



Field study of the building physics properties of common building types in the Inner Himalayan valleys of Bhutan



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ABSTRACT

Traditionally, buildings in the Inner Himalayan valleys of Bhutan were constructed from rammed earth in the western regions and quarry stone in the central and eastern regions. Whilst basic architectural design elements have been retained, the construction methods have however changed over recent decades alongside expectations for indoor thermal comfort. Nevertheless, despite the need for space heating, thermal building performance remains largely unknown. Furthermore, no dedicated climate data is available for building performance assessments. This paper establishes such climatological information for the capital Thimphu and presents an investigation of building physics properties of traditional and contemporary building types. In a one month field study 10 buildings were surveyed, looking at building air tightness, indoor climate, wall U-values and water absorption of typical wall construction materials. The findings highlight comparably high wall U-values of 1.0 to 1.5 W/m²K for both current and historic constructions. Furthermore, air tightness tests show that, due to poorly sealed joints between construction elements, windows and doors, many buildings have high infiltration rates, reaching up to 5 air changes per hour. However, the results also indicate an indoor climate moderating effect of more traditional earth construction techniques. Based on these survey findings basic improvements are being suggested.

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Introduction

Situated in the Eastern Himalayas the Kingdom of Bhutan is characterised by three distinct climates: the alpine conditions of the High Himalayas to the North, the more temperate highland climate of the Inner Himalayas in the centre of the country and humid subtropical conditions to the South (Dujardin, 1994). Up to the late 1950s/early 1960s when the country started opening up economically to the outside world, the Bhutanese society was essentially a rural subsistence economy engaged in the sectors agriculture, forestry and livestock (Ura, 1994). This also reflected in the way settlements were laid out and buildings were constructed. Traditionally, villages in the Inner Himalayan valleys, which are the focus of this study, were built at the base of mountain slopes overlooking fields in a river valley with a fast-flowing mountain stream (Nock, 1995). Villages typically consisted of a number of dispersed farmhouses often loosely grouped around a lhakhang (temple) or located in close proximity to a dzong (fortress) built at a strategic point of the valley

(Watson and Bertaud, 1976; DoWHR, 1993; Dujardin, 1994; Nock, 1995). However, depending on topography and the availability of arable land, dispersed settlements of isolated farmsteads were also common (DoWHR, 1993). Whilst these village layouts are still to be found today in the majority of valleys in the Inner Himalayan region of Bhutan, new urban settlements no longer follow this pattern (Walcott, 2009). The capital city Thimphu for example now covers large parts of the Thimphu valley, replacing the farmland that was previously present there.

Due to its history Bhutan is essentially a country without a long standing urban tradition (Dujardin, 1994; Herrle et al., 2014), with the two major conurbations of the country, Thimphu in the western Bhutan region and Phuntsholing to the south on the Indian border, having experienced rapid growth over recent decades as a result of large migration pressures from the countryside for employment opportunities (Walcott, 2009). This has created new challenges not only in terms of societal development but also for the construction sector as the requirements for buildings and the surrounding infrastructure have changed alongside these developments. In addition, the introduction of new construction methods and materials previously unknown to the country have played a significant role in the changes that have happened to the construction sector (DoWHR, 1993; Herrle et al., 2014).

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Residential and commercial building types in the Inner Himalayas of Bhutan

Traditional village farmhouse buildings in the Inner Himalayan valleys of Bhutan follow a common archetype, albeit with local variations in material use and design details (DoWHR, 1993; Dujardin, 1994). Farmhouses typically have two to three floors and are constructed of the locally available materials earth, quarry stone and timber (Nock, 1995; Herrle et al., 2014). As can be seen in Fig. 1, the ground floor, which was traditionally used as cattle barn, always consists of solid walls (DoWHR, 1993). The upper floors were used for storage and residential purposes (DoWHR, 1993). Where the building has three floors, the middle floor is typically also made entirely of solid walls (MoWHS and CIT, 2010). Depending on the total amount of floors the upper one or, rarely, two floors partly consist of solid walls and partly of a timber-frame structure usually with mud plastered infills on a bamboo grid, the so-called *ekra* (DoWHR, 1993; MoWHS, 2014). This timber-frame structure which is termed *rabse* is cantilevered about 15 cm beyond the main structural walls, which in the western parts of Bhutan are usually made out of about 60 cm to 100 cm thick rammed earth on a quarry stone foundation protruding about 40 to 80 cm above ground level and in the central and eastern regions out of quarry stones with mud mortar (DoWHR, 1993; Sethna, 2008; MoWHS, 2014). Whilst the solid walls often hardly contain any openings at all the *rabse* element is characterised by elaborate window openings. As seen in Fig. 1 the roof is an open structure on timber stilts built over a flat roof with the space in-between traditionally being used for drying and storing crops and hay for the livestock as well as for storing equipment (Watson and Bertaud, 1976; DoWHR, 1993; Nock, 1995; Lang et al., 2013). This roof structure which is sometimes described as an adaptation of the flat roofs found on the Tibetan Plateau to suit the monsoonal climate of Bhutan (Nock, 1995; MoWHS and CIT, 2010) has a slope of about 15° and was formerly covered with wood shingles secured by stones but now, for maintenance reasons, more often with imported corrugated steel sheets. The eaves are rather broad on all elevations in order to prevent rain from causing damage to the walls which, as described above, always contain some fraction of clay (MoWHS and CIT, 2010).

Traditional farmhouses built prior to the 1960s when the modern economic development of the country started (Ura, 1994) are now rare in the Thimphu valley where the study presented in this paper was conducted. Already in the 1990s the number of old buildings was deemed insufficient to give reliable clues on the historic local particularities and design features specific to the Thimphu valley (DoWHR, 1993).



Fig. 1. Traditional farmhouse constructed with rammed earth in the Paro valley in the western part of Bhutan, however with some modifications to the traditional façade structure and roofing.

However, what still remains today clearly follows the house archetype design with rammed earth walls as described above. A detailed architectural survey of some of these buildings was undertaken in 2009 in the Thimphu area with 4 houses in the village of Babesa and 1 in Changjiji having been extensively surveyed and documented with a set of detailed drawings highlighting their architectural features (MoWHS and CIT, 2010).

Buildings constructed in the Thimphu valley since the city was made capital of Bhutan no longer follow the traditional space usage patterns. New usages emerged as a result of the growing demand for central administration and the need to cater for private businesses that developed alongside government administration (Dujardin, 1994). The main new house archetypes span purpose built governmental office buildings, single family homes, multi-storey apartment buildings with and without business units/shops on the bottom floors and purpose built hotels to cater for international tourists. Whilst traditional buildings were constructed on the basis of mutual help from the village community under guidance of skilled craftsmen (Watson and Bertaud, 1976; Dujardin, 1994; Nock, 1995; Bajaj, 2014), these new buildings are increasingly being designed by architects and civil engineers (DoWHR, 1993; Dujardin, 1994). Until recently these architects and civil engineers were exclusively trained in foreign countries, mostly India, and the design was often undertaken and supervised by government bodies employing them. An example of this is the two-storey apartment building shown in the foreground of Fig. 2. This was completed in 2001 as part of a social housing programme.

The most common contemporary construction method for buildings of all types in Bhutan is a reinforced concrete frame structure with single leaf brick infills (Nock, 1995; Lang et al., 2013; Herrle et al., 2014). The walls are usually plastered with cement render and have a thickness of typically around 25 cm including rendering. Windows are made directly on site and are usually single glazed with aluminium or, more commonly, wooden frames. Structural design and material specifications are in compliance with Indian quality standards and building codes which means that there are some similarities with Indian buildings (Dujardin, 1994; Lang et al., 2013). However, according to the 'Bhutan Building Rules 2002' (DoUDH, 2002), architectural appearance and features such as the external façade design and roof structure should comply with national design guidelines as originally laid out in the 'Traditional Architecture Guidelines' (DoUDH, 1993). In 2014 these were superseded by the 'Bhutanese Architecture Guidelines' (MoWHS, 2014) which give guidance on the application as well as the proportions and the sizing of design elements that follow traditional Bhutanese architectural patterns. Further to this, recommendations are provided



Fig. 2. Government constructed apartment buildings in Thimphu in reinforced concrete frame construction with brick infills and concrete formwork for architectural design elements.

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