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Influencing Factors of the Energy Consumption Behaviour of Civil Buildings in Hubei Province, China

Wei Xian Zhong
Architecture Engineering College, Huanghuai University, Henan Zhumadian 463000, China
Corresponding author: Wei Xianzhong

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ABSTRACT

Civil buildings are among the structures that consume the most energy in society. Reducing the energy consumption of civil buildings has become an important component of China's energy policy. Identifying the key influencing factors of the energy consumption of civil buildings and formulating effective energy-saving countermeasures are important to enhance the energy efficiency of civil buildings. This study conducted a systematic analysis of the influencing factors of the energy consumption of civil buildings in Hubei Province, China. First, existing studies on the influencing factors of the energy consumption of buildings in foreign developed countries were reviewed. The status of the population, economic life, and social life that influenced the energy consumption of civil buildings in Hubei Province in the past 10 years was summarized. Relevant influencing factors were estimated via ridge regression. Results demonstrated that developed countries generally investigated the influencing factors of the energy consumption of civil buildings from the energy supply-demand relation, family factors, and out-of-family factors. Gross domestic product (GDP), total population, tertiary industry development, per capita floor space, household consumption level, and urbanization facilitated the energy consumption of civil buildings in Hubei Province during the aforementioned period, and the regression coefficients were significant at the 5% level. Lastly, policy countermeasures were proposed to accelerate the energy-saving development of civil buildings. Research conclusions are important to enrich theories regarding the energy consumption reduction of civil buildings, to help relevant government sectors of Hubei Province recognize action points for the energy-saving development of civil buildings, and to accelerate the benign development of energy-saving buildings.

INTRODUCTION

Energy is an important material basis for human survival and development. Nevertheless, with the considerable progress in the use and reconstruction of nature, humans not only focus on survival and development but also on executing numerous activities that overuse energy resources, thereby resulting in the gradual exhaustion of energy resources and generating serious environmental threats. China has been promoting large-scale urbanization since the 21st century, and the construction of new rural areas has been promoted throughout the country. Consequently, the total building energy consumption in China has been increasing. Building energy efficiency is a key component in addressing energy shortage, improving people's living environmental quality, mitigating environmental pollution, and realizing sustainable development in China. Moreover, it plays an important role in accelerating the establishment of an energy-saving and environment-friendly society. To promote the development of building energy efficiency, the state has incorporated it into construction. Compared with energy consumption in other fields, such as industries and transportation, the energy consumption of buildings involves high proportion, evident growth, considerable energy-saving potential, and low cost.

Hubei Province is located in the core region of Central China. It is the hub and bridge that connects the eastern coastal developed regions to the relatively backward western regions. In the past decade, Hubei Province experienced rapid economic development, an accelerated urbanization process, a significant improvement in people's living standard, and rapid growth in the energy consumption of civil buildings. Hubei Province has entered an important period of rapid urbanization and extensive industrial restructuring. In addition, Fig. 1 shows that the value added of the building industry has increased quickly. This period is also the key moment to promote building energy efficiency. If this opportunity is missed, then the energy consumption status of civil buildings will not be improved on time. The contradiction between the energy consumption of civil buildings and that in other social fields is highlighted. However, this condition may exert considerable pressure on the energy construction and environmental protection of Hubei Province. This province will face a serious energy crisis, and the energy-saving cost will be increased considerably.

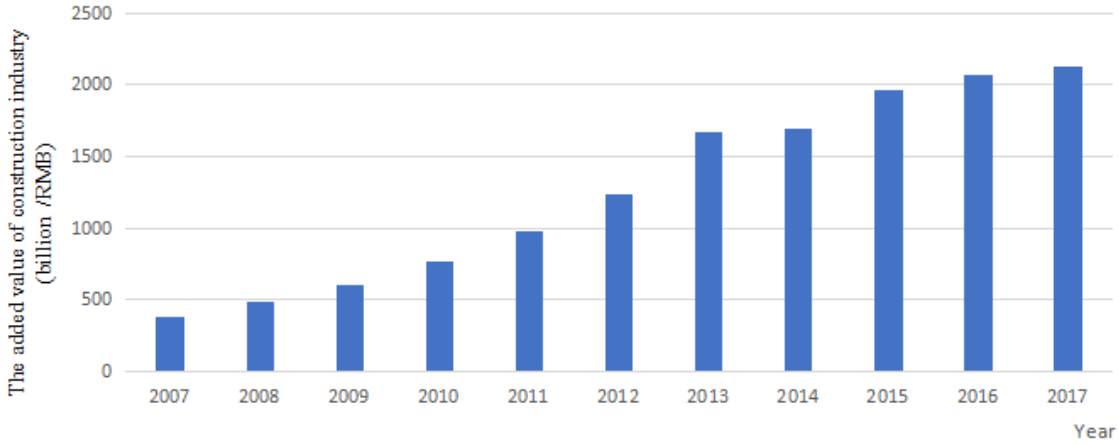

Fig. 1: Value added of the building industry in Hubei Province in 2007-2017.
(Data source: National Bureau of Statistics of China, http://www.data.stats.gov.cn/)

A comprehensive study of the energy consumption problems of civil buildings is necessary and urgent to help relevant government sectors in Hubei Province recognize key action points in building energy efficiency, mitigate the influences of unfavourable factors, and achieve energy-saving and emission-reduction buildings from the macroscopic perspective.

STATE OF THE ART

Many western countries have gathered statistics regarding the energy consumption of civil buildings in China using uniform statistical techniques and estimated relevant influencing factors in the 1970s. A civil building is a complicated system, and its energy consumption is influenced by many factors. Numerous scholars have investigated relevant influencing factors and have achieved abundant results. Saha estimated the energy use of civil buildings in New Zealand and proposed a concrete model (Saha 1980). Canyurt et al. found a significant correlation between the economic development level and the energy consumption of residential buildings in a state or region (Canyurt et al. 2005). Santamouris et al. concluded that the higher the income and consumption levels of residents, the higher the energy consumption of a building (Santamouris et al. 2007). Kelly believed that the number of households, the building area, and household income are the major driving factors of the energy consumption of buildings (Kelly 2011). Özcan et al. analysed several economic and social demographic factors that influence the energy selection of households in Turkey and found that monthly household income can considerably influence energy selection (Özcan et al. 2013). Song et al. reported that the large-scale construction of buildings in rural areas as a response to new rural construction projects in China increases energy consumption (Song et al. 2014). Nejat et al. found that the increase in energy consumption of buildings in developing countries is currently at its fastest rate; moreover, population, urbanization, and economic growth are major driving factors of energy consumption increase (Nejat et al. 2015). Using the system dynamics approach, Motawa et al. found that architectural features, external environment, and residents are three major factors that influence the energy consumption of buildings (Motawa et al. 2015). Jones et al. found 62 factors that influence the electricity consumption of buildings and divided them into socioeconomic (13), building (12), and household equipment factors (37) (Jones et al. 2015). Ma et al. assumed that energy consumption for the appearance and operation of civil buildings accounts for over 30% of the total energy consumption in China. In addition, the development of energy-saving technologies and changes in household lifestyle considerably influence the energy consumption of civil buildings (Ma et al. 2015). Liu et al. supposed that urban population, per capita floor space, building structure, and building energy intensity increase CO_2 emissions in the building industry (Liu et al. 2015). Ma et al. studied the energy consumption characteristics of public buildings in North China and conducted a statistical analysis of the energy consumption of 119 public buildings in the region (Ma et al. 2017). Yan et al. analysed the energy-saving design standards of public buildings in China and found that the actual operation of buildings and the behaviour of residents play important roles in the energy consumption of buildings (Yan et al. 2017). Chang et al. analysed the energy consumption of buildings in North China and identified the thermal comfort of buildings, residents' behaviour, and heating energy consumption as major factors that influ-

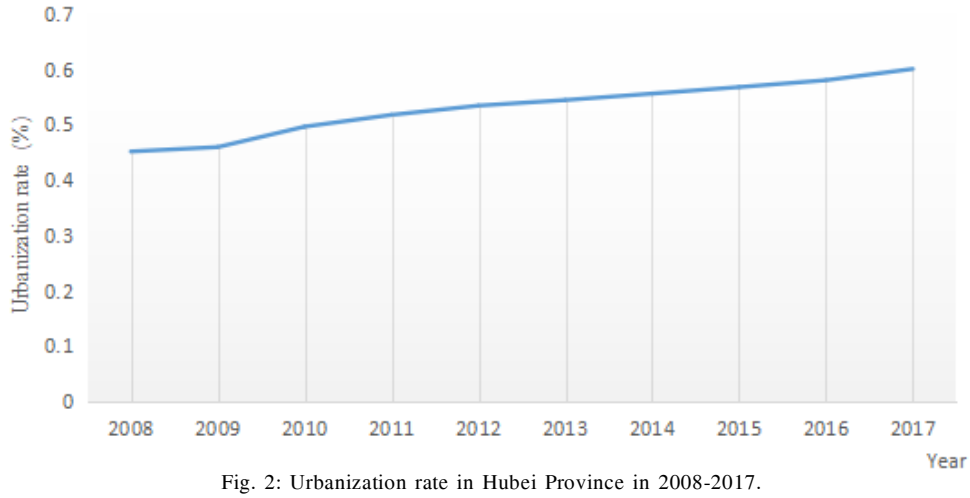

Fig. 2: Urbanization rate in Hubei Province in 2008-2017.
(Data source: National Bureau of Statistics of China, http://www.data.stats.gov.cn/)

ence building energy efficiency (Chang et al. 2018). Mora et al. recognized climate, heating type, residents' behaviour, and socioeconomic development as major factors that affect the energy consumption of buildings (Mora et al. 2018). The existing literature shows that all scholars have focused on factors that influence the energy consumption of buildings. Foreign studies have generally explored the influencing factors of the energy consumption of civil buildings on the basis of family and society, demographic features, the physical attributes of buildings, and city appearance in view of energy supply-demand relations, family factors, and out-of-family factors. This study constructed a hypothesis model of the influencing factors of the energy consumption of civil buildings based on existing studies and by considering the actual situations in Hubei Province. In addition, the major macroscopic influencing factors of the energy consumption of civil buildings in Hubei Province were analysed at the macroscopic level, thereby providing a correct direction for the development of energy-saving buildings.

INFLUENCING FACTORS OF THE ENERGY CONSUMPTION OF CIVIL BUILDINGS IN HUBEI PROVINCE

The energy consumption for the operation of civil buildings in Hubei Province is a complicated subsystem of the social system. The changes and development of this subsystem are not only related to population, abundance, and technological level, but also to people's social life. Hence, this subsystem is inevitably influenced by other subsystems, such as social, economic, technological, and ecological subsystems. Combined with the associated studies on the influencing factors of the energy consumption of civil buildings and the characteristics of Hubei Province, the macroscopic influencing factors of energy consumption for the operation of civil buildings were primarily summarized into three aspects: population, economy, and social life.

Population: Many studies have reported that pressure on the environment is intensifying with an increase in population, and population and energy consumption for the operation of buildings exhibit a significant correlation. The influences of the growth in total population not only directly change total energy consumption for the operation of civil buildings but also affect per capita energy consumption. The influences of changes in the population structure in urban and rural areas on the energy consumption of buildings are primarily manifested by the continuous migration of the rural population to urban areas, which considerably increases the urban population. The per capita commodity and energy consumption of urban residents are higher than those in rural areas. Moreover, the migration of the rural population to urban areas may replace commercial fuels with biological fuels, produce more construction activities, and improve household energy use standards, thereby increasing energy consumption. Recently, urbanization in Hubei Province has developed gradually (Fig. 2), as manifested by the continuous increase in urbanization rate for the past 10 years. Hence, urbanization rate is used to reflect changes in demographic structure in urban and rural areas.

Economy: Worldwide, a region with a higher economic development level and GDP exhibits higher per capita energy consumption for the operation of civil buildings. Many studies have discussed the influences of regional economic development on the energy consumption of civil buildings using the GDP of different regions as the influencing factor. Regional economic growth can considerably influence the

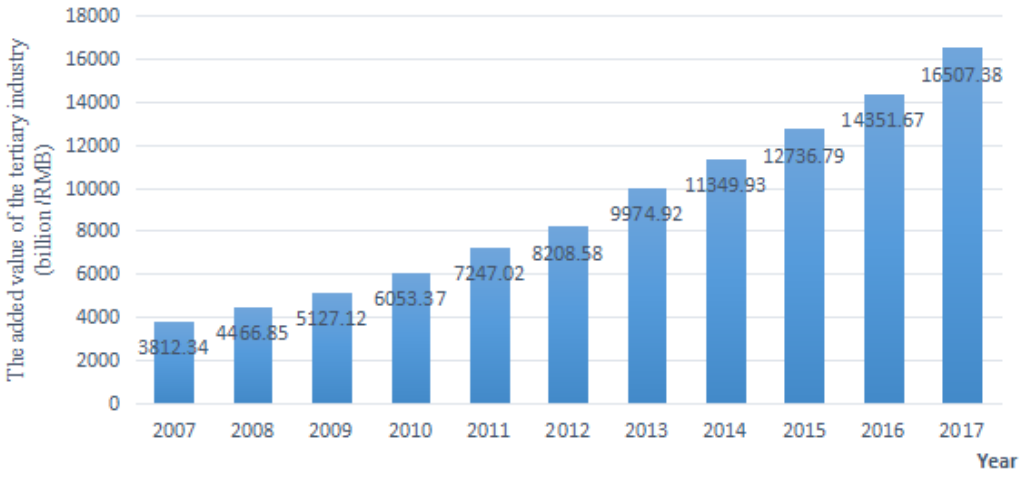

Fig. 3: Value added of tertiary industries in Hubei Province in 2007-2017.
(Data source: National Bureau of Statistics of China, http://www.data.stats.gov.cn/)

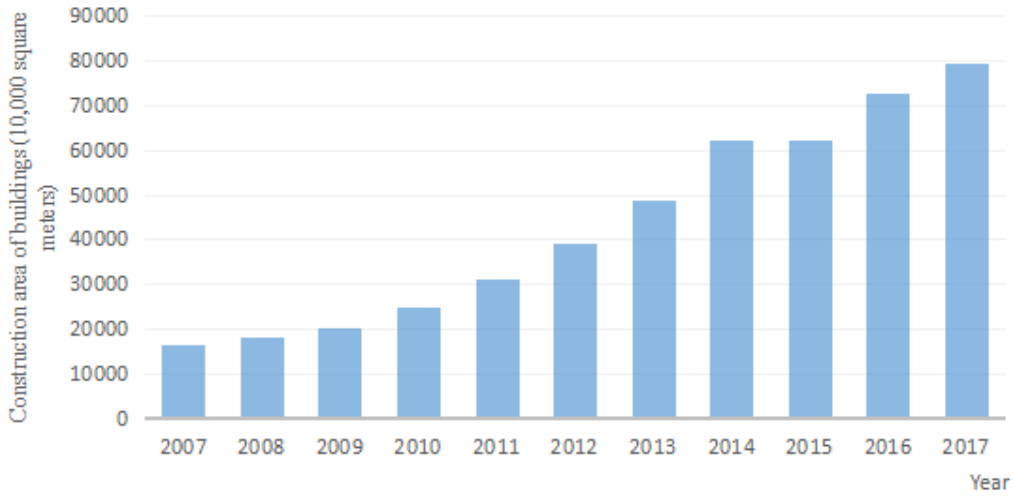

Fig. 4: Construction area in Hubei Province in 2007-2017.
(Data source: National Bureau of Statistics of China, http://www.data.stats.gov.cn/)

energy consumption of civil buildings. Hubei Province is currently undergoing industrialization and experiencing rapid changes in economic structure. The proportion of primary industries decreases to a certain extent, the proportion of secondary industries fluctuates slightly at a stable level, and the proportion of tertiary industries is increasing gradually. In the long run, the core of the industrial structure of Hubei Province will shift from traditional industries with low labour cost and high resource consumption to tertiary and modern manufacturing industries. As shown in Fig. 3, the value added of tertiary industries in Hubei Province increases annually. Given that the economic activities of tertiary industries do not belong to industrial production, technological energy consumption is extremely low, and occasionally, even zero. Energy consumption is mostly attributed to the building field. Therefore, the development of tertiary industries can considerably influence the energy consumption of buildings.

Social life: With the social progress and booming market economy of Hubei Province, the living standard of people is improving and their consumption concept is changing toward "high standard, high quality, and internalization". The living needs of residents have shifted from the early basic survival needs to the improvement of life quality. They have higher requirements for the comfort and convenience of the living environment, which increase the energy consumption of civil buildings. When living requirements and consumption level are increased, the demands for durable

consumer goods, such as relevant home appliances, are increased continuously. The increased consumption of home appliances, which are the major energy consumers in civil buildings, will increase the energy consumption for building operation. Accelerating urbanization leads to the large-scale implementation of building construction in different regions. As shown in Fig. 4, the construction area in Hubei Province increased continuously in the past decade. Moreover, the civil building area increased sharply due to the construction of a series of security housing projects, old city reconstruction, and shantytown transformation. The improvement in living standard allows people to continuously pursue wider and more comfortable living spaces, which may increase the energy load of civil buildings.

BRIEF INTRODUCTION TO THE MODEL AND DATA SPECIFICATION

Brief introduction to the model: Relations among socio-economic phenomena are frequently difficult to describe using determined functional relations. Most of these relations are random and have to be recognized through statistical observation. Regression analysis is an important method for the statistical description of correlations among variables. It establishes appropriate dependencies among variables on the basis of observation data. Analysing the internal law of data will not only determine whether one random variable is related to one or several controllable variables, but can also reflect concrete causality by a mathematical model. A multiple regression model based on the constructed hypothesis model was built by considering the practical situations in Hubei Province to analyze the influences of macroscopic factors on the energy consumption of civil buildings in the study area.

$$Y = \beta_0 + \beta_1 POP + \beta_2 CIT + \beta_3 GDP + \beta_4 STR + \beta_5 CUS + \beta_6 ARE + \gamma \quad ...(1)$$

Where, Y is the energy consumption of civil buildings in Hubei Province (10,000 tons of standard coals), which is used as an explained variable. *POP* is the total population in Hubei Province (person). *CIT* refers to the urbanization rate in Hubei Province (%). *GDP* refers to the gross domestic product (100 million/RMB). *ARE* is the per capita floor space (m^2). $\beta_{(i)}(i = 1, 2, 3 \cdots 6)$ is a parameter to be estimated. γ is a random error term. To eliminate multicollinearity in the model, ridge regression was applied to the fitting analysis of the model. Ridge regression is a biased estimation regression method that is used exclusively in collinear data analysis. It is a type of improved least squares estimation method and a more reliable regression method that obtains a regression coefficient that better conforms to the practical value at the cost of partial information and accuracy losses by abandoning the unbiasedness of the least squares method. Ridge regression is superior to the least squares method in terms of fitting pathological data.

Data sources: Data were collected from the China Energy Statistical Yearbook (2008-2018), the China Statistical Yearbook (2008-2018), and the Hubei Statistical Yearbook (2008-2018). The energy consumption of civil buildings, total population, urbanization rate, GDP, value added of tertiary industries, household consumption level, and per capita floor space in Hubei Province were obtained from statistics.

ANALYSIS OF RESULTS

The regression fitting analysis of the model equation in Eq. (1) was performed using SPSS version 22.0. The results are listed in Table 1.

Table 1 indicates the following findings:

1. All the ridge regression coefficients of independent variables in the model pass the 1% significance test, which conforms to the economic significance test. The coefficient of multiple determination (R^2) is 0.917 and the F significance test is P = 0.001<1%, thereby indicating its high significance and its passing of the significance test. The overall fitting effect of the model is good. The model can efficiently interpret the relationship between the energy consumption of civil

Table 1: Regression results of the model equation.

Variables	Regression coefficient	T value	P value
β_0	-412.104	-2.865	0.000
POP	0.145	3.639	0.000
CIT	0.074	2.785	0.000
GDP	0.112	1.874	0.003
STR	0.136	2.475	0.000
CUS	0.094	2.984	0.000
ARE	0.171	3.254	0.000

R^2 = 0.917F statistics = 26.574; F test value = 0.000

buildings in Hubei Province and its influencing factors.

2. In terms of population, the total population and urban-rural demographic structure of Hubei Province are significantly positively correlated with the energy consumption of civil buildings. The energy consumption of civil buildings may increase by 0.145% for a 1% population growth. Given that China began to implement a family planning policy in 1978, the population growth rate is controlled effectively. However, the population in Hubei Province is expected to increase more rapidly due to the implementation of the "second children for one-child parents" policy in 2013, which will exert pressure on the energy consumption of civil buildings. Moreover, the changes in urban-rural demographic structures also facilitate the increase in energy consumption of civil buildings. The energy consumption of civil buildings will increase by 0.074% for a 1% increase in urbanization rate. China has been promoting urbanization at present. The influences of urbanization on the energy consumption of buildings are further intensified in Hubei Province.
3. Economic growth and tertiary industry development in Hubei Province will facilitate the increase in the energy consumption of civil buildings. The energy consumption of civil buildings is increased by 0.112% when economic growth in the province is increased by 1%. The economy of Hubei Province exhibits a stable development, which further increases the energy consumption of civil buildings. Simultaneously, the development of tertiary industries also facilitates the increase in energy consumption of civil buildings. The energy consumption of civil buildings is increased by 0.136% when the value added of the tertiary industry is increased by 1%. At present, Hubei Province regards the promotion of the service industry's development as a key in economic restructuring. Continuously increasing the proportion of tertiary industries will further intensify the energy consumption of civil buildings.
4. In terms of social life, the energy consumption of civil buildings may also be increased with the development of household consumption level and the growth of per capita floor space in Hubei Province. The energy consumption of civil buildings is increased by 0.094% for every 1% growth of household consumption level. Given that China is comprehensively implementing industrial restructuring, Hubei Province regards consumption expansion as a lasting driving force for economic growth and builds a long-term effective mechanism for expanding consumption demands. With the improvement of residents' consumption level, the energy consumption of civil buildings is increased continuously. Moreover, the growth of per capita floor space will raise the energy consumption of civil buildings. The energy consumption of civil buildings is increased by 0.171% for every 1% increase of per capita floor space. At present, the construction industry considered one of the important industries that promote economic growth in Hubei Province, and its development is accelerated continuously. The civil building area is expanded rapidly, thereby increasing the energy consumption of these buildings.

POLICY COUNTERMEASURES

Perfecting the incentive mechanism for the energy conservation of civil buildings: The energy conservation of civil buildings is characterized by positive externality. Therefore, the government shall set up an all-around incentive mechanism for energy conservation through tax revenue and currency policies to the guide the implementation of energy-saving standards for newly constructed buildings and market development for the energy-saving reconstruction of existing buildings. Different incentives shall be offered to various players. For energy-saving product manufacturers (i.e., energy-saving service providers), the cost risk shall be reduced, and market share can be increased by offering tax preferences, fiscal subsidies, and increasing government purchase. In addition, energy-saving rewards for enterprises shall be set to strengthen guidance over energy-saving enterprises. Real-estate developers shall be offered loans with favourable terms, fiscal subsidies, and tax preferences to strengthen their enthusiasm in energy-saving buildings; their negative benefits from the promotion of energy-saving buildings shall also be reduced. Moreover, non-material rewards for enterprises shall be strengthened, and an environmental protection green brand image shall be established for energy-saving building developers. The purchase cost of energy-saving products can be reduced for house owners, and their willingness to purchase can be increased through preferences, gifts, and purchasing subsidies. In addition, the energy price incentive mechanism shall be perfected, and the gradient price for energy consumption by residents shall be implemented to stimulate the energy-saving enthusiasm of individuals.

Perfecting the contract energy management mechanism for civil buildings: As a type of service mechanism that facilitates energy conservation by using market means, contract energy management can address practical, financial, and technological problems in energy-saving building reconstruction; it also plays an important role in building reconstruction toward energy conservation. Relevant government sectors shall focus on contact energy management for energy-saving building reconstruction, a perfect relevant

law system, and a standardized market development environment to assure the implementation of contract energy management and the sound development of energy-saving service enterprises. The government shall strengthen the auditing and monitoring of third-party construction. It shall encourage and support professional energy-saving building enterprises with comprehensive technical strength to be developed into third-party independent organizations for building energy auditing and monitoring. In addition, the government shall advocate for demonstration projects of excellent energy-saving building enterprises in the region with good contract energy management condition. The entire energy-saving building service industry shall be developed on the basis of the principle of "pilot first and promotion gradually."

Accelerating the green construction of civil buildings: The government of Hubei Province shall seize the opportunity to be a pilot of a national low-carbon province, transfer the urban-rural construction mode from the overall urbanization plan and layout, further promote the implementation rate of mandatory standards on new energy-saving buildings in urban areas, accelerate the reconstruction of existing buildings toward energy conservation, and promote green buildings, new energy-saving building materials, and renewable building materials. In rural areas, the government shall promote energy-saving buildings, the updating of firewood/coal-saving stoves, and the application of clear and renewable energy sources, such as solar energy. In addition, the government shall decrease the consumption of traditional energy resources, optimize the energy consumption structure of buildings, facilitate water conservation, concentrate heat supply and heat power cogeneration in urban areas, and decrease the energy consumption of civil buildings in urban areas.

Enhancing the energy-saving consciousness of civil buildings: Increasing energy-saving consciousness is conducive to realizing the energy conservation and emission reduction of large public buildings in China. The concepts of "appropriate comfort" and "perfect service" can be combined by increasing energy-saving consciousness. In addition, it advocates the natural view of harmony between human and nature while increasing the building service level. The government shall propagate energy-saving and low-carbon consciousness positively. The energy consumption of large public buildings, including office buildings, hospitals, schools, and shopping malls, has publicity that determines huge energy waste. The government shall increase public consciousness in energy saving through propagation, which can considerably reduce energy consumption and carbon emissions. Emission reduction paths through policy support and energy-saving consciousness. Finally, the energy consumption and carbon emissions of large public buildings will be decreased by reducing energy use at terminal ends.

CONCLUSIONS

The accelerating urbanization and industrialization in China further intensify the energy consumption of civil buildings. The status of population, economic life, and social life that influenced the energy consumption of civil buildings in Hubei Province in the past 10 years was summarized. Relevant influencing factors were estimated via ridge regression. GDP, total population, tertiary industry development, per capita floor space, household consumption level, and urbanization facilitated the energy consumption of civil buildings in Hubei Province during the aforementioned period, and the regression coefficients were significant at the 5% level. Lastly, several specific policy countermeasures were proposed, including perfecting the incentive mechanism for the energy conservation of civil buildings, perfecting the contract energy management mechanism for civil buildings, accelerating the green construction of civil buildings, and enhancing the energy-saving consciousness of civil buildings. Further studies shall focus on analysing the influencing factors of the carbon emissions of buildings and the provincial difference in the energy consumption of civil buildings, predicting the energy consumption of civil buildings, and enriching the influencing factor system of the energy consumption of civil buildings.

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