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Geometric classification method of rural residences at regional scale

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ABSTRACT

With the rapid growth of construction area, residential energy consumption has sharply increased in China. Under this background, energy consumption estimation and energy performance assessment for rural residences at regional scale has become a significant issue that needs to be solved. Bottom-up approach is widely used to establish the representative residence models for estimating building energy consumption. However, there are some difficulties when applying bottom-up method to estimate energy consumption for residential building stock in rural region of China. For instance, the rural residences classification, which is a fundamental step of bottom-up approach cannot be finished by the typology and classification approaches that have been proposed. In order to solve this problem, a new classification method for rural residences of China is presented in this article. This method includes four steps. Firstly, the remote sensing image of target region is checked whether the application conditions are met. Secondly, the target region can be divided into several sub-regions and the villages are randomly selected by stratified sampling from each sub-region. Thirdly, the 3D data of residences in each selected village is obtained with Google Earth. Lastly, based on the obtained 3D data, the residential buildings are classified and the representative geometric models for each group can be established. In order to further illustrate this method with more details, the municipal region of Hangzhou in Zhejiang province of China is taken as an example. The new method is significant to establish representative model for rural residences at municipal scale, which supports not only energy consumption estimation and energy performance assessment of residential building stock, but also the evaluation of energy saving potential and the impact of retrofit measures from the perspective of regional scale.

1. Introduction

In the twenty-first Century, building construction area has rapidly increased both in urban and rural areas of China. With the rapid growth of construction area, residential energy consumption has sharply increased in China. In 2015, rural residential building sector consumed 2.13 billon tons of standard coal, which represented 25% of national building energy consumption [1]. This proportion will become larger in the future [2]. Under this background, energy consumption estimation and energy performance assessment for rural residences at regional scale has become a significant issue in China.

There are two fundamental methods used to estimate building energy consumption and assess building energy performance at different regional scales: the top-down and bottom-up approaches [3]. The top-down modelling approach tends to be used to investigate the inter-relationships between the energy sector and the economy at regional scale [4–6]. Often, these models are seen as a way to identify the most cost effective options to achieve energy reduction targets based on the best available technologies and processes [7].

Compared with top-down approach, bottom-up approach is used more widely. Before bottom-up method can be applied, classification of buildings at different regional scale is a crucial work for the establishing of representative building model. Building typologies can be a useful tool to facilitate the energy consumption calculation and energy performance assessment of a building stock [8]. Over the past few years, various building typology and classification approaches have been proposed and applied on residential building stock. According to household type and dwelling type, residential buildings can be divided into different groups which has been widely used during the past decade [9–13]. Generally speaking, household types include single-family and multi-family, while dwelling types usually contain detached buildings and attached buildings [8,14]. As new dwelling type, attention has also been paid to terraces or apartments [15]. Besides, residential buildings can be sorted by another major classification basis which includes architectural structure and construction period [2,8,16,17]. Except for the above classification approach, climate zone or climate cluster

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Nomenclature

N	Total number of villages in Hangzhou
n	Total sampling size of villages in Hangzhou
h	Sub-region number
N_h	Total number of villages in hth sub-region
n_h	Sampling number of villages in hth sub-region
V	Population variance of building length of rural residences in Hangzhou
W_h	Weight of hth sub-region
S_h^2	Population mean variance of building length of rural residences in hth sub-region
Y_{hi}	Building length of ith residence in hth sub-region
$\overline{Y}_h$	Population mean of building length of residences in hth sub-region
Δ	Absolute error limit
γ	Relative error limit
t	Bilateral critical values of standard normal distribution

[8,18–19], building height [20], household size [21] and occupancy types [22] are also applied to group the selected residential buildings.

However, there are some difficulties of applying bottom-up method to estimate energy consumption or assess energy performance for residential buildings in rural regions of China. For instance, most of the above classification methods cannot be used due to the lack of basic information about rural residential buildings in China. Most of the rural residences are self-built by local residents without design drawings which lead to the aforementioned lack of information. On the other hand, the annual census provides only quantitative statistics data of rural residential buildings at provincial or national level which also hinders the application of bottom-up approach. So far the representative model of rural residential buildings at region level has not been proposed which hinders the research on building energy performance assessment and building energy consumption estimation. Considering the above problem, a new classification method for rural residential buildings is presented in this paper and more details are illustrated in the following sections.

2. Methodology

The geometric classification method of rural residences at regional scale is proposed based on the dimensional measurement function of Google Earth. Google Earth is a computer program that renders a simulacrum of the Earth based on satellite imagery. It maps the Earth by the superimposition of images obtained from satellite imagery, aerial photography and geographic information system (GIS) onto a 3D globe. Using Google Earth, ontology information of building shape and orientation can be obtained more efficiently. There are four steps for geometric classification of rural residences at municipal region scale. The first step is to test the application conditions for remote sensing image of target region. Building height need to be obtained by corner-shadow-length-ratio method(CSLR) proposed by Feng Qi, which requires slope inspection, solar altitude angle and solar azimuth tests. More details of the above tests can be found in literature [23]. If the remote sensing images of the target area do not pass the above tests, Google Earth time bar can be adjusted until the available RS images can be found. In the second step, the target region needs to be divided into several sub-regions with Google Earth. Then minimum sample size of villages of each sub-region is calculated by stratified sampling, which is more efficient because it can greatly reduce the workload of geometric data acquisition. According to the minimum sample size, a certain number of villages are randomly sampled as the target villages. Thirdly, the 3D data of the residences in each target village is obtained with the size capturing function of Google Earth. Lastly, according to the obtained 3D data in third step, the representative geometric arrays of each village are figured out and all the village will be divided into several groups by cluster analysis. The 3D data of residences can be aggregated into a whole sample and the representative geometric residential model is established for each group. In order to further illustrate this method with more details, the municipal region of Hangzhou in Zhejiang province of China is taken as an example in the next section. The flow chart of the above procedure is shown in Fig. 1.

3. Application to a case study: the municipal region of Hangzhou, Zhejiang, China

3.1. Division of sub-regions

In most rural areas of China, the basic aggregation form of rural residences is village. According to statistical yearbook of Zhejiang Province, there are 2044 villages in Hangzhou in 2015, and there are 50–150 residential buildings in most villages. Consequently, geometric data collection of all the residences in this region is a highly time-consuming work. Considering this problem, the whole municipal region can be first divided into several sub-regions, and then a certain number of villages are selected from each sub-region. Finally, geometric data of rural residences in selected villages can be obtained. When designating sub-region areas, a square grid picture is taken as background layer, and the remote sensing images of Hangzhou will be divided into several sub-regions in grid format. By adjusting size of the square grid picture, Hangzhou region can be divided into different sizes of sub-regions. When carrying out sub-region division of Hangzhou area, square grids of sub-regions used in this paper are 20 km long. The division map of sub-regions in Hangzhou is shown in Fig. 2.

3.2. Identifying village samples for each sub-region

3.2.1. Introduction to stratified sampling

After division of municipal area, the village sample amount and village sample selection method from each sub-region is the next problem. Stratified sampling method can be used to solve the above two problems. Stratified sampling is a kind of investigation method, and it is an important non-overall investigation and statistical method. It adheres to the random principle. Stratified sampling is also known as classification sampling, which is carried out independently on each layer. The total sample is composed by the samples from each layer, and the overall parameters are estimated based on the aggregation of the sample parameters from each layer. Stratified random sampling has three necessary conditions; (1) Each layer is sampled; (2) All layers are sampled independently; (3) Sampling method at each layer is simple random sampling. Stratified sampling is usually used to group residential buildings. For example, Banfi S uses a choice experiment, which is based on stratified sampling, to evaluate the consumers' willingness to pay for energy-saving measures in Switzerland's residential buildings [24]. The experiments have been performed on two separate samples which were stratified with the purpose of including a sufficient share of new and existing buildings [25].

3.2.2. Total sample size of villages in municipal region

When the sample numbers of each layer needs to be calculated, the total number of samples should be provided. Once it is fixed, the next question is how to reasonably allocate the samples to each layer. The different allocation patterns of the sample size