007 and made further addition in the Code in 2008 to provide minimum requirements for energy-efficient design and construction of buildings and their systems [7].

The principal aim of building design and construction at present should be a judicious selection of building envelope materials to eliminate the need for costly mechanical heating and cooling wherever possible. Most of the earlier studies on thermal performance of building envelope materials are based on the laboratory experiment and numerical analysis, which is useful to understand the thermal properties of the materials used. Many researchers have suggested the need for field experiment. Hence, in the present study a novel approach is adopted to find empirical data on thermal performance of houses by conducting field-experimentation of actual buildings located in the study area, which should help to derive suitable proposals for the buildings of that geo-climatic location. This paper will present the study about the effect of various building envelope materials, used in walls and roofs of naturally ventilated residential buildings at Mandi town in Himachal Pradesh (H.P.) located in the lower western Himalayan region of India with 'composite' climate, on the indoor thermal condition of the houses during winter and summer months through field-experimentation. Further, the energy performance of the houses constructed with conventional practice and with wall and roof insulation is evaluated by the e-QUEST [8] building energy simulation tool to find the potential annual energy consumption and energy savings during the functioning of buildings. The result of the analysis is used to suggest appropriate building envelope materials for residential buildings at Mandi, having composite climate, to develop and maintain sustainable built environment.

2. Building Envelope Performance – brief literature review

Many researchers have done studies on thermal and energy performance of building envelope materials and the whole buildings using building energy simulation tool and analytical modeling [9–13]. As per ASHRAE Standard 55 [14,15], ceiling temperature is not allowed to be more than 5 °C warmer, but wall surface temperature may be up to 23 °C warmer than the other surfaces to prevent radiant asymmetry for indoor thermal comfort. Too cool or too warm floorings can also cause discomfort, hence, ASHRAE Standard 55 [14,15] also recommends that floor surface temperatures stay in the range of 19–29 °C in room spaces for thermal comfort where occupants will be wearing light-weight shoes.

Chandra [16] described 'thermal performance index' (TPI) of wall and roof sections, developed from peak heat gain for conditioned buildings and inside surface temperature for unconditioned buildings, based on the study conducted in hot-dry climate of India. The TPI values for typical wall and roof sections, calculated by Chandra [16], are adopted and published by the BIS in the code BIS SP: 41 (S&T) [6]. Suman and Saxena [17] calculated the effect of roof treatment on thermal performance of buildings under hot conditions based on the unsteady state harmonic method. Kumar and Kaushik [18] have assessed the performance of green roof and shading for thermal protection of buildings in hot climate. Chel and Tiwari [19] have done the thermal performance and embodied energy analysis of a passive mud house with vaulted roof located in Delhi, having composite climate. Kabre [20] proposed a thermal performance index for dwelling roofs in warm-humid climate based on the study done at Trivandrum and Pondicherry in India. Researchers [21] have suggested that room performance descriptions may be interpreted as "high-level" behavioral properties, whereas building component properties may be interpreted as "low-level" performance indicators.

3. Methodology of the study

In India, few field-studies on thermal performance of residential buildings [2,3,22–24] and office buildings [25,26] are reported till date. In this present study, the field-survey was conducted at Mandi during winter months of December, 2013 to February, 2014 and summer months of May and June, 2014 to find out the thermal performance of the building envelope materials commonly used for house construction and their impact on indoor thermal environment of the houses. Fifty naturally ventilated houses were selected representing both present day houses designed by architects and the traditional dwellings. The limited accessibility to the residences and availability of resources was a hindrance in the study.

3.1. Location and climate

The study area is located at Mandi town (31.32° North latitude, 76.53° East longitude, and average altitude of 850 m above mean sea level), the headquarter of Mandi district in the western Himalayan Indian state of Himachal Pradesh. Mandi has 'composite' climate as per the Indian climate classification based on NBC [4] with hot summers and cold winters. Table 1 shows the average climatic data of Mandi town (weather station is at Sundernagar town which adjoins Mandi). The intensity of solar radiation, received by Mandi town, ranges from 3.45 kW h/m^2/day in January to 7.42 kW h/m^2/day in May-June [27].

Table 1
Average climatic data for Mandi town (H.P.).[a]

Month	Mean temperature (°C)			Mean total rainfall (mm)
	Daily minimum	Daily maximum	Average	
January	3.0	17.3	10.2	56.3
February	5.0	18.9	12.0	81.5
March	8.9	23.5	16.2	88.6
April	12.6	28.5	20.6	45.8
May	16.9	33.2	25.1	79.1
June	20.0	34.3	27.2	197.9
July	21.7	30.7	26.2	404.9
August	21.5	29.8	25.7	333.9
September	18.6	30.2	24.4	132.4
October	11.8	28.4	20.1	34.3
November	6.3	23.8	15.1	20.7
December	3.6	18.9	11.3	22.4
Annual	12.4	26.4	19.4	1497.7

[a] Source: Indian Meteorological Department, Shimla [28].