Frontiers of Architectural Research (2015) 4, 212–219

HOSTED BY ELSEVIER

Available online at www.sciencedirect.com

ScienceDirect

www.elsevier.com/locate/foar

Frontiers of Architectural Research

RESEARCH ARTICLE

External wall structure of green rural houses in Daqing, China, based on life cycle and ecological footprint theories

Hong Jin*, Wei Ling

School of Architecture, Harbin Institute of Technology, Harbin 150006, China

Received 24 October 2013; received in revised form 8 March 2015; accepted 30 April 2015

KEYWORDS
Life cycle assessment;
Ecological footprint;
Green rural house;
External wall

Abstract
Daqing is situated in one of the severely cold regions of China. The living environment in this region is extremely poor because of the harsh climate and the backward economy. The external wall is an important component of the external envelope of buildings, and it greatly contributes to the indoor thermal environment. By taking the external wall as the research object, this study summarizes the characteristics of the external wall structure and analyzes the common materials used in existing rural residences. Specifically, we combine life cycle theory and ecological footprint (EF) theory and introduce the green external wall structure, as well as its application in practice, in accordance with the local ecosystem. Results show that anecological residence offers a better environment and greater economic benefits than a traditional residence. The annual energy consumption, CO_2 consumption, and EF of the ecological residence in this study are lower than those of the traditional residence by 69.61%, 17.5 t, and 99.47%, respectively.

1. Introduction

1.1. Location and climate

Lindian County, Daqing City, is located in the midwestern part of Heilongjiang Province and is situated between east longitudes 124°18′ to 125°21′ and north latitudes 46°44′ to 47°29′. The west part of the county is contiguous to the Zhalong Nature Reserve, which is home to the world-famous red-crowned crane and to a 3,150,000-acre natural wetland, which is one of the eight wetland reserves in the world. In winter, the mean outdoor wind speed in Lindian County is 3.5 m/s, and the prevailing wind direction is the northwest wind. The mean temperature in the coldest month, the minimum temperature, and the outdoor mean air temperature during heating periods are −19.9 °C, −38.1 °C, and −10.4 °C, respectively. The mean relative humidity is 64%, and the length of the heating period is 182 days. The heating degree day is 5112 °C d, and the maximum depth of frozen land is 205 cm. The winter season in Lindian is long and cold, whereas the summer season is short and cool.

*Corresponding author.
Peer review under responsibility of Southeast University.

http://dx.doi.org/10.1016/j.foar.2015.04.002

1.2. Materials and structural characteristics of external walls in existing residences

1.2.1. Materials of external walls

On the basis of our investigation into the local rural residences in Daqing, we find that the external walls are predominantly made of 83% homegrown solid clay brick and 7% adobe (Figure 1). The adobe wall is constructed by using raw building materials. Therefore, this type of wall is simple and inexpensive to construct. However, the adobe wall has poor durability. Along with the development of construction technology, adobe has been gradually replaced by solid clay brick and red brick. The application of these wall materials significantly improves wall durability. In the last decade, building energy conservation in rural residences has achieved notable progress. New energy-efficient wall materials, including hollow board, hollow brick, and perforated brick, have been applied in practice.

Residences with thermal insulation walls account for 3% of the total number of residences in the research scope. Thermal insulation materials are mainly made of expanded polystyrene (EPS) board. A considerable amount of vegetable-based thermal insulation materials, such as straw board and straw bale (Figure 2), are also used.

1.2.2. External wall structure

The external wall of local residences in Daqing generally comprises a 490 mm red brick wall and a 400 mm-thick adobe wall. With the application of local energy-saving policies in recent years, walls such as external thermal insulation walls, internal thermal insulation walls, sandwich thermal insulation walls, and straw board walls have been widely applied in practice.

2. Ecological footprint analysis of different structural walls

2.1. Life cycle assessment theory

Life cycle assessment (LCA) is the research on environmental factors and their potential effects on the entire process of a product's life cycle (i.e., from the acquisition of raw materials to their production, utilization, and final deposition). LCA emphasizes that at the beginning of a design period of any product or project, the aspects of production, use, waste, and recycling must be considered (Sharma et al., 2011). In its practical application, LCA is aimed at reducing environmental impact to the minimum, shortening the design period, and lowering relevant costs. Hence, it brings considerable economic and ecological benefits (Bettles, 1992). Construction projects can also be seen as a product of the production process. At the early stages of construction, building design involves decisions on building material types, building material usage, building operation, and eventual disposal of materials. Buildings are special products. Unlike other industrial goods, buildings are large in scale, entail high resource consumption, and operate for long periods. The service life of a residential building is 50–70 years, whereas that of a public building is more than 100 years. The present work focuses on the influence of the external wall of a rural house on the environment. With the aforementioned advantages of LCA, it is deemed suitable for use in the construction industry, as well as in the evaluation of building design plans (Bilec et al., 2010).

Figure 1 Adobe wall.

2.2. Overview and calculation model of ecological footprint theory

Ecological footprint (EF, which is expressed in terms of global hectare (gha)), represents not only the amount of biologically productive land and sea areas necessary to supply the resources consumed by the human population but also the amount of associated waste (Wackemagel and Rees, 1996). Canadian ecologist Rees first presented the concept of EF. Wackemagel later remedied the drawback of EF and consequently optimized it. Wackemagel calculated global EF to be 2.8 ha. The global ecological capacity per people was found to be 2.1 ha, and the ecological deficit per people was calculated at 0.7 ha. The figures indicate the severity of the ecological deficit. Vuuren et al. took seven countries as examples and studied the index division of EF. Their article states that index should be divided into the land use index and CO_2 absorbing land index to reduce calculation errors (Vuuren and Smeets, 2001). This calculation method is effective in macroscopically analyzing the relationship between a nation's trade and ecological environment. Each type of economic or social behavior has its own EF. EF theory, which elaborates the relationship between human development and ecology environment in a new perspective, is simple to calculate and easy to use.

The main factors of the EF calculation model are as follows:

2.2.1. Ecological productive area

The following land types are considered in EF theory: farmland, woodland, grassland, construction land, water area, and energy land. Each land type has its own ecological functions. The ecological productive area represents the areas occupied by different productive lands. It is calculated as follows:

$$A_m = \sum_{i=1}^{n} \left(C_i \frac{a_i}{P_i} \right) \tag{1}$$