A study of citywide urban residential energy information system for the building energy efficiency management: a cluster model of seven typical cities in China

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Abstract The lack of empirical data demonstrating the relationship between influencing factors and building energy performance is one of the primary barriers in energy efficiency management. A citywide residential energy information database and the data-based analyt-ical methodology help increase the knowledge about the local real estate situation, explore energy efficiency opportunities and measures, financial investment, and market trend in the local building stocks, and make the reasonable policies as well. Few databases were established in USA and Europe only covering the uilding information and energy use, while there are lack of an indices system and database of building energy efficiency information in China. Therefore, in this study, a definition of urban residential energy infor-mation system is suggested, covering the parameters of building characteristics, household characteristics, possession and operation of domestic appliances, indoor thermal environment, climate condition, energy market, economic level, municipal infrastructure, and energy use consequence. Consequently, a database is developed to collect the raw data in seven typical cities in China. A classification model is established by Quantitative The-ory III to classify and characterize the urban residential energy use systems into three different city groups, and suggestions are made to guide the energy efficiency work for different city groups. The case study is a good example to demonstrate the methodology and the anal-ysis provided a helpful reference for the citywide build-ing energy efficiency management.

Introduction

The national residential sector is of great concern in many countries due to its rapid increase and large pro-portion in the total energy use and CO_2 emissions in the recent decade. Nationally, the average value of energy use of the residential sector accounts for nearly 30% of the total energy use by all the sectors in the society and gives more than one sixth of the carbon emissions globally (Stanley et al. 2016). Compared to other countries, the percentage of the residential energy consumption (REC) in the national energy consumption in China provides a reference for the 12.45% in 2016, lower than the world average (National Bureau of Statistics of China 2018). However, the residential energy consumption increases rapidly year by year due to the improvement of the living standard, and it is expected to reach the level as high as in developed countries. Hence, much attention on energy conservation of residential buildings regionally or nationally has been increasingly paid (Nie and Kemp 2014). From the perspective of national or regional energy conservation, the lack of empirical data demonstrating the relationship between influencing factors and building energy performance becomes one of the primary barriers in residential energy efficiency management. A citywide residential energy information database and reasonable analytical methodologies provide quantitative analysis with plentiful basic data, which help increase the knowledge about the local real estate situation, explore energy efficiency opportunities and measures, financial investment, and market trend in the local building stocks, and make the reasonable policies as well (Monteiro et al. 2018). Very few databases have been established in USA and Europe covering only the building information and energy use, while there are lack of a comprehensive indices system and database of residential energy efficiency information for Chinese condition (Mathew et al. 2015; European Commission 2017; Zhou et al. 2012). In order to support residential energy efficiency management in a city from the perspective of data collection and analytic methodology development, it is very meaningful to set up a comprehensive residential energy information database, covering all the necessary information. Such a database may include data of energy use, the main influencing factors of both building itself and external environment, and the environmental and social economic effect, etc. Scientific analyses should be conducted based on the empirical data so that meaningful strategies can be made to guide the energy efficiency work of different Chinese cities.

Building energy information databases

A regional or even national building energy information database should provide all the necessary information for building energy efficiency management. Lots of research work has been done to explore the influencing factors of residential energy use from the building perspective. For example, some key factors influencing residential energy use, such as building thermal performance, and indoor and outdoor climate environment conditions, were identified and quantified by some large-scale field investigations (Chen et al. 2010; Xu et al. 2013; Yu et al. 2011). Annex 53, Total energy use in buildings: Analysis and evaluation method, under the International Energy Agency's program within Energy in Buildings and Communities (EBC), put great effort to figure out the influencing factors of building energy use, and the authors' research group put forward taxonomy in this project to present the building information, energy use, building service system and appliances, and the operation of building and appliances by using three-level structures for statistical analysis, case studies, and simulation, respectively (Chen et al. 2013). Another program within the EBC is Annex 66 that focuses on understanding the influence of occupant behavior on building energy use (Hong et al. 2017a, b). The results from this project show that the performance and running schedules of energy-consuming equipment are two of the main contributors of residential energy consumption (Chen et al. 2015, 2017a, b; Hong et al. 2016). However, all the above analyses on the influencing factors of building energy use are developed from the angle of the building itself, while from the point of view of citywide building energy efficiency management or energy planning, many other factors may also have large influences on residential energy use, and thereby should be taken into consideration. For example, the availability of energy resources and end-use structure would also affect the energy consumption and environment (McNeil et al. 2016; Zhou et al. 2013). Related research also indicates that residential energy use is also influenced by the GDP, energy price, and energy resource supply structure (Wu and Chen 2017; Zhou et al. 2013). Therefore, all the elements mentioned above and the interactions among energy use, factors inside the buildings, and the energy market and even social conditions should be taken into consideration for the purpose of proper energy planning. Consequently, a comprehensive understanding of residential energy use and the influencing factors related to both the external influences of outside the buildings, and inherent mechanism of individual buildings could be achieved.

After the identification of all the necessary parameters, the establishment of building energy information database is a fundamental step for the citywide building energy efficiency management. As one of effective attempts, Energy Information System (EIS), which can monitor and organize building energy consumption and other related data online, such as indoor environment, has been putting into broad use in the fields of large commercial buildings, university campuses, and even one single residential house (Granderson et al. 2011; Ueno et al. 2006). Time-series data from meters, sensors, and external data are commonly used to perform analyses such as load profiling and building level fault detection (Granderson et al. 2011). From the citywide and even national wide perspective, the establishment of a regional or national database is fundamental to provide the first-hand data for policy development. Some of the successful examples are the Commercial Buildings Energy Consumption Survey (CBECS) and Residential Energy Consumption Survey (RECS) which are taken every 4 years in the USA. These examples are based on the national surveys for thousands of buildings requiring huge labor force. Therefore, the mentioned databases contain only basic information, such as floor area, construction year, types of domestic appliances, the operation frequency, energy consumption amount, energy use expenditure (U.S Energy Information Administration 2016a, b). Another database called Building Performance Database (BPD) was also established in the USA as a publicly accessible database with anonymous and empirical data of the similar parameters, by integrating Energy Efficiency Program Administration Databases, CBECS, and RECS, etc. (U.S. Department of Energy 2017). In Europe, Energy Performance Certificate (EPC) is an influencing labeling scheme, which forms the database with hundreds of thousands of EPC records. The basic building performance and the calculated delivered energy demand are included in the database. However, data on actual user behavior and climate on the building site are not recorded (Hörner and Lichtmeß 2018). The EPC database increasingly provides for an overview of the energy standard in the European building stock and supports statistical analysis. Besides the national database, there are several regional ones. For example, in Belgium, there is the database for residential buildings in Liege and its neighborhood, including the information of building performance and energy use (Singh et al. 2013). The Chinese government has been also developing a national platform of commercial building energy consumption, which is monitoring the hourly real-time data of the commercial buildings in each province (Ministry of Housing and Urban–Rural Development of China 2008). The Ministry of Housing and Urban-Rural Development of China also set up the statistics reporting system to collect the energy consumption data of civil buildings. However, the data only covers the construction year, floor area, and annual total energy use, and the data for residential buildings are very few and not open to the public (Zhou et al. 2012). The authors' research group has conducted the large-scale investigations of residential energy use, building information and thermal performances, ownership and operation of building appliances, and indoor thermal comfort in 10 cities of five climate zones in China, and more than 6000 families have been investigated (Chen et al. 2008, 2010). However, most of the existing databases just cover the information of building thermal performance, energy use, while very few provide information on building description and appliances operation, together with the data on external environment in the society, which are important for the macro management.

Building energy efficiency assessments based on the building energy information database

Base on the building energy information database, building energy efficiency analysis and assessment could be made, and hence practical strategies could be provided for the energy efficiency management of residential buildings in the cities. A holistic approach has been adopted to analyze the building stock of Liege, based on "General Socio-economic survey 2001" and "Housing quality survey 2006 in Walloon region" databases, and it is found that 69% of buildings constructed before 1945 needs serious renovation toward the improvement of roof and external wall insulation level (Singh et al. 2013). The existing data with national coverage and the measured electricity and gas consumption of groups consisting of, on average, 500–700 households have been used to benchmark and track domestic gas and electricity consumption across England. The comparison of the actual gas and electricity demand of the houses with the modeled benchmark clearly identifies those areas with the greatest potential for demand reduction (Morris et al. 2016). Few studies have focused on residential energy savings in China using household survey data. Feng et al. (2010) investigated the barriers to energy efficiency in the residential sector based on the questionnaire surveys covering more than 600 households in Liaoning province China. The status of residential energy use and the influencing factors in typical cities in China based on the large-scale investigations in 10 cities of five climate zones in China were thoroughly analyzed by Chen et al. (2010). Through these studies, several problems have been observed as possible challenges of such an analysis from the citywide perspective. One of the most significant barriers for citywide building energy efficiency assessment is the lack of enough data open to public from different municipal departments. The second problem is that monitoring system and large-scale on-site investigations are also greatly needed for the evaluation of sustainable residential energy use at citywide level, especially in China. The third problem is that most of the assessments are performed from the angles of energy use, building thermal performance, and building technical and service systems, and some of them consider the environmental benefits, while there is little assessment work performed considering the energy market, municipal infrastructure, economics, and social development. In that situation, a comprehensive assessment covering these factors is greatly helpful to guide the building energy conservation work in a city. The fourth problem is that some qualitative assessment indices are usually quantified by the expert scoring method based on their subjective experiences during the assessment, and thereby it makes hard to achieve objectivity and accuracy.

Aiming to solve the problems above, firstly, a definition of citywide urban residential energy information system (UREIS) is developed. The UREIS consists of residential building energy use, influencing factors inside the building, such as household characteristics, performance and operation of domestic energy consuming appliance, etc., and the factors outside the building and related to the society, such as the climate, energy market, etc., and the environmental benefit as well. Secondly, a database of the UREIS is established by taking the cases of seven typical cities in China. Third, a classification model of the UREIS is developed by Quantification Theory III, which introduces qualitative variables into the model with an objective way to quantify the variables, so that the subjectivity of the expert evaluating method is overcome (Dong et al. 1979). By using the database, a classification of the seven cities is made to characterize the different urban residential energy use systems of different city groups, and hence the corresponding strategies are made to guide the energy efficiency work of different city groups. This research should show a helpful reference for the citywide residential energy efficiency management.

Definition of urban residential energy information system

For the reasonable residential energy efficiency management in a city, it is fundamental to fully understand the characteristics of urban residential energy use, its influencing factors and the energy use consequences from the citywide perspective. After full-scale literature retrieval, a definition of the UREIS is developed. The definition covers the following four parts of information, as illustrated in Fig. 1:

1. Factors inside the building: building characteristics, household characteristics, the ownership and operation of the main energy-consuming appliances, and indoor thermal environment are proved to greatly affect energy use of residential buildings, so as to be included in the definition (Chen et al. 2008, 2010; Xu et al. 2013; Yu et al. 2011);
2. Total energy use and energy use breakdown by the energy carriers are definitely as the main part of the UREIS;
3. Situation outside the building: climate, energy market, social economy, and municipal infrastructure form the external environment of residential energy use, which also have direct or indirect influences leading to different situations of residential energy use in different cities (McNeil et al. 2016; Zhou et al. 2013);
4. Environmental consequence and socio-economic effect are the two aspects caused by the citywide energy use.

Based on the concept of the UREIS, specific indices are developed in the four categories to reflect the citywide residential energy information characteristics. Table 1 lists the UREIS indices.

Part 1: factors inside the building. The indices in four categories of building characteristics, household characteristics, the ownership and the operation of energy-consuming appliances, and indoor thermal environment were developed, such as construction year, building orientation, building materials in Part 1.1, the number of family members and income in Part 1.2, usage monthly and daily use hour of appliances in Part 1.3, and indoor temperature and subjective evaluation of indoor thermal environment in Part 1.4 (Chen et al. 2010).

Part 2: Energy use amount. Energy use and the breakdown by the energy carriers are developed.

Part 3: Situation outside the building. Since the outside temperature, fuel price, and per capital GDP value are the non-negligible influencing factors of residential energy use, they are taken into consideration in Part 3 (McNeil et al. 2016; Zhou et al. 2013). In addition, the indices of gas popularization rate and the density of pipeline gases are used to reflect the construction status of municipal infrastructure of a city, and hence are also included in this indices system.

Part 4: Environmental consequence and socio-economic effect. As a result of residential energy use, the emission amounts of greenhouse gases (GHG) can be used to reveal the environmental effect and is thereby included in this part. An economic index, the ratio of per capita fuel expenditure to per capita annual living expenditure of urban households, which is indirectly affected by household wealth and social economic level in the city, is also included in this part.

The database of RUEISs of a seven-city case study in China

Description of the analyzed cities

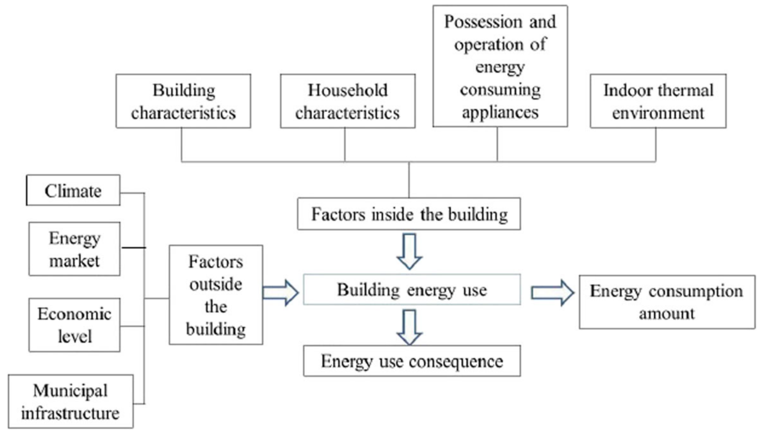
Seven cities were selected as a case study to establish the database of RUEISs, as shown in Fig. 2. Sampling method was designed in a scientific way to obtain representative family samples in each city. Three-phase sampling method was adopted. In the first phase, by the way of representative sampling, typical cities were selected in each climate zone of China, namely very cold zone, cold zone, moderate zone, hot summer and cold winter zone, and hot summer and warm winter zone, which were officially classified by the Code of thermal design of civil building GB50176-2016. Both the residential buildings and residents have the different characteristics of building performance, air conditioning modes, and residential energy use in different climate zones of China, and in this case, the respective characteristics of both air conditioning modes and residential energy use in each climate zone can be covered. In the second phase, in order to ensure the representativeness of the selected samples, several typical residential communities were selected in each administrative division of the cities. Each residential community was required to represent the common situation for the UREISs' parameters. In the third phase, families were finally chosen by random sampling. It should be pointed out that attention was also paid on selecting the samples, so that diversities in the household backgrounds and domestic economic levels were taken into consideration (Chen et al. 2010).

Data collection

Face-to-face surveys were conducted in all the investigated families in the seven cities in summers from 2004 to 2009. Considering the experiment difficulty and the huge workload in these cities, the summer scenario is taken as the case study to verify the methodology developed in this paper, and to show the significance and effect of UREIS on building energy efficiency management. Uniform questionnaires were conducted in the seven cities, covering the indices in Parts 1 and 2 of Table 1, such as building characteristics, household characteristics, and the ownership and operation of electric appliances. Energy consumption data of 1 month in summer were recorded for these families. Indoor temperature of each investigated family was also recorded by the residents by reading the thermometers in the morning, noon, and evening during the investigated periods. The thermometers had the measurement range between −30 °C and 60 °C, with the precision of ± 0.6 °C calibrated by the instrument manufacturers. Indoor thermal comfort in summer was also evaluated by the surveys.

The data in Part 3 and the social economic effect in Part 4 were additionally collected from the related local municipal departments, such as gas supply company, the weather bureau and the price bureau, as well as some document sources, such as yearbooks. Since the ratio of per capita fuel expenditure to per capita living expenditure of urban households was difficult to obtain for some

Fig. 1 Concept mapping of an Urban Residential Energy Information System (UREIS)



cities, the ratio of per capita residential expenditure to per capita living expenditure of urban households is used as a substitute. Per capita residential expenditure consists of fuel expenditures and housing expenditures. Table 2 lists the GHG amounts emitted by burning one unit calorific value of fuel (Streets and Waldhoff 2000; Xiang 2000). The values of the indices of environmental consequences are obtained by multiplying the monthly use amounts of different energy resources in summer by their corresponding amounts of emitted GHG shown in Table 2.

Summary of energy information indices

The indices for the situation outside the building and consequences of the REU in Parts 3 and 4 are given in Table 3 for each city for the investigated year based on local statistic yearbooks and other related references (Comprehensive Financial Affairs Department of Ministry of Construction 2005; Harbin Statistical Bureau 2004; Hong Kong Official Languages Agency (HKOLA) 2001; Hunan Statistical Bureau 2003; Kunming Statistical Bureau 2006; Urumqi Statistical Bureau 2005).

The features of some important indices in Table 1 are summarized briefly as following:

1. Building characteristics among the seven cities. Buildings constructed in the 1990s are dominant in Harbin, Urumqi, Changsha, and Kunming; buildings in Shanghai and Beijing are relatively newer, with 66% and 42% built in the 2000s, respectively; buildings in Hong Kong are comparatively older, where 58% were built before the year of 1985. In terms of the construction structure, brick–concrete structure plays an important role in building envelope, with the percentage of larger than 60% in all the seven cities. Concerning household floor areas, Shanghai and Beijing have the mean values above 100 m^2/household, while Hong Kong has the smallest average value of only 58 m^2/household, and the average values are round 80 m^2/household in the rest cities. Figure 3 shows the building orientation in the seven cities. More than 60% of the buildings in Changsha, Shanghai, and Urumqi have the south–north orientation, which is a good orientation for energy conservation in China, while Harbin, Beijing, Kunming, and Hong Kong have more than half of the buildings with other orientations, especially for Hong Kong with the large percentage of 86%.
2. Household characteristics. Hong Kong has four persons per household on average, and Shanghai, Beijing, and Harbin have 3.3, 3, and 3 persons per household, respectively; Urumqi and Kunming have the smallest family members, with the same value of 2.8 persons per family. In terms of household annual incomes in the seven cities, the families in Hong Kong have the highest income, with a percentage of 66% ranging from 40,000 to 200,000 RMB (US$1 = 6.7 RMB) per year per household after tax. It is followed by Shanghai and Beijing with the ranges of above 60,000 RMB per year, and between 40,000 and 60,000 RMB per year, respectively. Domestic economic levels in Kunming and Changsha are basically similar, with 52% and 36% of the families earning between 20,000 and 40,000 RMB per year, respectively.

Table 1 Attribute indices of the urban residential energy information system

Part	Category	Evaluation indices
Part 1: factors inside the building	1.1 Building characteristics	1. Construction year
		2. Construction structure
		3. Material of window frame
		4. Building orientation
		5. Household floor area
		6. The number of building floors
	1.2 Household characteristics	1. Number of family members
		2. Domestic income
		3. The ratio of energy expenditure to income
		4. Daily occupancy hour on weekdays and weekends
	1.3 The possession and the operation of energy-consuming appliances	1. The number of main kinds of domestic appliances
		2. Usage months and daily use hour of appliances
	1.4 Indoor thermal environment	1. Indoor temperature
		2. Subjective evaluation of indoor thermal environment
Part 2: Energy use amount		1. Annual or monthly energy use amount
		2. Annual or amount of different end uses (optional, if enough data can be obtained)
Part 3: Situation outside the building	3.1 Climate	1. Monthly average outside temperature
	3.2 Energy market	2. Fuel price
	3.3 Economic level	1. Per capita GDP value
	3.4 Municipal infrastructure	1. Gas popularization rate (which is equal to the ratio of population using the gas to the total population in the city)
		2. The density of pipeline gases
Part 4: Consequences of residential energy use	4.1 Environmental consequences	1. Emission amount of CO2
		2. Emission amount of SO_X
		3. Emission amount of NO_X
	4.2 Social economic effect	1. Ratio of per capita fuel expenditure to per capita living expenditure of urban households

Fig. 2 General information of seven target cities and the family samples

Families in Urumqi and Harbin have the lowest income, and around half of them earn less than 20,000 RMB annually. Figure 4 shows the ratios of energy expenditure to the income among the seven cities. From Fig. 4, it may be noted that more than 80% of the families in Harbin and Urumqi have the ratio of energy expenditure to income less than 10%, due to the low energy expenditure for space cooling in the two cities, regardless of their lowest income. The same situation occurs in Kunming. Shanghai has the relatively higher ratio, compared with the previous cities, while Changsha has 62% of the families with the ratio higher than 10% because of the higher energy use for space cooling but relatively lower family income. Although the families in Hong Kong have the highest economic level,

Table 2 Greenhouse gas amount emitted by the burning of energy resources of unit calorific value

Energy resources	CO_2 Emission Amount (g/MJ)	NO_X Emission Amount (g/MJ)	SO_X Emission Amount (g/MJ)
Electricity	307	0.004	0.144
Coal gas	45.1	0.106	0.004
Natural gas	50.3	0.05	0.001739
Liquefied petroleum gas	59	0.17	0.001

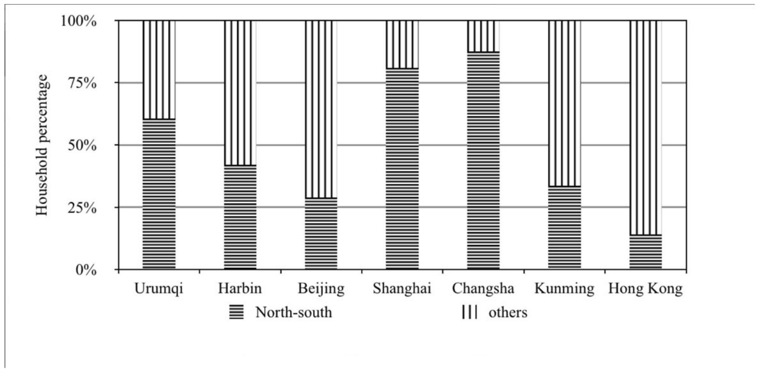
the frequent use of air conditioners and other domestic appliances finally leads to the high ratio.

3. The ownership and the appliances operation. Figures 5 and 6 show the household ownership of air conditioners and electric fans among the seven cities. As shown in the two figures, most of the families in Urumqi, Harbin, and Kunming have no air conditioners, while about half of the families have two air conditioners in each family in Shanghai, Beijing, Kunming, and Hong Kong. There is the similar situation for electric fans in these cities. Further, Fig. 7 shows the average values, standard deviation, and maximum and minimum values of daily usage hours of air conditioners and electric fans in these cities in summer. The mean values of daily use hour in the three cities are less than 2 h per day in Kunming Urumqi and Harbin. Most of the families in the three cities nearly do not use space-cooling appliances, and this leads to the large standard deviation, even larger than the mean value. In the other four cities, air conditioners are used for 10 to 12 h per day and electric fans for 8 to 11 h per day. Regarding the ownership of water heaters, the gas water heaters are most commonly used in Beijing, Shanghai, Changsha, and Hong Kong, while the electrical water heaters are widespread in Harbin and Urumqi. Many families in Kunming and Urumqi use solar energy to heat water, especially in Kunming with the percentage of more than 60%.
4. Indoor thermal environment. The average value of the temperature in the morning, noon, and evening in the investigated period is used to reveal the indoor temperature. It shows that Changsha, Beijing, Hong Kong, and Shanghai have the mean indoor temperature of 25.5 °C, 27.4 °C, 28.9 °C, and 30.1 °C, respectively, when occupied, and Harbin and Urumqi have the values of 25.7 °C and 25.8 °C, and Kunming has the lowest value of 23.2 °C. Regarding the thermal environment satisfaction in the summer by the residents, nearly half of the families in Hong Kong do not care about the thermal environment, and 32% of the families are satisfied with the current thermal environment. About half of the families in Beijing, Shanghai, and Changsha, and nearly all the families in Kunming are satisfied as well. Although the indoor

Table 3 Indices related to outside of the building situation

Indices		Harbin	Urumqi	Beijing	Shanghai	Changsha	Kunming	Hong Kong
Average outdoor temperature of the investigated month (°C)		22.1	24.6	27.4	29.5	27.9	20.4	28.1
Gas price (Yuan/MJ)	Pipeline coal gas	0.057	0.076	0.068	0.06	0.068	0.045	2.25
	Pipeline natural gas	0.056	0.038	0.053	0.059	0.062	0.045	–
	Pipeline LPG	0.1	0.044	–	–	0.138	–	0.287
	Bottled LPG	0.067	0.044	–	0.108	0.083	0.092	0.238
GDP per capita (Yuan/capita)		14,872	22,820	28,449	46,718	14,763	18,773	188,835 (HKD)
Gas popularization rate		98.1	99.7	99.57	100	92	81.5	96.2
The ratio of per capita living expenditure to total consumption expenditure of urban households		9.80%	7.89%	9.00%	11.60%	12.49%	8.27%	35%

Fig. 3 The building orientation among seven cities



temperature in Harbin is lower than in Beijing, Hong Kong, and Shanghai, a large part of the families in Harbin are dissatisfied with the thermal comfort.

5. Energy consumption amount. Household energy consumption of the investigated month in summer in each city is used for the analysis. The results show that the household electricity consumption in Hong Kong is much higher than that in other cities in summer, with the average value of 2694 MJ/(household · month). The mean household electricity use amount in Beijing, Shanghai, and Changsha is 825 MJ/(household · month), 926 MJ/(household · month), and 812 MJ/(household · month), respectively. Families in Harbin, Urumqi, and Kunming consume electricity in small amounts, with the average values all below 500 MJ/(household · month). For monthly gas use, Shanghai has the largest mean value of 1119 MJ/household, while Harbin has the lowest mean value of 535 MJ/household. Beijing, Changsha, and Hong Kong are at the moderate level, with the mean values between 767 and 846 MJ/household.
6. Environmental consequence. Figures 8, 9, and 10 show the monthly GHG emission in summer in the seven cities. Hong Kong, Shanghai, Beijing, and Changsha have larger CO_2 and SO_2 emission than other cities, which have similar trend as electricity use. As for NO_X, the families in Changsha have the largest emission, followed by Hong Kong and Shanghai, and Beijing has the smallest emission value. The GHG emission above shows the differences of energy structures in the seven cities.

Characteristic analyses of UREISs in the seven cities in China by the classification model

The above analyses have shown the basic situation of UREISs of the seven cities. Based on this database, a classification model of UREIS was developed by Quantification Theory III, and the classification of the seven cities was made to characterize the different urban residential energy use systems of different city groups. The

Fig. 4 The ratios of energy expenditure to income among the seven cities

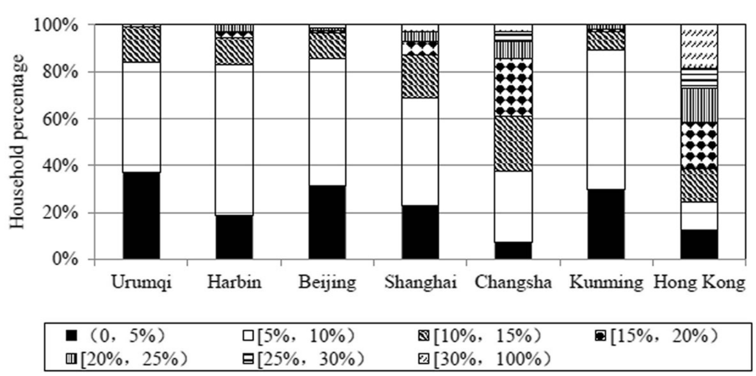
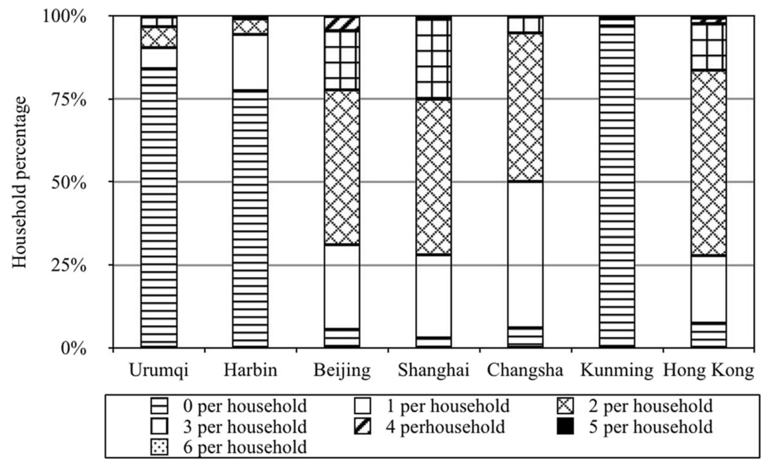


Fig. 5 The ownership of air conditioners in the seven cities



corresponding strategies were made to guide the energy efficiency management in different city groups, based on the results of classification analysis. Since only the data of energy use amount and indoor thermal environment in summer were collected, only the summer scenario was considered in this case study.

The mathematical model to classify the features of UREIS of different cities by using Quantification Theory III

Quantification Theory is a branch in the multivariate statistical analysis. It was mainly applied in the econometric sociology at the beginning, and it has been extended to many fields, such as forestry, mining, and clinical medicine (Dong et al. 1979). Quantification Theory III, as a classification methodology in Quantification Theory, has been widely used to make the classification or rank the levels (Li et al. 2010). Compared with traditional statistical theories, such as Principal Component Analysis (PCA), Cluster Analysis, and Decision Trees, there are several distinct advantages of Quantification Theory III: firstly, both qualitative variables and quantitative variables can be introduced into the model; secondly, the responding relationship between the factors and samples can be revealed in a quantitative way; thirdly, the weights of the variables can be decided by the data calculation, with no need of expert scoring, that is to say an objective way can be used to quantify the influence of variables on samples by this methodology, so as to overcome the subjectivity of the expert evaluating method. In this paper, Quantification Theory III is used to cluster the samples and variables of the UREIS, in order to get the features of UREISs for the analyzed cities.

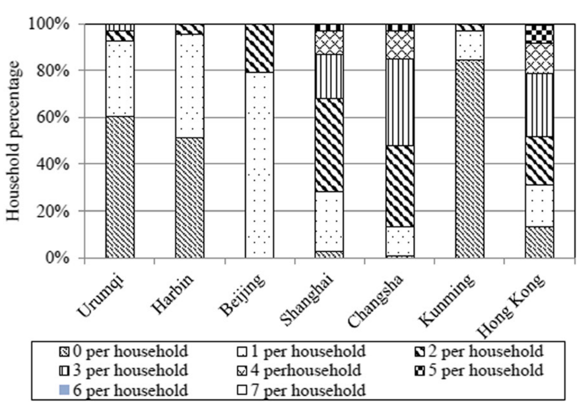


Fig. 6 The ownership of electric fans in the seven cities

The basic principles of Quantification Theory III are as follows: (1) each sample (or each variable) is given a suitable value, namely the score of the sample (or the variable). The samples (or the variables) which have close scores can be categorized into one group; (2) the samples (or the variables) in the same group usually demonstrate similar performance in some aspects; (3) the variables with larger scores in their absolute values can be judged as important indices to explain reasons for sample classification in different groups (Dong et al. 1979).

In Quantitative Theory III, assuming there are n samples, s quantitative variables and m qualitative variables among the independent variables, as follows:

$$X = \begin{bmatrix} \delta_1(1) & \dots & \delta_1(m) & U_{11} & \dots & U_{1S} \\ \delta_2(1) & \dots & \delta_2(m) & U_{21} & \dots & U_{2S} \\ \vdots & & \vdots & \vdots & & \vdots \\ \delta_n(1) & \dots & \delta_n(m) & U_{n1} & \dots & U_{nS} \end{bmatrix} \quad (1)$$

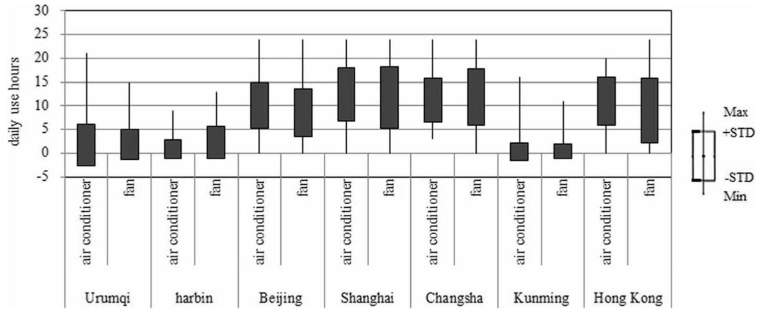


Fig. 7 Daily operation hours of air conditioners and electric fans in the seven cities

where $\boldsymbol{X}$ is reaction matrix of samples; $\delta_i(j)$ is the value of the qualitative variable j in sample i, and u_{i1} is the standardized value of the first quantitative variable in the sample i. The aim of the Quantitative Theory III is to score the $m + s$ variables and the n samples. The score of each variable, namely the weight of each variable, can be expressed as in Eq. (2):

$$\boldsymbol{b} = (b_1, b_2, \ldots, b_m, \alpha_1, \ldots, \alpha_S)' \tag{2}$$

The score of each sample, namely $\boldsymbol{Y}$, is obtained by Equation (3).

$$\boldsymbol{Y} = (Y_1, Y_2, \ldots, Y_n)' = X\boldsymbol{b}/(m+s) \tag{3}$$

The mean value of the total scores of the n samples can be obtained by Eq. (4):

$$\bar{y} = \frac{1}{n(m+s)} \left(\sum_{j=1}^{m} \sum_{k=1}^{r_j} b_{jk} \sum_{i=1}^{n} \delta_i(j,k) + \sum_{l=1}^{s} a_l \sum_{i=1}^{n} u_{il} \right) \tag{4}$$

Assuming that $g_{jk} = \sum_{i=1}^{n} \delta_i(j,k), j = 1, 2, \ldots, m, k = 1, 2, \ldots, r_j$ (5)

then

$$g = \left(g_{11,\ldots,}g_{1r_1}, \ldots, g_{m1,\ldots,}g_{mr_m}, 0\ldots, 0\right) \tag{6}$$

Introduce the matrix H as

$$H = X'X - \frac{gg'}{n} \tag{7}$$

Finally, $\boldsymbol{b}$, the weight of each variable, is the eigenvectors of Eq. (8) as the following:

$$Hb = \lambda(m+s)Lb \tag{8}$$

By replacing the values of $\boldsymbol{b}$ into Eq. (3), the score of each sample can be calculated.

According to the variable scores of $\boldsymbol{b}$ and sample score of $\boldsymbol{Y}_i$, the variables and samples can be classified. Score is a quantity representation of variables (or samples), which can be used to express the relationship between variables (or samples). Each sample is a grouping of variable scores. The scores of variables are selected based on the principle of maximum correlation ratio of among-group variance, and the mean score for each group is taken as the sample score, which can make the selected score reflect the difference between these samples to the largest extent. The detailed calculation method can be found in Dong et al. (1979).

In this study, Quantification Theory III is used to classify the families based on the characteristics of UREISs in different cities. Families can be taken as the

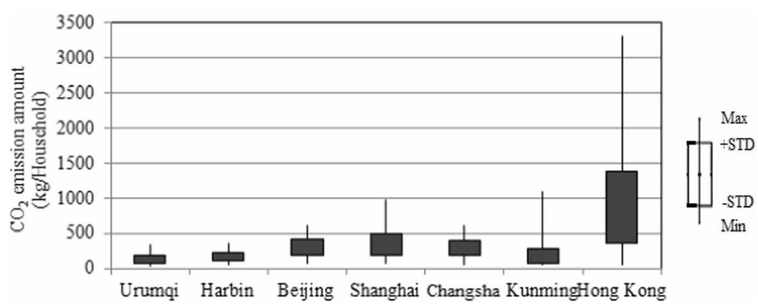


Fig. 8 CO_2 emission amounts in the seven cities

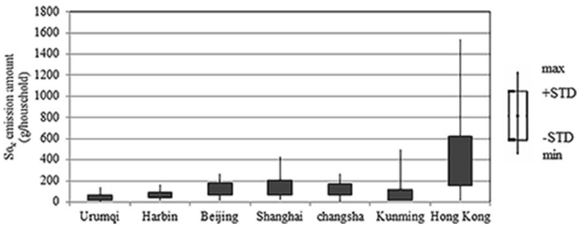


Fig. 9 SO_X emission amounts in the seven cities

samples, and the indices of the UREIS are taken as the variables in this model. Each family is actually characterized by the indices shown in Table 1. The scores of both families and indices can be calculated by Quantification Theory III. Then, according to the above principles, the family samples with the scores in a small interval are usually classified to the same sample group, which indicates these families have some similar characteristics in the UREIS, and vice versa. The same principle applies to those variables, and then the variables with similar scores can be also classified to the same variable group, and can be used to explain the characteristics the corresponding sample groups have. The calculation model was developed in MATLAB (2014), which has many available statistical toolboxes.

Classification analyses of UREIS in the seven cities in China

Based on the classification model above, Fig. 11 shows the classification results of the family samples ($N = 707$) in the seven typical cities, calculated by Quantitative Theory III. The first two eigenvalues, namely the values of their corresponding variables of b_1 and b_2, are chosen as the principal components, as they occupy 60% of the total variance contribution (Dong et al. 1979). The two axes of Fig. 11 show the values of y_1 and y_2 of each sample. According to the principal of Quantification Theory III that the samples with the close scores of y can be clustered into the same group, the following conclusions could be made: (1) Samples of Hong Kong can be classified into Group A because all of them are located in one area and far from the samples of the rest six cities; (2) the samples of Shanghai, Beijing, and Changsha can be classified into Group B, where nearly all of them have y_2 less than zero, and have y_1 between -0.5 and 0.3. In Group B, nearly all the samples of Shanghai and most samples of Beijing are close, which can be divided as Subgroup B1, while nearly all the samples of Changsha and few samples of Beijing can be divided as Subgroup B2 which are relatively farther from Subgroup B1; (3) the samples of Harbin, Urumqi, and Kunming can be classified to Group C, where most of them are located in the first quartile. In Group C, the samples can be further divided by Subgroup C1 and Subgroup C2, where C1 consists of nearly all the samples of Urumqi and Harbin, while C2 is composed of nearly all the samples of Kunming; (4) it can be further inferred that the family samples in each group have the similar features of the residential energy information system.

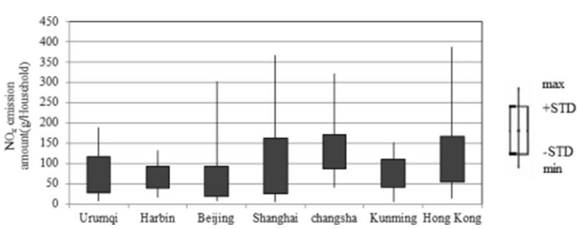
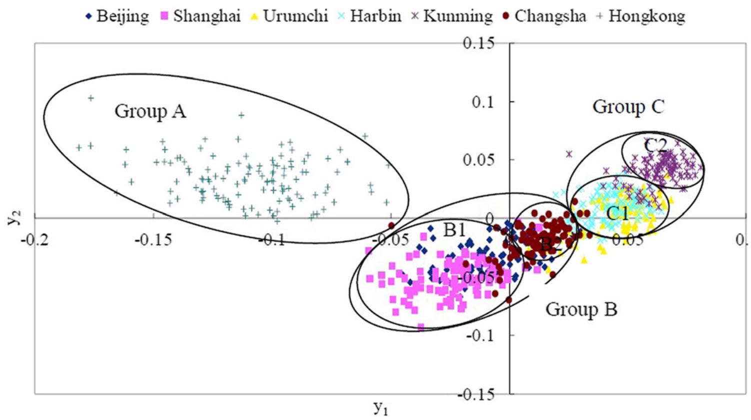


Fig. 10 NO_X emission amounts in the seven cities

Furthermore, based on Quantitative Theory III, vector $\boldsymbol{b}$ is equal to the results of R Type Factor Analysis, and y is equal to the results of Q Type Factor Analysis (Dong et al. 1979). Combined with R Type Factor Analysis and Q Type Factor Analysis, the relationship between the variables and samples can be further revealed (Xue 2001). Similarly, combined with $\boldsymbol{b}$ and y, the relationship between the variables and samples can be revealed as well. Additionally, there is a corresponding relationship that the larger absolute values of $\boldsymbol{b}$ are usually related to the larger absolute values of y (Dong et al. 1979). This means that the variables with the larger absolute values of $\boldsymbol{b}$ are usually the main features of the samples with the larger absolute values of y. In this case, the relationship between the sample group and the variables can be revealed. Table 4 lists values of $\boldsymbol{b}$ for each variable. Figure 12 shows the distribution of the variables, where two axes show the values of b_1 and b_2 of each variable. Combining Figs. 11 and 12, analysis and conclusions could be made:

1. For Group A, most of the families in Hong Kong have similar features in the UREIS: being built before 1990s, the other structure types except "brick and concrete" and "reinforced concrete (RC)," the large number of building floors, other orientation except "south and north," window frame with aluminum/steel, the highest income of more than

Fig. 11 Classification results of the family samples in the seven cities



200,000RMB, the high ratio of energy expenditure to income, indifference attitude toward the indoor thermal environment, the large monthly energy consumption of (6000, 11,000) MJ/household and (3000, 6000) MJ/household in summer, the high SO_x and CO_2 emission amounts, the highest ratio of per capita residential expenditures to per capita annual living expenditures of urban households, the highest per capita GDP value, and the highest fuel price among the seven cities.

2. For Group B, most of the families in Shanghai, Beijing, and Changsha have similar features in the UREIS as below: monthly energy consumption of (2000, 3000) MJ/household in summer, large floor area, the large number of air conditioners and fans, the long daily usage hour of air conditioners and fans, the long daily occupancy hour on weekdays and weekends, the relative high outdoor temperature compared with the other cities, gas water heaters, the combined use of gas water heaters and electricity water heaters, satisfied with thermal environment, the annual income between 40,000 and 200,000 RMB (only for Subgroup B1 of Beijing and Shanghai), built after the year 2000 (only for Subgroup B1 of Beijing and Shanghai), RC structure (only for Subgroup B1 of Beijing and Shanghai), pipeline gas (only for Subgroup B1 of Beijing and Shanghai), and south and north orientation (only for Subgroup B2 of Shanghai and Changsha).
3. For Group C, most of the families in Urumqi, Harbin, and Kunming have the similar features in the UREIS as below: built in the 1990s, annual income below 40,000 RMB, monthly energy consumption below 2000 MJ/household in summer, brick and concrete structure (only for Subgroup C1 of Urumqi and Harbin), window frame with wood/plastic steel (only for Subgroup C1 of Urumqi and Harbin), electric water heaters (only for Subgroup C1 of Urumqi and Harbin), other types of water heaters (only for Subgroup C1 of Urumqi and Harbin), dissatisfied with thermal environment (only for Subgroup C1 of Urumqi and Harbin), and the solar water heater (only for Subgroup C2 of Kunming).

Discussions about the residential energy efficiency management in the seven cities

In this study, the sample classification in seven cities was conducted, and the corresponding characteristics of each classified sample group were identified from the aspects of building characteristics, household characteristics, possession and operation of domestic energy-consuming appliances, indoor thermal environment, climate, energy market, municipal infrastructure, regional economic level, and environmental benefits. In order to provide the reference to guide the energy planning of urban residential buildings and form a more energy-efficient roadmap, based on the current energy efficiency situation in the seven cities, the following conclusions and suggestions could be drawn:

1. Hong Kong is the most developed city in China, even reaching the level of developed countries. The climate in summer is very hot in this city, and the monthly energy use in summer is much higher than in the other Chinese cities. Based on the investigation data in the database, the thermal performance of

Table 4 The scores of evaluation indices

	Evaluation indices			Score of B1	Score of B2
	Construction year	No. 1	Before 1990s	− 0.122	0.167
		No. 2	In 1990s	0.056	0.022
		No. 3	After 2000	0.025	− 0.215
		No. 4	Brick and concrete	0.099	− 0.009
Part 1.1: building characteristics	Construction structure	No. 5	Reinforced concrete (RC)	0.013	− 0.119
		No. 6	Others	− 0.237	0.160
	Building orientation	No. 7	South–north	0.04	− 0.089
		No. 8	Others	− 0.037	0.083
	Material of window frame	No. 9	Aluminum/steel	− 0.042	0.056
		No. 10	Wood/plastic steel	0.066	− 0.088
Part 1.1: building characteristics	(Quantitative variables)	No. 11	The number of building floors	− 0.087	0.020
		No. 12	Household floor area	0.022	− 0.136
		No. 13	Below 40,000	0.121	0.043
Part 1.2: household characteristics	Domestic annual income	No. 14	40,000–200,000	− 0.11	− 0.096
		No. 15	Above 20,0000	− 0.406	0.350
		No. 16	Population	− 0.086	0.003
Part 1.2: household	(Quantitative variables)	No. 17	Ratio of energy expenditure to income	− 0.057	0.018
		No. 18	Daily occupancy hour on weekdays	− 0.026	− 0.066
		No. 19	Daily occupancy hour on weekends	0.013	− 0.083
		No. 20	The number of air conditioners	− 0.124	− 0.120
Part 1.3: the possession and operation of energy appliances	(Quantitative variables)	No. 21	Daily usage hour of air conditioners	− 0.126	− 0.115
		No. 22	The number of fans	− 0.11	− 0.081
		No. 23	Daily usage hour of fans	− 0.094	− 0.114
		No. 24	Electricity	0.026	0.064
Part 1.3: the possession and operation of energy appliances	Category of water	No. 25	Gas	− 0.079	− 0.089
		No. 26	Electricity + gas	− 0.065	− 0.400
		No. 27	Solar energy	0.198	0.261
		No. 28	Others	0.114	0.024
Part 1.4: indoor thermal environment	(Quantitative variables)	No. 29	Indoor temperature	− 0.127	− 0.106
	Satisfaction of summer thermal environment	No. 30	Dissatisfied	0.044	0.000
		No. 31	Indifferent	− 0.152	0.036
		No. 32	Satisfied	0.029	− 0.013

Table 4 (continued)

	Evaluation indices			Score of B1	Score of B2
	Construction year	No. 1	Before 1990s	−0.122	0.167
		No. 2	In 1990s	0.056	0.022
		No. 3	After 2000	0.025	−0.215
		No. 4	Brick and concrete	0.099	−0.009
Part 2: energy use amount	Monthly energy use amount	No. 33	0–2000	0.086	0.006
		No. 34	2000–3000	−0.103	−0.268
	(MJ/household)	No. 35	3000–6000	−0.321	0.171
		No. 36	6000–11,000	−0.514	0.464
Part 3.1: climate	(Quantitative)	No. 37	Average outdoor temperature of the investigated month (°C)	−0.137	−0.141
Part 3.2: energy market	(Quantitative)	No. 38	Fuel price	−0.14	0.093
Part 3.3: economic level	(Quantitative)	No. 39	Per capita GDP	−0.17	0.090
	The status of pipe gas popularization	No. 40	Pipeline gas	−0.022	−0.035
		No. 41	Bottled gas	0.047	0.074
Part 3.4: municipal infrastructure	(Quantitative)	No. 42	Gas popularization rate	−0.063	−0.128
Part 4.1: environmental consequence	(Quantitative)	No. 43	CO2 emission amount	−0.153	0.071
		No. 44	NO_X emission amount	0.06	0.007
		No. 45	SO_X emission amount	−0.143	0.079
Part 4.2: social economic effect	(Quantitative)	No. 46	The ratio of per capita residential expenditures to per capita annual living expenditures of urban households	−0.17	0.092

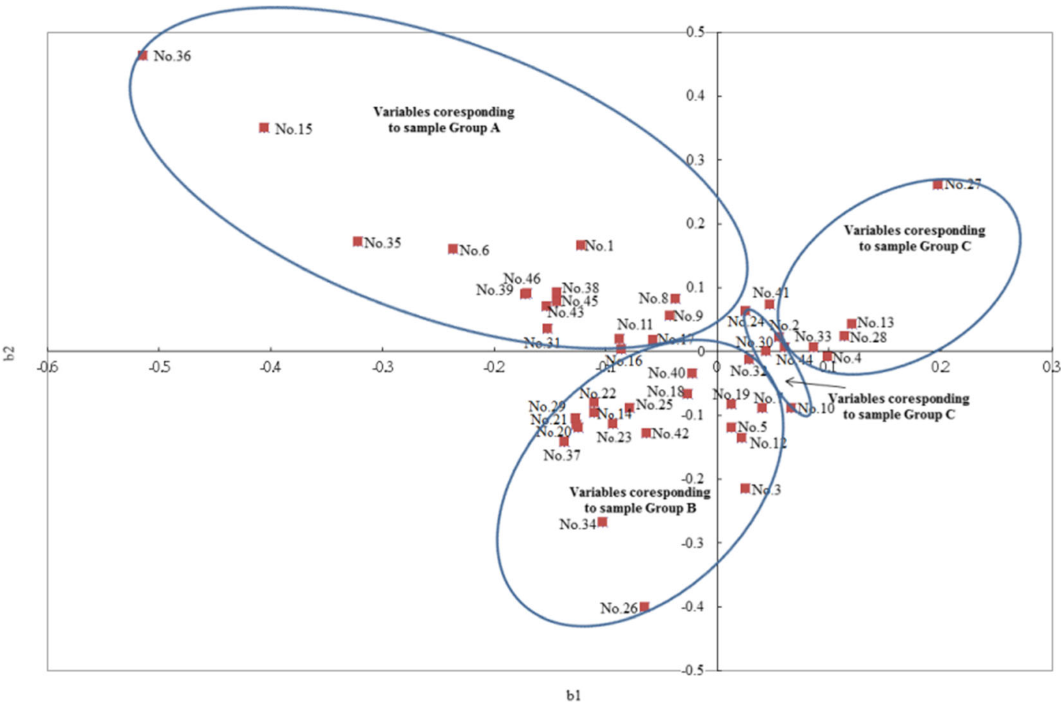


Fig. 12 Classification results of the variables in the residential energy information system

residential buildings is relatively poor because most of the buildings were built a long time ago. New buildings are very few, and the building design of many buildings is not good as well, such as the improper orientation, because of the narrow territorial area of Hong Kong Island. The high-income households usually have the high energy use because they do not care about the energy expenditure with such income level, though the fuel prices are relatively higher than the other cities. With the high energy use and the high income as well, indoor thermal environment is comfortable all the time, and unlike in the other Chinese cities, it is not a problem any longer which attracts much attention from the residents. Further, the high energy use definitely leads to the high ratio of energy expenditure to income, the highest ratio of per capita residential expenditures to per capita annual living expenditures of urban households, and the high SO_x and CO_2 emission amounts as well. Based on the features of the UREIS, poor building performance becomes a big obstacle for the building energy efficiency in Hong Kong, and hence more endeavors including building retrofit should be made. Besides that, there is a certain potential for the energy savings by the occupant behavior. For example, by introducing the incentive policies and publicity to strengthen energy-saving consciousness, the residents will become thriftier with the usage of domestic appliances.

2. Beijing and Shanghai can also represent the developed cities in China, but not as developed as Hong Kong, and per capital GDP and household income are much less than in Hong Kong. Although the two cities are located in different architecture thermotechnical design zones, they are classified into the same group, as they have many similarities in the UREIS: the families in the two cities also have a relatively high energy use in summer (compared with other cities except Hong Kong), the relatively hot weather in summer, the long use of air conditioners and electric fans, and the large household floor area compared with other cities. In addition, compared with the situation in Hong Kong, the modernization and the high-speed development in the two cities started later, and new building construction and building retrofit have been conducted in a large scale in the last two decades. Therefore, the building performance is better in both cities. A combined effect of the relatively lower income and higher consciousness on energy saving

gives energy use much lower than in Hong Kong. With the improvement of the living standard and household income, and the increase of GDP as well, the energy use and GHG emission of Beijing and Shanghai will still increase. Therefore, great attention on building energy efficiency should be continuously paid from the government, and building energy conservation should be in the leading position in the two developed cities in China.

Changsha represents the most common second tier cities in China. However, due to the similar characteristics in the UREIS, it is also classified to the same group with Beijing and Shanghai. Changsha also has a hot climate, relatively large ownership of air conditioners and electric fans, and long daily operation. Besides that, the average floor areas of the three cities are all bigger than 80 m^2 per household. The prices for electricity and gas are also nearly the same in the three cities. Nevertheless, Changsha shows some differences compared to the two cities mentioned above and is thereby classified into the other subgroup. For example, although Changsha is in the same climate zone as Shanghai with the high temperature in summer, its energy use in summer is a bit less than in Shanghai while similar as in Beijing in summer. Per capita GDP value and the annual income are lower than that of Beijing and Shanghai, and the less developed economy of the city and lower economic condition of the families lead to slightly less energy use compared with Shanghai. In addition, the municipal infrastructure is also not as well developed as in the two cities. Based on this situation, it is supposed that the energy use in Changsha will also definitely increase in the coming decades, although residents pay greater attention on energy conservation. Finally, the NO_X emission is relatively larger than other cities due to the wide use of liquefied petroleum gas. The energy structure affects the GHG emission, and the energy structure in Changsha is not so reasonable and should be improved.

3. Urumqi, Harbin, and Kunming are the common second-tier cities in the severe cold zone and moderate zone, which are also divided into the same group. Due to the relatively comfortable climate in summer, the usage time of air conditioners is very short. The three cities also have a relatively low GPD level and household income among the seven cities. All of these lead to the lowest household energy use level. In addition, another important factor is the application of solar energy water heater as a renewable technology, which greatly contributes to the improvement of the UREIS of Kunming.
4. Based on the current situation of the economy and energy use in different groups of the analyzed Chinese cities above, it is expected that there would be a rigid increasing trend of residential energy use in China due to the development in the economy and the improvement of the living standard and family income. Consequently, the energy expenditure will also become higher for Chinese families, occupying an even larger percentage in the income and household living expenditures. GHG emission will also increase accordingly. Building energy conservation in buildings should be always important work in the coming few decades for the Chinese government. The implementation of energy efficiency technology is highly necessary for building conservation. A reasonable energy supply structure is also fundamental for the greenhouse gas emissions. In addition, it is also important to enhance the energy-saving consciousness of the residents, as it is also an important factor affecting the living-life energy use, especially when the incomes of residents increase significantly.

Discussion and conclusions

In this study, a definition of the UREIS is developed to describe the energy use, the influencing factors on energy use, and the energy use consequences from the citywide perspective. A classification model is developed to analyze the characteristics of the UREIS for different cities by Quantification Theory III. As the case study, the database of the UREISs of seven typical cities in the five architecture thermotechnical design zones of China is established, and the features of the UREIS of the seven cities are classified and analyzed. Discussions and suggestions are made for the residential energy efficiency management in the seven cities:

1. The UREIS includes building characteristics, household characteristics, ownership and operation of domestic appliances, indoor thermal environment, climate, energy market, economic level, municipal infrastructure, environmental consequence, and social economic effect. The classification model

established by Quantitative Theory III introduces not only quantitative variables but also qualitative variables, and it can be used to reveal the features of different classified groups of UREISs. The model was validated by a case study of seven Chinese cities.

Among seven target cites, samples of Hong Kong are classified into one group of Group A, and samples of Shanghai, Beijing, and Changsha are classified to Group B, while Harbin, Urumqi. and Kunming have their samples divided to Group C. Family samples in the same group always have similar features for the residential energy information system.

These three groups have distinct differences in the characteristics of the UREISs, and pertinent suggestions can be made for different city groups to guide their energy efficiency management. As the most developed city in China, Hong Kong has the highest household income, low energy saving consciousness, and comfortable indoor thermal environment. All of these lead to the high energy consumption. Poor building performance becomes a big obstacle for building energy efficiency in Hong Kong, and more effort should be put in this field. Some incentive policies and publicity should also be implemented to strengthen energy-saving consciousness and energy-saving behavior. Beijing and Shanghai can also represent the developed cities in China, but not as developed as Hong Kong. Although the hot weather in summer, the long usage time of air conditioners and electric fans, and the even larger floor area lead to relatively high energy use, the value is still lower than that of Hong Kong. With the improvement of the living standard and household income, and the increase of GDP as well, the energy use and GHG emission in Beijing and Shanghai will still increase. However, due to the great attention on building energy efficiency from the government, building energy conservation is also in the leading position in the two developed cities in China. Changsha, the typical second tier city with hot climate in hot summer and cold winter zone, is classified to the same group as Beijing and Shanghai because of the similarity in UREIS, while the analysis shows the energy structure in Changsha is not so good and should be improved. As the common second-tier cities in the severe cold zone and moderate zone, Urumqi, Harbin, and Kunming are classified to the same group with the lowest energy use in summer. Implementation of renewable energy technology shows a big contribution to energy conservation in the three cities.

Overall, the existing databases, such as CBECS RECS, BPD, and EPC, give the enlightenment to develop the fundamental parameters of UREIS in this paper, such as the building thermal performance, energy consumption amount, etc. By further full literature review, some other important parameters are included, such as the ownership of domestic appliances and the actual user behavior, as well as the indicators to evaluate the environmental consequence and social economic effect. These essential data can serve as the basis for many energy conservation initiatives. The government can gain comprehensive knowledge about the current status of building characteristics, household information, energy market, municipal infrastructure, energy use, environment benefit, etc., from the citywide database. Further analyses can be made for energy efficiency opportunities and measures, financial investment, and market trend in the local building stocks of different cities. What is more, the data in the RUEIS, such as the saturation and actual operation of the appliances, the measured energy use amount, etc., can close the energy efficiency gap between the calculation and actual situation, and make the analysis more accurately. The case study of summer scenario in this paper just serves as an example of the building energy efficiency management. By the development of the above methodology, the characteristics of the RUEISs in the same city group can be revealed, and the reasons and consequences of residential energy use can be explored. The characteristics of the RUEISs can be compared among different city groups as well, to reveal the difference in the building thermal performance, physical and operation performance of building systems among different city groups with different energy saving technologies, and hence energy efficiency potential and opportunity, and technical approaches can be put forward by the comparison. Besides the above, there are also some other important potential uses of the UREIS in China. For example, the database can be used to develop the reference buildings when developing the energy efficiency design standards for residential buildings in China. Energy efficiency retrofit of residential buildings is the key work of the central government in the 12th Five Year Plan and 13th Five Year Plan. Therefore, realistic energy saving target for the residential building retrofit in the city can be made based on a proper analysis and well-developed

UREIS for the observed cities. Further, the retrofit guideline and the specific retrofit plans can be developed after detailed analysis of well-organized and high-quality UREIS (Chen and Hong 2018; Hong et al., 2017). Finally, the residential energy efficiency roadmap and energy saving scenarios in the coming 20 or even 50 years must put the current situation into consideration as well.

Although the UREIS database is greatly beneficial to the building energy management, the data accessibility is an important issue to form the database. Currently, the data in the UREIS are partly accessible by different sources. For example, the data for the indices in Part 1.3 of the ownership of energy-consuming appliances, Part 1.2, Part 3.2, Part 3.3, and Part 3.4 can be obtained from the national Year Book published by the National Statistics Bureau; the data of the indices in Part 3.1 can be accessed from the public meteorological website; while the data of the indices in Part 1.1 can only be accessed in the construction bureaus and archives bureaus after a set of application procedures and approval. A few indices such as the thermal environment and the usage of energy-consuming appliances can only be obtained by the surveys and measurement. The absence of data disclosure will make it difficult for the stakeholders to understand the energy use and saving, and hamper the effort for energy efficiency management. However, in foreign countries, for example, the database of CBECS and RECS in the USA are all open to the public. Fifteen US cities and one US county have published the disclosure ordinances that building owners should disclose their annual energy use and benchmark it relative to other buildings. This approach is also popular in Europe where it is driven largely by the European Union's Energy Performance of Buildings Directive, first issued in 2002 and updated in 2010 (Palmer and Walls 2017). Therefore, more effort should be made in China for the raw data collection and public data accessibility.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

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