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Multi-model prediction and simulation of residential building energy in urban areas of Chongqing, South West China

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ABSTRACT

Energy simulation and prediction plays a vital role in energy policy and decision making. This study has been conducted to predict the future energy demand in the urban residential buildings of Chongqing a city in south west China. The comparative study adopts and compares the results of different demand models to improve estimation efficiency for future projections. A structured questionnaire survey was undertaken to collect primary household energy consumption data for inclusion in the annual energy consumption simulation model. An ANN model, two Grey models, a Regression model, a Polynomial model and a Polynomial regression model were used to forecast and compare demand. The precision of the models have been used statistical methods. The predicted results show that the total residential building energy and electricity consumption in urban areas of Chongqing is increasing rapidly. Based on MRPE (%) and the statistical tests, the study concluded that an ANN model is the most acceptable forecasting method of the six models. Hence, based on ANN model, urban residential building energy consumption will be at 1005×10^4 SCE and electricity consumption will be at 264.81×10^8 kW h in 2025 which is about three times and four times higher than that of the 2012, respectively.

1. Introduction

Energy is considered as a key factor and element of the national economy [1]. With the rapid development of the world economy, global energy consumption is increasing [2]. The use of different types of end use devices such as air conditioner and electric heaters, oven, washing machine, vacuum cleaner etc. are increasing in China with the growth of China's economy. In addition, un-insulated buildings and low efficiency end use devices, residential building energy consumption is increasing rapidly. Hence, the objective of this study was to predict the pattern and level of future building energy demand in urban residential areas resulting from rapid urbanization. However, the excessive production and misuse of energy has some negative impacts on the environment, which can restrict regional economic development.

For the past two decades, China has experienced a fast-paced growth of its economy and has been in a phase of rapid urbanization development [3]. In 2001 building energy consumption accounted for about 27.6% of the total energy consumption. It is projected that the energy consumption in buildings will increase by up to 35% by 2020 [4]. Total carbon emission and environmental pollution has significantly increased as result of building energy consumption. Nowadays all over the world, energy and environmental problems have become a public concern. China is taking steps to reduce the energy demands of new buildings by investigating new construction methods and the development of eco-communities and eco-cities [5].

Chongqing is an important growth center in South West China with a total area of 82,400 km^2 and a total population of 33 million. Around 17 million (51%) of the population is considered rural and the remaining 16 million (49%) is considered to be an urban population [6]. For the ongoing development of both the urban and rural regions of Chongqing, the government has given the city municipality status placing it directly under the control of the central government [7]. Chongqing may be considered as a development hub of west China. The energy consumption

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in Chongqing is increasing at a geometric rate in all sectors. Amongst these sectors the residential building sector energy consumption is remarkable. From 1987 to 2012 residential building energy consumption in Chongqing increased from 2998,500 tce to 6628,800 tce, which is 121.07%. In 2012, Chongqing residential building energy consumption was 8% of total energy consumption of Chongqing [8]. In summer, Chongqing is an extremely hot and humid region and there has been increasing demand of air conditioning equipment and heating requirement [9]. Air conditioning alone consumes around 23% Chongqing's total energy consumption [10].

Multi-model prediction was the selected as the approach to the comparative study of selecting a valid and accurate prediction model. A structured questionnaire was used to collect primary data, and energy intensities of various drivers were collected from literatures for the annual energy consumption simulation. In addition, secondary data about residential building energy consumption and other relevant socio-economic data were collected from China Statistical Yearbook 2000–2012, Energy statistical yearbook of China 2000–2012 and Chongqing Statistical Yearbook 2000–2012. Annual urban residential energy consumption in Chongqing was simulated by a stock turn-over model. The model implies various energy demand drivers such as total household, number of people per household, total population, electrification rate, and end-use appliances such as space cooling and heating, water heating, cooking, refrigeration, lighting, and the powering of a wide variety of appliances with their intensities within a specific region. Therefore, the study has been calculated the total energy consumption in urban areas of Chongqing by integrated all drivers, end-use technologies and their intensities. Then a number of models Artificial Neural Network (ANN) model, Grey model such as GM (1,1), DGM (2,1), Regression model, Polynomial model and a Polynomial regression model were used for forecasting and comparing the precision of the models.

2. Literature review

In the EU in 2004, residential building energy consumption was 37% of the total energy, higher than both the transport (32%) and the industrial sector (28%). Residential building energy consumption in the UK was 28% of total building energy consumption (39%), which is slightly larger than the EU figure, whilst Spanish residential building used only 15% of total final building energy consumption (23%) [11]. The EIA has analyzed and forecasted future building energy consumption trends in their International Energy Outlook. In the next 20 years, energy consumption for building services is expected to increase by 34% (overall increase in 20 years) with the average annual rate of 1.5%. By 2030, energy consumption in non-domestic and residential sectors will be 33% and 67%, respectively [12]. Governments should fund for residential and commercial buildings energy consumption analysis by sectors, building stock (location, type, age, area, etc.) and energy parameters such as fuels, end uses, consumption, expenditures, etc., for making a comprehensive database which is very important for future planning [13,14]. Electricity is an important type of energy and is highly used in residential building and other sectors. In China, it is estimated that residential building energy consumption accounts for one third of the total energy consumption [15]. Residential building energy consumption increases rapidly with the development of living standards, urbanization, economic development, people's income. Within the period 1996 to 2006, residential building energy consumption in China increased by 1.3 times and in 2006 residential building energy consumption in urban areas was 45% (0.255 billion tce) of the total energy consumption. Clearly residential building is an important sector for energy consumption and contributes a larger portion of the total energy consumption than other sectors of the economy [15,16].

Different types of models such as ANN, Polynomial, Grey models, ARMAX and others model have been used for analyzing and predicting energy consumption in residential building sector. It is very important to understand which the effective models for predicting and analyzing present and future energy consumption in different sectors. Recently Pao et al. proposed an improved Grey model to evaluate and forecast future energy consumption in different sectors including residential buildings and industrial sectors in China [17]. Huang et al. have developed a Grey-Markov prediction model to examine and predict the electric-power supply demand and load in China [18]. Artificial Neural Network (ANNs) models are effective tools for analyzing various time series models [19]. ANNs are universally accepted tools for approximation that can approximate a large class of function with higher accuracy [20]. ANN models have received a great deal of attention and have proved powerful computational tools to forecast energy loads [21]. ANN architecture presents more insights than other regression based models and the traditional polynomial model [22]. A stock turn-over model has been applied by Zhou [23] to simulate the total residential building energy consumption by considering various energy consumption drivers and factors (Eq. (1)). The stock turn-over model has also been applied by Hossain et al. [7] for forecasting rural residential building energy consumption in Chongqing by using various energy consumption drivers. Engineering and statistical methods can be used to forecast the building total energy consumption. Artificial intelligence models, including Support Vector Machines (SVMs) and Artificial Neural Networks (ANNs) are useful tools to predict the consumption of building energy with higher accuracy but require adequate historical data and complex estimation process [5].

According to previous studies mentioned above, most of them have used only one or two modeling method to compare and forecast future energy demand. It is very difficult to take decision for future prediction by comparing one or two model, because accuracy of the model is an important factor. For better prediction, comparison and get higher accuracy of prediction, it's important to predict and compare by several models. Therefore, the study has considered six popular models to compare and forecast future energy demand in Chongqing, China.

3. Methodology

3.1. Urban residential annual energy consumption simulation by stock turn-over modeling

Residential building energy provides various services related with household living including space cooling and heating, cooking, lighting, water heating, refrigeration, and the powering of other end use devices. According to the Zhou [23] and Hossain et al. [7], end use devices were divided into four groups by technologies and their intensities were 390, 260, 1385 and 323.93 kWh/household/year. These groups were space heating and cooling, lighting energy use, cooking and water heating and other (miscellaneous) end use devices, respectively. The intensities of these groups have been used in the stock turn-over model. In addition, Hossain et al. [7] modified Eq. (1) by adding the space heating and cooling requirements of Chongqing rural areas (Eq. (2)). Space heating and cooling requirements need to be considered as one important driver as well as other end use devices (for example, computer, TV, refrigerator, washing machine, dryer). The present study has modified Eq. (2) by adding this driver to simulate the total annual energy consumption