Relationship Analysis between Urbanization and Building Energy Consumption in China Based on a Structural Equation Model

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Received 15 November 2014, www.cmnt.lv

Abstract

In this paper, a qualitative analysis is firstly conducted on the relationship between urbanization and building energy consumption from five perspectives which are: urbanization rate, floor space of newly built residential buildings in urban areas, value-added of the tertiary industry, annual per capita consumption of residents and new urban population. Based on the qualitative analysis, a structural equation model is built and quantitative analysis is carried out. The result confirms that there is a strong positive correlation between urbanization and building energy consumption, as well as, the correlation coefficient is gained. Lastly, some suggestions on building energy-saving are given accordingly with the results of the analysis.

Keywords: Urbanization; Building Energy Consumption; Structural Equation Model

1 Introduction

From historical point of view, Urbanization plays a vital role in China's modernization. Premier Li once emphasized "The biggest development potential in next decade's lies in the urbanization". It is widely believed that in the process of urbanization, a large number of new buildings are constructed and this will lead to massive building energy consumption during operation period. Under the background of universal energy shortage worldwide, China has already recognized the importance of building energy-saving and considered it as a key area of energy saving. As early as 1980s, efforts were made aiming at building energy-saving. In 1989, building energy consumption data of northern heating areas and four typical cities including Nanjing, Wuhan, Yichang and Chongqing along the Yangtze River was collected by "Economic and Technological Policy Research Team for China's building energy-saving" [1]. This provided solid statistical support for further policy making on building energy-saving. Following the survey, associated works were started and series of policy and standard were established. However, with the rapid urbanization process, energy-saving policy is unable to match intensive energy-saving demands. According to Ministry of Housing and Urban-Rural Development, building sector nowadays accounts for 28% of total energy use in China. China is under rapid urbanization process. Every year, there are 5.2 billion square meters of buildings to be constructed.

With the sharp growth of construction, as well as the increasing demand on comfortable living conditions, it is expected that building energy consumption will surge aggressively, putting enormous pressure on environment. Under such circumstance, exploring the impact of urbanization on buildings' energy consumption turns out to be crucial for formulating targeted energy-saving policy.

2 Literature review

Many studies on the relationship between urbanization and energy consumption mainly concentrate on the following two aspects. Firstly, there is a wide range of literature examining the positive connection between urbanization and energy consumption. Jones studied the relationship between urbanization and energy consumption by using data of 59 developing countries based on regression analysis, considered that urbanization is an important reason for the increased energy consumption [2,3]. Parikh conducted a quantitative research on the direct impact of urbanization on energy consumption, and built an evaluation model [4]. However, Kenworthy & Laube, Lariviere&Lafrance and Ewing&Rong found that more urbanized areas has lower per capita energy consumption, there is a strongly negative correlation between urbanization and energy consumption [5-7]. The second research perspectives focus on the causal relationship between urbanization and energy consumption. Mishra et al. demonstrated the existence of a short-term Granger causality between urbanization and energy consumption [8]. The Lean's study also found that there are long-term and short-term correlation between urbanization and energy consumption in Tunisian city [9].

Meanwhile, due to the growing focus on the relationship between building energy consumption and urbanization, many researchers have investigated the topic from various perspectives. In the process of prediction for Chinese building energy consumption in 2020, China Energy Research Institute of NDRC used LEAP (Long range energy alternative planning system) and set urbanization as the influence factor of building energy consumption [10]. Bai Wei thought that one of the key factors for analyzing civil building energy demand is the process of urbanization [11]. The research of Yang Jia Etc. shows that population growth, urbanization, economic growth, adjustment of industrial

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structure, technology and energy price influence the main tendency of building energy demand in the future. There is a complex nonlinear relationship among all the factors [12]. Cai made a qualitative analysis on the influence factors of driving the increase of building energy consumption. He also regarded urbanization as a factor and used STIRPAT for quantitative study [13].

Although it is widely accepted that there is a correlation between urbanization and building energy consumption, there is still lack of detailed analysis on whether there is a positive relationship between urbanization and building energy consumption in China and how strong the relationship is. Through constructing a structural equation model (SEM), the paper conducts a quantified analysis on the relationship between urbanization and building energy consumption in China. Furthermore, it also discusses the effect of various factors in the process of urbanization on building energy consumption, as well as, offers constructive references on formulating targeted energy-saving policy.

3 Qualitative analysis on relationship between urbanization and building energy consumption

In this paper, urbanization is the social process of economic change, which includes numbers of cities increasing, city scale expansion, and rural labour moving towards cities. Building energy consumption refers to operation energy consumption of buildings, such as lighting, air conditioning, washing, cooking etc. The operation energy consumption plays a predominate role in building energy consumption.

Urbanization is a comprehensive concept. In order to reflect the current circumstance of urbanization objectti-vely, there is need to measure it from various perspectives. Through literature review and practical survey [10,13], we confirm five major representative factors: "urbanization rate", "new urban population", "floor space of newly built residential buildings in urban areas", "value-added of the tertiary industry" and "annual per capita consumption of residents". The paper is going to discuss the qualitative relationship between urbanization and building energy consumption from the five perspectives, which will lay the foundation for setting up one structural equation model (SEM) and further quantitative analysis.

3.1 URBANIZATION RATE

Urbanization rate is the most commonly used to measure the urbanization level. Comparing to developed countries, it has taken much shorter time for the urbanization rate to reach over 50% in China (from 17.8% in 1978 to 52.6% in 2012). Take the United Kingdom for example, the urbanization rate increased from 26% in 1800 to 51% in 1851 (50 years); In the U.S, the rate rose up from 19.8% in 1860 to 51.2% in 1920(60 years); While in France, it took 140 years for the rate to reach 53.2% in 1946 from 17.3% in 1806. The surge of urbanization rate in such a short period means millions of people moving from rural areas to cities. The huge amount of immigration creates enormous energy requirements, which increase building energy consumption substantially (FIGURE 1).

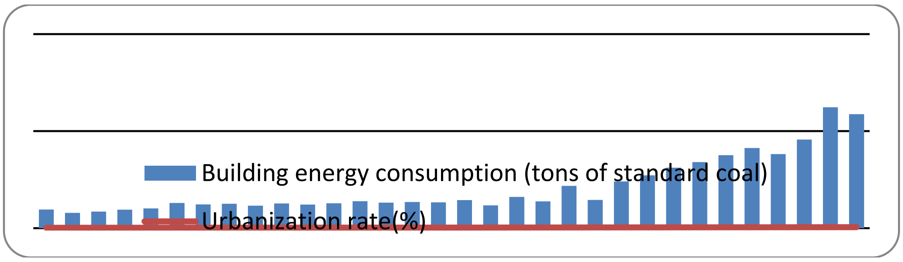

FIGURE 1. Urbanization rate and building energy consumption from 1980 to 2011
Source: China Statistics Yearbook 2013

3.2 NEW URBAN POPULATION

The rapid progress in urbanization witnesses the expansion of cities and rapidly growing population in urban area. New urban population has various impacts on both energy consumption and carbon emission. The increase of urban population would add civil building energy demands and lead to growth in carbon emission and greenhouse effect; it also has significant influence on energy consumption by changing age structure of urban population, for example, the rising proportion of people aged 15-64.

3.3FLOOR SPACE OF NEWLY BUILT RESIDENTIAL BUILDINGS IN URBAN AREA

Urbanization inevitably increases floor space of newly built residential buildings in urban areas, which plays a major role in building energy consumption [13]. Lighting, air conditioning and heating system are both designed based on building floor space. The larger the floor space is, the more energy the building consumes. It will add another 20 kilograms standard coal per year for warming every additional square meter [13]. The total building floor space under construction has increased from 350 million square meters in 1985 to 8.5 billion square meters in 2011. The completed floor space has also grown from 170 million square meters to 3.16 billion square meters in 2011. Experts expect the massive construction would continue for another 25 to 30 years [14]. According to this rate, it is believed the building energy consumption will keep rising progressively in next decades.

3.4 VALUE-ADDED OF THE TERTIARY INDUSTRY

In terms of industrial structure, tertiary industry generally occupies the largest proportion among all industries in highly urbanized areas of developed countries. According to the statistics, tertiary industry accounts for more than 70% of GDP in developed countries. From a long-range point of view, in the process of urbanization, it is inevitable that industrial structure would transfer from labor-intensive traditional industry to modern manufacturing industry and tertiary industry [15]. However, the growth in value-added of the tertiary industry raises the requirement of in-house environment condition, and finally increases the building energy consumption. In accordance with the general principles of international energy statistics, this part of energy consumption is included in public building energy consumption. The statistics show that large public building, floor space of which only accounts for 4% of civil building in China, make up 22% of total electricity consumption of civil building [16]. As shown in FIGURE 2, the electricity consumption of tertiary industry grows progressively. The rapid growth in value-added of tertiary industry will promote public building energy consumption to increase.

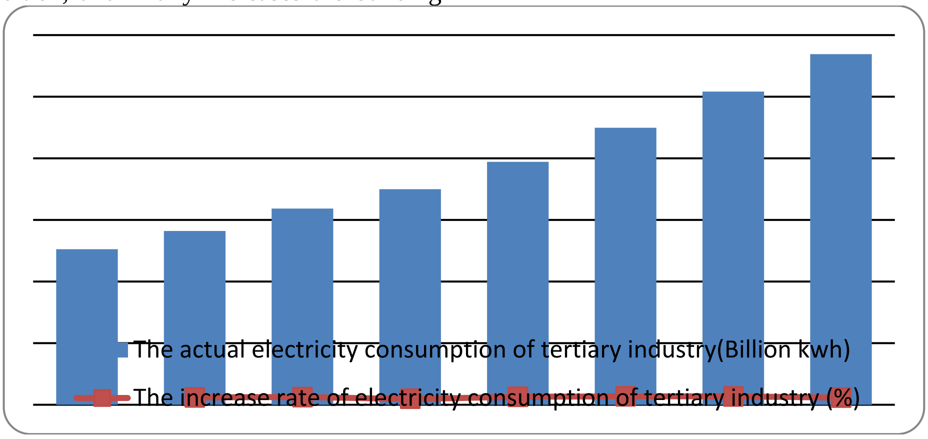

FIGURE 2. The electricity consumption and its increase rate of tertiary industry
Source: Statistical database of China economic and social development

3.5 ANNUAL PER CAPITA CONSUMPTION OF RESIDENTS

Annual per capita consumption of residents is measured by the sum of money on products and services the average resident consumes annually. It refers to how satisfied a resident is in meeting the needs for survival, development and enjoyment. Along with the rapid urbanization, people's living standard improves. The material and spiritual needs increase constantly, and so is the need for comfortable environment. All of these contribute to rise of annual per capita consumption of residents. Annual per capita consumption of residents is regarded as direct reflection of people's living standard. Annual per capita consumption of residents is higher in more urbanized areas. The increasing in annual per capita consumption of residents leads to rise of building energy consumption. For instance, the rise of annual per capita consumption causes the increase in numbers of house appliances (FIGURE 3) and hence the electricity consumption (FIGURE 4). Finally it leads to the growth of building energy consumption.

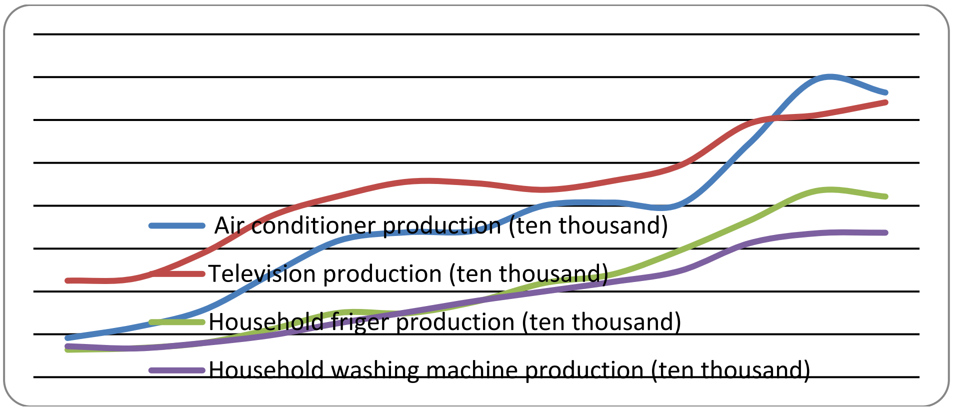

FIGURE 3. Numbers of home appliances
Source: Statistical database of China economic and social development

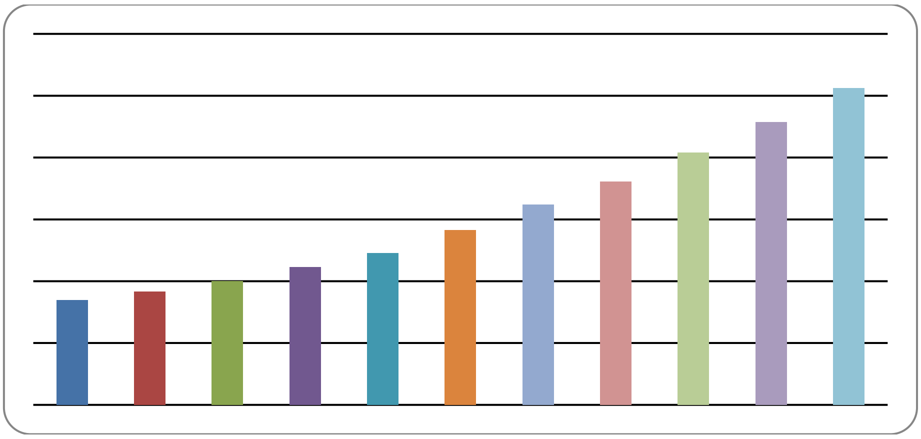

FIGURE 4. Electricity consumption of residents' living(Billion kwh)
Source: Statistical database of China economic and social development

Due to limited space, the paper only explains relationship between urbanization and building energy consumption from five prominent perspectives above. Through qualitative analysis, we could make the assumption that urbanization has direct impact on building energy consumption growth. We will set up a structural equation model to analyze the quantified relationship of the two, and then verify the hypothesis.

4 Establishing the structural equation model

4.1 THE INITIAL MODEL

Structural equation model (SEM) is a statistical technique based on covariance matrix for testing and estimating causal relations between variables. It is considered as a comprehensive mathematical model for exploring the relationship between independent variables and dependent variables. The paper is going to use SEM to explain the relationship between urbanization and building energy consumption. SEM combines the advantages of both factor analysis and path analysis, provides one way to handle the measurement error and eliminates the restrictions on assumed conditions required by path analysis [17-18].

Variables in SEM can be divided, from measurability perspectives, into endogenous variable and exogenous variable. Endogenous variable refers to variables that can be observed and so is called observation variables; exogenous variable also called latent variable, which means it could not be observed straightly. The exogenous variable can be measured indirectly by indicators. Meanwhile, it holds an influence on endogenous variable. Based on the assumption that urbanization would contribute to the growth of building energy consumption, the paper sets "building energy consumption" as endogenous variable, and "urbanization" as exogenous variable and formulates a structural equation model. The name and introductions of five indicators for urbanization are shown in TABLE 1.

TABLE 1. Endogenous variable, exogenous variable and indicators in SEM

Endogenous Variable	Exogenous Variables	Name of Indicators	Introductions
Building Energy Consumption	Urbanization	Urbanization Rate	ratio of urban population to the whole population
		Indices of Annual Per Capita Consumption of Residents	according to 100 in 1978
		Indices of Value-added of the Tertiary Industry	according to 100 in 1978
		Floor Space of Newly Built Residential Buildings in Urban Areas	according to statistics in statistical yearbook
		New Urban Population	urban population this year minus urban population last year

Structural equation model (SEM) in this paper consists of measurement model and structural model. Measurement model describes the relationship between exogenous variable and its indicators, showing which indicators are used in measuring the exogenous variable. A simple measurement model is also recognized as a confirmatory factor analysis model. Structural model integrates multiple regression analysis with path analysis, and illustrates quantitative relationship between exogenous and endogenous variables. In this paper, we use AMOS 17.0 for analyzing. The initial model is shown in FIGURE 5.

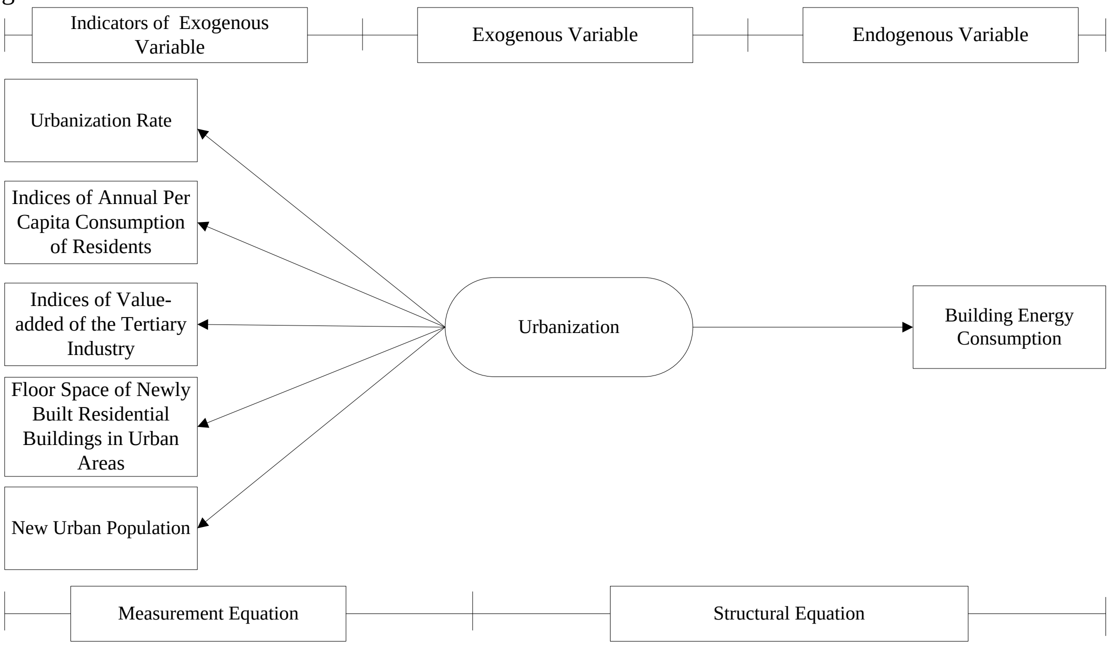

FIGURE 5. The initial model for relationship analysis between urbanization and building energy consumption

The model takes urbanization as exogenous variable and uses five indicators to measure it. Although Figures 5 doesn't show measurement error existing in all five affecting factors, the following step of analyzing with AMOS will take the error into consideration. In the initial model, building energy consumption is endogenous variable, and path demonstrates that building energy consumption is the consequences of urbanization.

The data used in this paper comes from China Statistics Yearbook. The data sample is taken from 1978 to 2011. And all the prices have been adjusted on the base price in 1978.

4.2 MODEL EVALUATION

By adopting maximum likelihood method, parameters are estimated in initial model. And then evaluation process is carried out to see whether the model is eligible or not, according to the output of software. The key content of model evaluation is fitting evaluation which illustrates whether correlations between variables fit the actual data and how they are fitting with each other. Fit indices should be integrated into fitting evaluation of the model. There are two types of fit indices: absolute fit index and relative fit index. Commonly used criteria for fit index is shown in TABLE 2.

TABLE 2. Criteria for fit index in SEM

Fit Index	Suggested Value
Chi-Square / df	<3
RMSEA	<0.08
GFI	>0.9
AGFI	>0.9

The initial model which is run in AMOS is shown in FIGURE 6. The error terms e1, e2, e3, e4 and e5 existing in the five indicators are taken into consideration.

The operation results of initial model are shown in TABLE 3, 4, 5 and 6

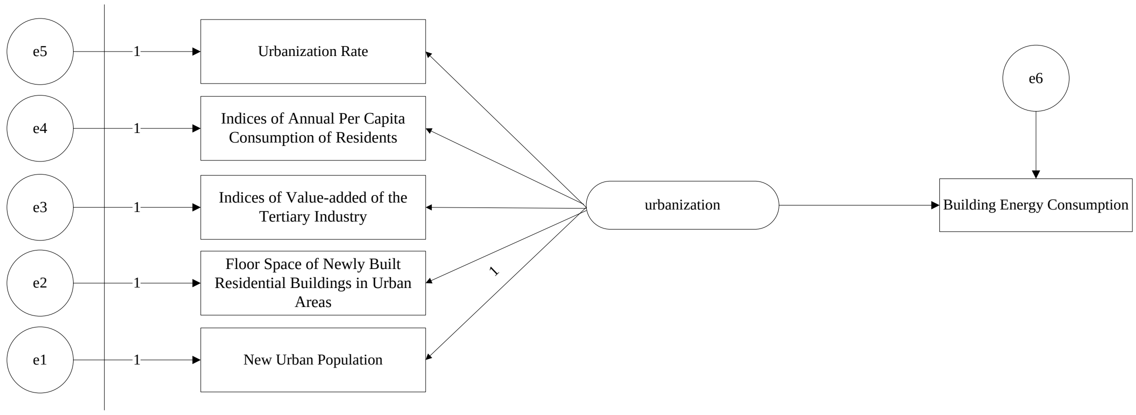

FIGURE 6. The initial model run in AMOS

TABLE 3. Result

Result
Chi-square = 2.970
Degrees of freedom = 9.000
Probability level = 0.705

TABLE 4. CMIN

Model	NPAR	CMIN	DF	P	CMIN/DF
Initial model	12	2.970	5	0.705	0.594
Saturated model	21	0.000	0		
Independence model	6	186.884	10	0.000	18.688

TABLE 5. RMR, GFI

Model	**RMR**	**GFI**	**AGFI**	**PGFI**
Initial model	226535.850	0.929	0.787	0.310
Saturated model	0.000	1.000		
Independence model	3477642.207	0.305	-0.042	0.204

TABLE 6. RMSEA

Model	**RMSEA**	**LO 90**	**HI 90**	**PCLOSE**
Initial model	0.000	0.000	0.270	0.721
Independence model	1.086	0.953	1.225	0.000

As the results show, the estimated Chi-square value of initial model is 2.970 and significance probability p=0.705>0.05. So null hypothesis is acceptable, meaning that theoretical model could fit the observed data. CMIN/DF(Chi-Square/df)=0.594<3,RMSEA=0.000<0.08, GFI=0.9290.900 .These figures are fit within standards. However, considering the fact that AGFI=0.787<0.900, which means the initial model has poor overall fitting performance, some modification is needed.

4.3 MODIFICATION OF INITIAL MODEL

Urbanization rate and new urban population are both related to population proportion. In order to overcome the collinearity problem, we add measurement of co-variation relationship between error term e1 and e5. The relationship isn't inconsistent with the basic assumption of SEM, so it can be added to the model (FIGURE 7)

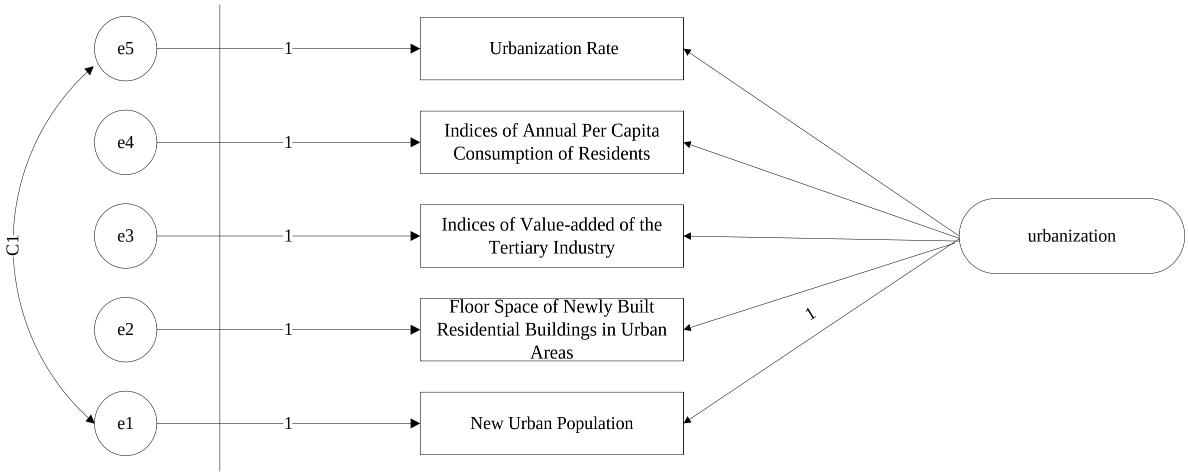

FIGURE 7. Measurement model after adding co-variation relationship between error terms

The operation results after adding error co-variation relationship are shown in TABLE 7, 8, 9 and 10

TABLE 7. Result

Result
Chi-square = 2.208
Degrees of freedom = 4.000
Probability level =0 .698

TABLE 8. CMIN

Model	**NPAR**	**CMIN**	**DF**	**P**	**CMIN/DF**
Modified model	13	2.208	4	0.698	0.552
Saturated model	21	0.000	0		
Independence model	6	186.884	10	0.000	18.688

TABLE 9. RMR, GFI

Model	**RMR**	**GFI**	**AGFI**	**PGFI**
Modified model	266575.600	0.948	0.905	0.253
Saturated model	0.000	1.000		
Independence model	3477642.000	0.305	-0.042	0.204

TABLE 10. RMSEA

Model	**RMSEA**	**LO 90**	**HI 90**	**PCLOSE**
Modified model	0.000	0.000	0.294	0.712
Independence model	1.086	0.953	1.225	0.000

After modification the estimated Chi-square value of initial model is 2.208, and significance probability $p=0.698>0.05$. So null hypothesis is acceptable, theoretical model could fit the observed data. In addition, CMIN/DF(Chi-Square/df)=0.552<3,RMSEA=0.000<0.08, GFI=0.948>0.900, AGFI=0.905>0.900. All reach the fitting standard. So the modified model is acceptable.

4.4 VERIFICATION

The causal path of modified model is shown in FIGURE 8 and TABLE 11.

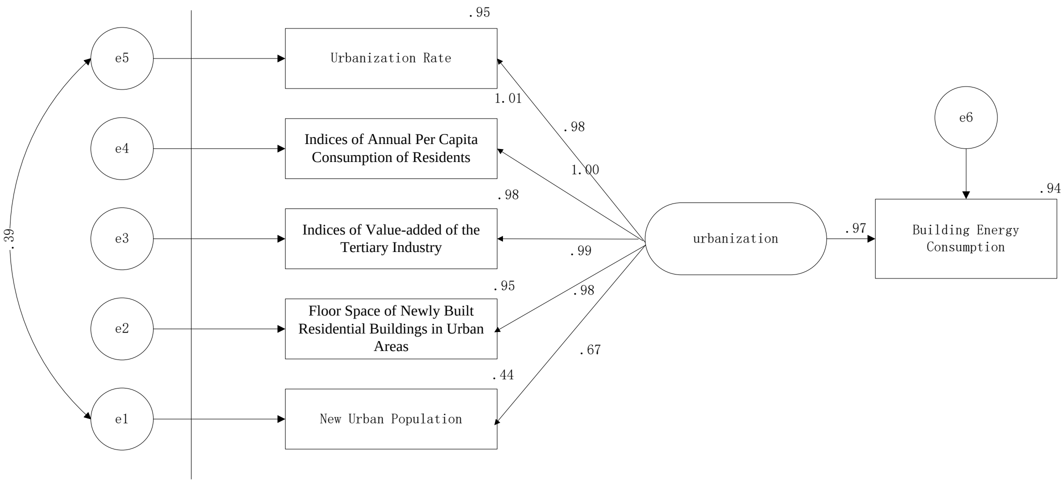

FIGURE 8. Path coefficient diagram of urbanization's impact on building energy consumption after adding co-variance relationship

TABLE 11. Path coefficient of the modified model

			Estimate
New Urban Population	<---	F1	0.666
Floor Space of Newly Built Residential Buildings in Urban Areas	<---	F1	0.979
Indices of Value-added of the Tertiary Industry	<---	F1	0.990
Indices of Annual Per Capita Consumption of Residents	<---	F1	1.003
Urbanization Rate	<---	F1	0.976
Building Energy Consumption	<---	F1	0.972

Notes: F1 represents urbanization

Through structural equation model, we verify that urbanization has influence on building energy consumption. The path coefficient of exogenous variables on the endogenous variables is 0.972, R^2=0.94, Standardized regression coefficient is positive. The statistics is consistent with our initial theory that urbanization as exogenous variable has significant influence on the growth of building energy consumption. This in return, confirms the basic assumption we made at the beginning.

The most significant influence is "Indices of Annual Per Capita Consumption of Residents" whose path coefficient is 1.003. The second largest influencing factor is "tertiary industry" whose path coefficient is 0.990. Because tertiary industry energy consumption is the largest component of public building energy consumption, with the development and prosperous of tertiary industry, energy consumption in public building would increase simultaneously.

"Floor space of newly built residential buildings in urban areas" is also key factor for the growth of building energy consumption. The path coefficient is 0.979. The increase in floor space will inevitably cause growth in energy consumption of lighting and air conditioning system. As to the rest two factors, the impact of "urbanization rate" is bigger than that of "new urban population".

5 Discussion and suggestion

Through structural equation model, we come to the conclusion that the process of urbanization has a positive contribution to the rising building energy consumption. Due to the fact that urbanization process has direct influence on the rapid growth of building energy consumption, energy-saving countermeasures should focus on various perspectives of urbanization and rational policies should be designed. According to research result above,we propose several energy-saving countermeasures:

(1) "Indices of annual per capita consumption of residents" has the most significant influence on building energy consumption growth. So there is need to provide positive guidance on residents' living style and consumption preference. Apart from giving publicity to energy-saving behaviour and subsidizing such practice, we should also encourage the use of green techniques and green home appliance. By matching customers' request for comfort with building energy-saving demand, it is more practical in achieving energy-saving goal during operation period.

(2) Path coefficient of "Indices of value-added of the tertiary industry" on building energy consumption is 0.990. Attention should be paid on public building energy-saving as public buildings are the carriers of tertiary industry. The primary method is to set rational goal on energy-saving for public building, build up an ideal energy trading system and encourage the use of latest energy-saving techniques. In addition, local climate and resource availability should be taken into account to establish circulation system that satisfies the resource and energy demand, and finally reduce building energy consumption.

(3) Path coefficient of "Floor space of newly built residential buildings in urban areas" on building energy consumption is 0.979. It requires enough attention as third highest influencing factor following "Indices of annual per capita consumption of residents" and "Indices of value-added of the tertiary industry". So we suggest matching the construction practice to real demand, reducing the number of large unit apartment and encouraging small-sized apartment. We should also encourage the use of green

material, which is environmental friendly in both utilization and disposal ways.

(4) "Urbanization rate" together with "new urban population" have relative strong influence on building energy consumption growth. We should be cautious during the urbanization and avoid unplanned and blind urban expansion. Economic, social and environmental capacity should be taken into consideration to minimize the unnecessary energy consumption. Another that worth mentioned is the influence coefficient of "urbanization rate" is higher than that of "new urban population". This indicates that compare to restrict the absolute number of people in cities, rational planning of the relative ratio of urban population is more likely to reduce building energy consumption. Improve the living condition in rural areas and narrow the gap between rural areas and cities also have positive effect on controlling building energy consumption.

Acknowledgements

The authors would like to thank the Sustainable Construction Research Programme of Chongqing University.

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