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Performance assessment of a passive solar building for thermal comfort and energy saving in a hilly terrain of India

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ABSTRACT

The construction of passive solar buildings in government sector has been made mandatory in the western Himalayan Indian state of Himachal Pradesh. A number of passive solar buildings are constructed in the state to reduce dependence on conventional energy sources. In this study, results of a constructed passive solar building in Mandi town are presented. The passive solar architectural design features in the building include: modification of floor plans, fenestration and external shading design, providing solar air-heating panels, creating cross-ventilation, warm air circulation during winters and appropriate glazing for fenestrations. The main objective was to maintain indoor-thermal comfort and reduce annual energy consumption. Thermal comfort conditions in the building are analysed through a field survey as per ASHRAE Standard 55 protocols. The impact of passive solar features on heating, cooling and energy savings is evaluated using e-Quest simulation software. The indoor thermal comfort operative temperature in winters is found to range between 15.0 °C and 17.7 °C. The space heating, cooling and mechanical ventilation loads and total annual energy consumption are found to be reduced due to passive solar design features in the building. Follow-up research areas are also identified.

1. Introduction

The use of energy from Sun was in practice to keep houses warm in winters for centuries all over the world [1,2]. The utilisation of southern mountain slopes to establish villages is common in the most of hilly regions. The traditional houses, temple complexes, big buildings were designed in India, as per path of the Sun to use natural day light, avoid summer heat and capture heat during winters. However, with the advent of mechanical heating, cooling and modernisation, this age long practice has been forgotten. There has been renewed interest in passive solar architecture during recent years with the design and construction of demonstrative passive solar buildings in a number of countries. The solar-passive design approach has been promoted in a series of publications since 1950s [3,4]. Olgyay [5] and Givoni [6] have developed bioclimatic charts and Koenigsberger et al. [7] have developed 'Mahoney tables' and passive design guidelines from the analysis of local climatic data. The computer aided climate analysis tools were developed by Milne et al. [8] to formulate architectural design criteria for buildings. The energy crisis of 1970s and the global environmental concerns of the 1990s made people aware about the need to reduce fossil fuel consumption which will lead to reduction in environmental pollution and global warming. The scientific basis for solar passive design is developed from a combination of local climate, solar heat gain, heat loss, building materials and human thermal comfort [9]. This approach is also known as 'bio-climatic design' of buildings [10]. Proper solar-orientation of building on site according to the prevailing climate, architectural design and selection of building-materials for construction, placement of windows with glazing and shading elements and integration of thermal mass can greatly help in achieving energy-efficiency in buildings by reducing energy-consumption of the building and provide thermal comfort, health benefits to occupants almost throughout the year [11,12].

Buildings consume considerable energy both during its construction and its operation; hence, they are a great source of CO_2 emissions to the atmosphere. The energy consumption in the building sector is expected to increase further with the improvements in living standards and increase in world population [13]. In India, building sector consumes about 33% of electricity out of which commercial sector consumes 8% whereas residential sector accounts for 25% [14]. Understanding the implication of this situation on energy resources of India, Government of India has enacted the Energy Conservation Building Code (ECBC) in 2007 and made further

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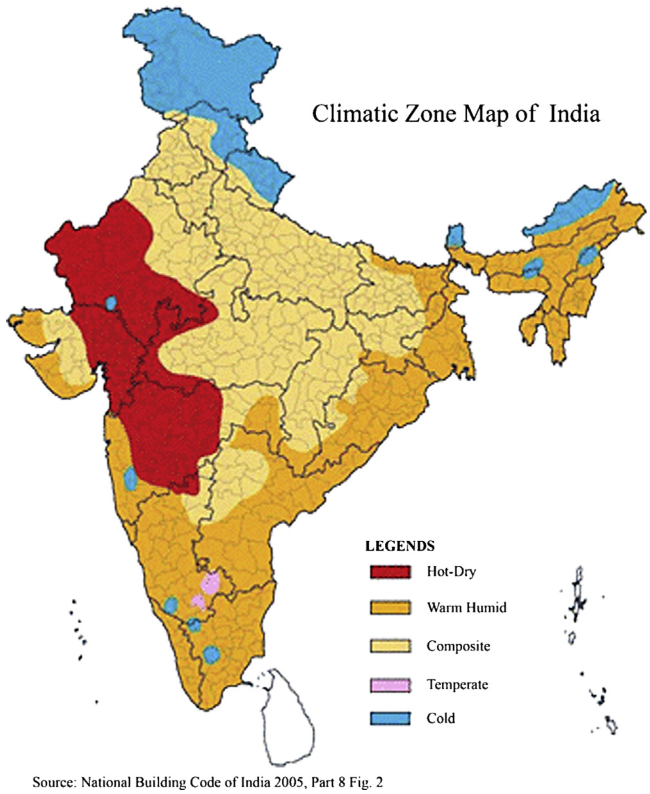

Fig. 1. Climatic zone map of India (*Source*: National Building Code of India 2005, Part 8 Fig. 2).

addition in the ECBC in 2008 to provide minimum requirements for energy-efficient design, construction of buildings and their systems [13]. It is estimated that the nationwide mandatory enforcement of the ECBC will yield annual savings of approximately 1.7 billion kW h [14].

As per the National Building Code of India (NBC) [15], India is divided into five climatic zones namely hot-dry, warm-humid, composite, temperate, and cold, as shown in Fig. 1, based on the studies carried out by Bansal and Minke [16]. Under the 'solar passive building programme' launched by the Ministry of New and Renewable Energy (MNRE), Government of India, detailed solar passive design techniques and guidelines for various climatic zones have been prepared [17]. A number of solar passive buildings were constructed in different parts of the country including the western Himalayan Indian state of Himachal Pradesh. Some of the buildings with solar passive design features in different climatic zones of India are also documented by MNRE [18].

Himachal Pradesh experiences winters for almost six months from October to March requiring space heating which is met by using fuel wood in rural areas and coal, kerosene, LPG and electricity in urban areas. The state government has to provide wood on highly subsidised rates to tribal and remote areas in high altitude regions by importing from lower regions of the country. This necessitates the use of solar passive heating features in buildings in high altitude regions of the state to reduce pressure on conventional fuel sources and forests.

Keeping in view the harsh winter climatic conditions, Himachal Pradesh (H.P.) government took an important policy decision in 1994 vide which design and construction of all government/semi-government buildings incorporating 'solar passive features' were made mandatory to maintain indoor-thermal comfort by reducing dependence on conventional fuels for space heating in winters. H.P is the first and only state in India to take such a policy decision with long term benefits for the state. Prior to enforcing this decision a 'Solar House Action Plan' for Himachal Pradesh was formulated and 25 solar passive buildings were designed and constructed for creating awareness among people about the benefits of this technology [19]. This plan was implemented in the state by H.P. State Council for Science, Technology and Environment in co-ordination with state housing agencies and MNRE. One of the authors (S.S. Chandel) had co-ordinated this 'Solar House Action Plan'. Besides design and construction of solar passive buildings, the programme included extensive training of architects and engineers in solar architecture and solar passive technologies.A large number of architects and engineers in the state has been trained. The programme also included modifying building byelaws to incorporate solar passive features in building design, which was done in 2009 by the Town & Country Planning Department of the state [20], with inputs provided under the 'Solar House Action Plan'. The amended building bye-laws have been made mandatory for all future buildings like offices, hotels, industries and commercial buildings to be constructed in the state both in government and private sector. More than 200 solar passive buildings, including schools and teacher hostels in rural areas, have been constructed in the state [21]. The performance evaluation of the first constructed solar passive building—a Bank in Shimla, Himachal Pradesh, was carried out by Chandel and Aggarwal [2], which has shown substantial energy saving due to the integration of solar passive features. The parameters which greatly influence building performance are building orientation, materials of construction, use of natural ventilation, design of fenestration that include window glazing type and opening area, shading devices and their position, use of day-lighting, solar-passive cooling and heating strategies.

Under the 'Solar House Action Plan', the Forensic Science office cum Laboratory building was planned to be constructed at Mandi town of Himachal Pradesh, The authors provided the solar passive design recommendations for the building under a consultancy project [22]. In the present study, performance assessment of the constructed building is done for thermal comfort and energy-efficiency.

The paper is organised as follows: in Section 2, location and climatic conditions of the project area are described; thermal comfort criteria for the naturally ventilated building is presented in Section 3; Section 4 highlights the passive solar architectural design recommendations; in Section 5, methodology for indoor thermal comfort field-survey and for building energy-efficiency simulation is presented; the results are presented and discussed in Section 6, followed by conclusion in Section 7.

2. Location of the building and climate description

The state of Himachal Pradesh (H.P.) is located from 30.38° to 33.2° North latitudes and 75.77° to 79.07° East longitudes, in the western Himalayas, covering a geographical area of 55,673 km^2. The altitude of the state ranges from 350 m to 6975 m above mean sea level. The state is divided into 12 districts surrounded by Jammu and Kashmir in the North, Tibet in the Northeast, Uttarakhand in East/Southeast, Haryana in South, and Punjab in Southwest/West. The state is divided into 3 major climatic zones based on altitude and related biogeography. Parts of Una, Bilaspur, Hamirpur, Mandi, Kangra, Solan and Sirmaur districts in the western and southern regions, lie below 1000 m, have tropical to subtropical climate. Some parts of Solan, Sirmaur, Mandi, Chamba and Shimla districts, with altitude ranging between 1000 and 3500 m, have climatic conditions varying from subtropical to wet-temperate. Lahaul-Spiti, Kullu and Kinnaur districts, at altitude range between 3500 and 6700 m, are part of the dry-temperate, subalpine and alpine zones with very sparse rainfall [23].