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Straw bale construction in northern China – Analysis of existing practices and recommendations for future development

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ABSTRACT

Straw bale buildings in China have been mainly limited to rural farm houses and self-builders. An expansion of straw-bale construction into main-stream medium-rise buildings has the potential to make a significant contribution to the reduction of both embodied and operational carbon in China as well as removing a major source of pollution. As a response, there has been the construction of straw bale buildings, however these buildings have several issues, resulting in the limited adoption of the technology.

This paper makes recommendations for future straw bale design in northern China based on an inspection of existing buildings. The issues identified with existing construction details were subjected to computational simulation analysis which identified shortcomings in existing practice and proposes revisions to design detail in order to accommodate the environmental conditions in northern China. The paper provides a unique insight into current straw bale practice in northern China and proposes a practical and environmentally sound solution to the pollution crisis in this region.

1. Introduction

The Chinese government has set up a carbon reduction target of 40–45% of each unit GDP by 2020 with reference to the 2005 level [1]. As the building industry contributes 40–50% of greenhouse gas emissions (GHG) globally [2], it is essential that this industry makes a substantial contribution to the reduction of GHG emissions. The design and construction of buildings in China are informed by five climate regions differentiated by the climatic characteristics of the regions (Fig. 1). The climatic regions are described and the design of buildings is regulated by a national code for thermal designs of civil buildings [3]. The regulations include a specification for the u-values of building envelopes ranging from 0.4 to 0.7 W/m^2K, depending on the number of stories in the building and the particular climate regions in which the construction site is located.

The health and welfare problems caused by air pollution within the severe cold regions and cold regions of China are exacerbated by the present approach to the disposal of agricultural waste which involves burning straw in the fields [4]. This has been a strong motivation for the expansion of the use of straw within the building industry. The use of straw bales in the building industry would contribute to harmless disposal of straw and would provide an energy efficient alternative to the current building types. Straw bale buildings use bales of straw to form building envelopes, and the straw used in the construction is commonly wheat, oats or rice straw [5].

The use of straw bale construction to replace building envelopes can deliver not only improved thermal insulation, but can also contribute to China's carbon reduction targets through lower emissions in the construction phase of a building. A typical 16 kg wheat straw bale can sequester 32 kg CO_2 through photosynthesis [6]. Evidence for a reduction of operational energy through the improved thermal envelope delivered by straw bales can be taken from the Low Impact Living Affordable Community (LILAC) project in UK. A typical flat in the LILAC project has a heating energy use of 35.73 kWh/m^2/year [7] and this compares with average space-heating demand of existing housing stock of 140 kWh/m^2/year [8].

The first use of straw bales as a construction material was in Nebraska in the US, where they were used because of the unavailability of more traditional materials such as bricks and timber. This was enabled by the invention of mechanized baling machines in the late 19th century [5]. The advent of the railways gave access to mass produce building materials and the system lost popularity by the 1920s. Modern straw bale construction was reintroduced in the western USA in 1980s [9] as part of the ecological building movement. There are two distinct structural solutions for straw bale construction: Load Bearing and Infill. Load bearing straw bale buildings use straw bales and a render layer to carry the vertical load of the building whereas the infill straw bale walling acts as an insulation layer within a separate structural system

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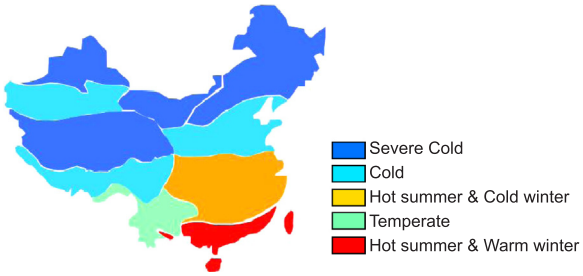

Fig. 1. Climatic regionalization in the GB50178-93.(reproduced from [3]).

[10]. The building types have historically mainly been constructed and occupied by self-builders in US and European countries [5,6,11]. More recently, the construction system has been industrialized through the production of pre-fabricated structural elements in the UK [12] using straw bales within a structural timber panel and in Slovakia [13] where compressed straw is used as an insulating infill in timber framed elements. Both construction techniques use engineered timber to act as the structural element of a straw bale walling system which contains straw bales or straw stems inside a giant timber box [14]. The methods combine straw and straw bales with a quality controlled prefabricated process [15].

Straw bale buildings in China were first constructed at the turn on the last century by the Adventist Development and Relief Agency (ADRA) - a central government and local government aimed at improving the build quality of farmhouses and reducing their construction cost for local farmers with low income. Although straw bale construction techniques have been used in China for 20 years, it is not a mainstream technology and represents a very small proportion of buildings in China. Straw bale buildings have been primarily used for housing and for community centres in rural areas [16]. By the end of the project in 2006 the total number of straw bale buildings was in excess of 600 and many of these buildings are still occupied by local residents [17]. Since completion of the ADRA project, few straw bale buildings have been constructed in China. The existing straw bale buildings are mainly in the form of a brick-concrete frame construction with straw bale infill although there is one steel structure straw building built for experimental purpose [18]. Most Chinese research on straw bale construction is based on the ADRA project [16,19,20] with others discuss the application of straw bale construction in rural areas of the severe cold regions in China [21,22].

Wang [16] reviewed the ADRA project and published an energy saving ratio for the energy consumption of straw bale houses in 2005–2006 in Jiamusi. Taking into account initial construction energy input, the total energy saving ratio is over 60% and coal consumption is reduced by 50% [16]. Compared with typical farmhouse in northern China, operational heating energy of straw bale buildings can be reduced by 62–76.8% [20]. In the research, coal use of simulated straw bale building was 2.6 t less than a typical farmhouse with conventional constructions [20]. Yang et al. [19] proposed the use of straw bale construction to replace existing cob (straw and mud mixture) houses in northeast China, concluding that in-fill construction is the most suitable type of straw bale construction for the regions. The conclusions are mostly based on interviews with local residents and reviews of other research. As a result, the research may only be relevant to straw bale construction for the ADRA project in Jiamusi rather than being generally applicable to straw bale construction in China. Developed from previous research on the ADRA project, Liu [22] discusses the applicability of straw bale construction in northern China, stating that straw bale construction has superior thermal properties and affordability when compared with more traditional construction systems in the regions [22]. The construction cost of straw bale building was 300 ¥/m^2 comparing to 400 ¥/m^2 for the construction cost of a typical farmhouse in China in 2005 [20]. Traditional wall construction of typical farm houses in the northern regions do not contain any thermal insulation materials [22]. Compared to traditional brick walling construction systems used for farmhouses, straw bale wall construction is considerably cheaper and has a significantly better thermal performance. Following the ADRA project, the construction method and the connection design of a steel frame with a straw bale infill was investigated by Jilin Jianzhu University in 2010 [18]. While this research demonstrated an improvement in straw bale building design, there has been no further application of these construction methods and designs, and it is not representative of the Chinese state of the art.

The aim of the paper is to provide an understanding of the state of existing straw bale construction in the ADRA project and to make recommendations for further straw bale construction in the northern China. The objectives of the research involved the evaluation of existing straw bale buildings of the ADRA project in Jiamusi, identifying and understanding potential problems associated with the design and construction method used by the ADRA project and developing recommendations for future straw bale construction informed by the analysis of the ADRA project. The following sections of this paper describe the straw bale construction technology applied in the ADRA project, giving examples of straw bale building in the ADRA project and discussing current straw bale building practices in northern China. The construction method used for the ADRA project is then compared with other straw bale construction techniques applied in other countries. The lessons learned from this analysis are then applied to propose an optimized approach for straw bale construction in northern China.

2. Reviews of straw bale constructions in China and globally

2.1. Design of straw bale buildings worldwide

Despite the international development of straw bale constructions, they all have similar components and constructions of the straw bale walls. These components include the toe-up knee wall, pinning system, and the rendering construction.

2.1.1. Toe-up knee wall

There is a generally accepted constructional approach used to connect straw bales with the foundations to mitigate against damage from rising damp [6, 23–25]. The construction system is known as ‘toe-up’ and it elevates the straw bale walls off the surface of a slab [6,23]. Toe-up construction ensures that straw bale walls are kept away from ground water damage on slabs during construction and it provides protection against any potential leaks of water [23]. There are three typical toe-up designs which are shown in Fig. 2 [23]. Toe-up construction should both have a vapour barrier layer to prevent damp damage from ground and allow moisture within the straw bale walls to drain away [23]. The Toe-up system is widely used worldwide [23]. A development of the typical toe-up is the baseplate construction which is designed by Jones [26]. The baseplate incorporates the typical timber toe-up construction and hazel pins for fixing first layer of straw bale walls (Fig. 3).

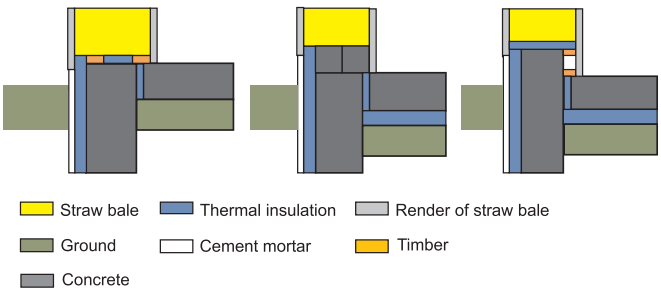

Fig. 2. Typical toe-up (left), toe-up with blocks (middle) and toe-up with knee wall (right). (redrawn from [23]).