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Research Article

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# Establishing Energy Consumption Quota for Residential Buildings Using Regression Analysis and Energy Simulation

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***Abstract***

The regulation of the design and construction of new buildings is insufficient; controlling the energy consumption of buildings in the service stage is the key to realizing the goal of energy saving of buildings by tiered pricing for electricity consumption based on quota. Fifty families in Kunming, China were investigated through questionnaire survey and spot test; regression analysis and energy simulation were conducted to obtain the annual energy consumption of a nuclear family. The quota was finally established based on the correction of the two results according to the actual situation; annual energy consumption per capita was used as the unit, which was more reasonable than the annual energy consumption per floor area that was used by numerous scholars. The study demonstrates that the annual per capita energy consumption is significantly related with per capita floor area and annual per capita income. With the popularity of solar hot water system, natural ventilation is the main way for cooling in summer and the requirement of indoor comfort cannot be met during winter in residential buildings in Kunming. Thus, the value of energy simulation is higher than that of regression analysis. Finally, the corrected value of energy simulation was determined to be the final quota, which was 7.7% lower than the value of regression analysis, to meet the requirements of energy efficiency and indoor comfort. To sum up, both the value of regression analysis and the adjusted value of energy simulation could be determined as the quota. The study has a reference value to the prediction of the energy consumption of buildings, which also offers a guideline for the local government to establish relevant policies.

*Keywords:* Building Energy Efficiency, Annual Energy Consumption Quota, Residential Buildings

## 1. Introduction

The plan for new type of urbanization (2014–2020), issued by the People's Government of Yunnan Province, states that building energy consumption accounts for about 20% of the total energy consumption and will reach 25% by 2020, because the urbanization level will increase from 27.64% to 35%. Therefore, energy saving of buildings plays an important role, which is similar to that of industries and transportation. A few crucial factors exist for energy saving of buildings, which include building performances, energy efficiency of equipment, application of renewable energy, and awareness of energy saving. In most countries, regulations for new buildings are in place to ensure that buildings are designed to meet the requirements of energy-efficient buildings. However, well-designed buildings do not mean low-energy consumption in the service stage, because awareness of energy saving cannot be defined in the design stage. Therefore, the local government plans to implement tiered pricing for electricity consumption to avoid wasting energy and realize the goal of energy saving of buildings. Hence, establishing rational energy consumption quotas is an urgent affair for this policy. After obtaining the basic information through site survey, this study would establish an energy consumption quota for residential buildings in Kunming, China using two methods: statistical analysis and energy simulation.

## 2. State of the art

A few scholars presented models to predict the energy consumption, which is considered as the quota. However, the accuracy of these models cannot meet the requirement of the quota because they can only be used to estimate. Yang et al. [1] established a three-hierarchy model through a bottom-up approach for residential buildings using Chongqing City as a sample to verify its validity. A new physical–statistical methodology for energy demand forecasting was presented by Lü et al. [2]. Lei [3] and Jiang [4] set up the prediction model from the BP neutral network based on survey data. The neural networks were applied by Karatasou et al. [5] to forecast the energy consumption of buildings, which was improved by statistical procedures. In some cases, the adjusted actual energy consumption is directly used as the quota; which produced insufficient analysis. An energy consumption quota was provided by Xin et al. [6] after the actual energy consumption of 54 hotels was adjusted from the climatic factors and building area, building age, number of guest rooms, occupancy rate, and other building characteristics. Energy usage intensity (EUI) was gained by Zhao et al. [7] based on the basic information and energy consumption data of the buildings and the standardized EUI was used as energy consumption quota. Wei et al. [8] chose 45 urban office buildings as survey samples to obtain the

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average building energy intensity, which was used as the quota. Also, regression analysis is often used to build the quota; however, it lacks the analysis of technical measures. An equation through regression analysis was built by Zhao et al. [9] based on the actual energy consumption of some residential buildings, especially considering behavior. A model with support vector regression was presented by Jain [10] to estimate the energy consumption of multifamily residential buildings. Frequently, scholars would use several ways for acquiring quota to compare different results, thereby obtaining a relatively satisfactory solution. Lu [11] presented regression equations of energy consumption according to the survey data of 463 households and studied the effect of influencing factors on energy consumption using eQuest software. An energy consumption model was constructed by Wang [12] via energy simulation software DeST-c after energy consumption per unit floor area was chosen as the index through partial correlation analysis. The statistical and technical energy consumption quota was acquired by Huang [13] based on regression analysis and energy simulation for Yunnan Normal University; the character and application of the two quotas were analyzed in the dissertation. The relationship of energy consumption with indoor comfort and household behavior were discussed in several researches. Liu [14] proved that the significant correlation between heating and cooling energy consumption and indoor comfort. Wang [15] offered a new approach for the quantitative description of occupant behaviors, which is simple and effective and can accurately quantitatively represent the behavioral characteristics of individuals. An occupant behavior model was set up by Yan et al. [16] for predicting building energy consumption. All scholars used the energy consumption per floor area as the quota, which is biased; the average per capita floor area of the rich is always higher than that of the poor, thereby making the poor have lower quota than the rich. Thus, the energy consumption quota for residential buildings was established with energy consumption per capita in this study.

This study is arranged as follows. The information of household survey and the two analysis methods were presented in Section 3. The results of the two methods were compared to determine the actual quota in Section 4. Finally, Section 5 presented the conclusions reached by the entire study.

## 3. Methodology

### 3.1 Entire research plan

Residential buildings were the object of this research; thus, a typical family should be described in detail. *Statistical Yearbook of Yunnan Province 2015* states that a nuclear family in Kunming has the highest proportion of 45%, and per capita floor area and annual income of 30.62 $m^2$ and $ 4534.6, respectively. Hence, the annual energy consumption of a nuclear family with the above characteristics was obtained by two methods: regression analysis and energy simulation.

### 3.2 Household survey

Fifty sample families were surveyed using complicated questionnaires with return ration of 100%. The investigation included family size, annual per capita income, per capita floor area, service life, monthly consumption of energy and water, and power and use of household appliances starting from January 1 to December 31, 2016.

Some household survey data used for statistical analysis are shown in Figures 1, 2, and 3. Choosing the annual energy consumption per floor area as the unit of the annual energy consumption quota is unfair. People with spacious rooms will benefit more than those in narrow spaces; thus, those who live in houses have the right to consume more energy than those in apartments. Hence, annual energy consumption, annual income, and floor area were all calculated using unit per capita in this study.

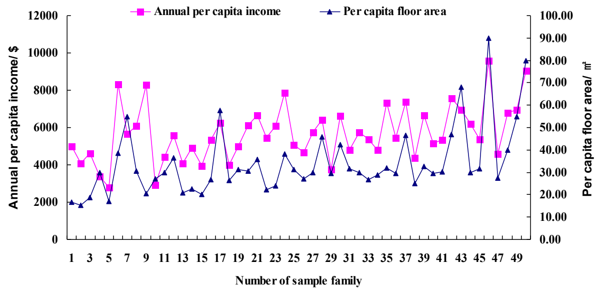


**Fig.1.** Annual per capita income and per capita floor area

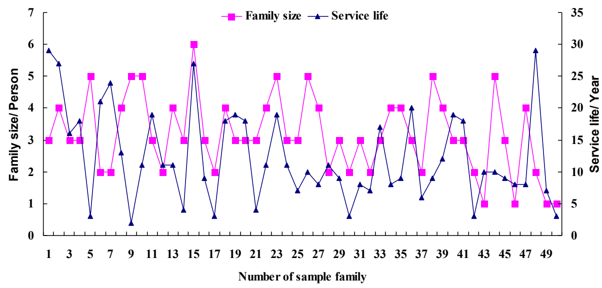


**Fig.2.** Family size and service life

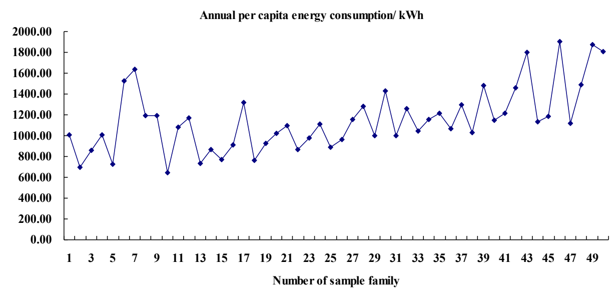


**Fig.3.** Annual per capita energy consumption

### 3.3 Regression analysis

Partial correlation coefficients of annual energy consumption were obtained using per capita floor area, annual per capita income, and service life as variables through SPSS 19.0 statistics software. The regression equation was acquired after selecting the independent variables, and the quota for a nuclear family was established by the equation.

### 3.4 Energy simulation

An eight-story residential building with a story height of 3 m at the south–north orientation (the architectural plan of the building is shown in Figure 4) was used for energy consumption simulation considering the characteristics of a typical nuclear family.

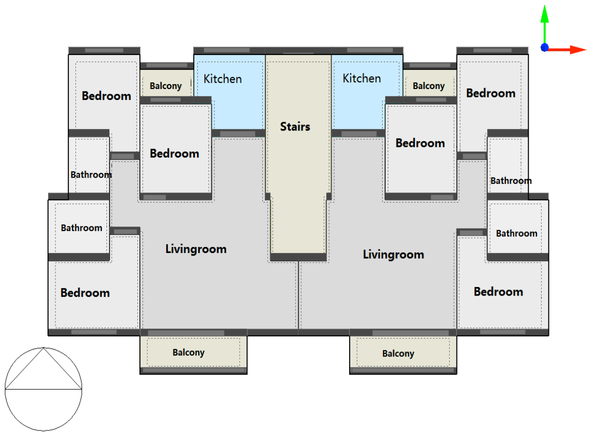


**Fig.4.** Architectural plan of the building

The envelope design meets the requirements of *Design Standard for Energy Efficiency of Civil Buildings* (DBJ 53/T-39-2011); the relevant parameters of which are shown in Table 1. On the basis of household survey, information about domestic appliances and household behavior of the typical family was shown in Table 2 and Figure 5. Lighting power density was set to 2 W/$m^2$ per floor area defined by *Standard for Lighting Design of Buildings* (GB 50034-2004) and bath water to 60 L per capita with a temperature of 45 ºC. The indoor setting temperature for bedroom and living room was 26 ºC during summer and 18 ºC during winter; for the kitchen and the rest of the rooms, temperatures were 22 ºC and 16 ºC. The weather data of the typical meteorological year was used for energy simulation.

**Table 1.** Relevant parameters of envelope design

| Component | Configuration | Heat transfer coefficient (W/($m^2$·K)) | |
|---|---|---|---|
| | | Design value | Standard requirement |
| Roof | Cast-in-place reinforced concrete slab with EPS insulation board | 1.24 | 1.5 |
| Outer wall | Cast-in-place reinforced concrete wall with exterior thermal insulation | 1.76 | 1.8 |
| Floor | Cast-in-place reinforced concrete floor with tiles | 2.08 | 2.2 |
| External window | Aluminum alloy window with double-layer hollow glass | 1.3 | 1.3 |
| Outside door | Double-layer mental door | 1.61 | 3 |

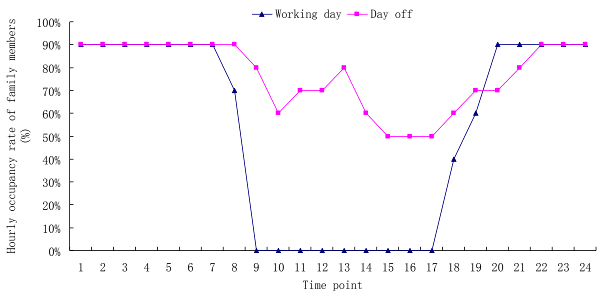


**Fig.5.** Hourly occupancy rate of family members in working days and days off

**Table 2.** Number and power of domestic appliances

| Type | Number | Power (W) |
|---|---|---|
| Television | 1 | 200 |
| Computer | 2 | 250 |
| Washing machine | 1 | 550 |
| Electric cooker | 1 | 800 |
| Induction cooker | 1 | 2000 |
| Microwave oven | 1 | 1200 |
| Water dispenser | 1 | 50 |
| Electric water heater | 1 | 2000 |
| Refrigerator | 1 | 180 |

## 4. Result analysis and discussions

### 4.1 Result of regression analysis

#### 4.1.1 Partial correlation analysis

The results of partial correlation analysis are shown in Table 3. The annual per capita energy consumption is significantly correlated with per capita floor area and annual per capita income with significant level of 0.1%, and not significantly correlated with service life. Thus, these two variables can be used as independent variables for linear regression analysis since there is no significant correlation between them.

**Table 3.** Results of partial correlation analysis

| Variables | Parameter | Value |
|---|---|---|
| Annual energy consumption, per capita floor area | Correlation index | 0.708 |
| | Significance (2-tailed) | 0.000 |
| Annual per capita energy consumption, annual per capita income | Correlation index | 0.519 |
| | Significance (2-tailed) | 0.000 |
| Annual per capita energy consumption, service life | Correlation index | 0.173 |
| | Significance (2-tailed) | 0.240 |
| Per capita floor area, annual per capita income | Correlation index | 0.032 |
| | Significance (2-tailed) | 0.830 |

#### 4.1.2 Linear regression analysis

The results of linear regression analysis are shown in Tables 4, 5, and 6 using SPSS 19.0 statistics software with annual per capita energy consumption as dependent variable and the two correlated variables as dependent variable. The regression equation can be established as follows:

$$Y = 313.993 + 12.186X_1 + 0.074X_2 \quad (1)$$

where, $Y$ denotes the annual per capita energy consumption (kWh); $X_1$ denotes the per capita floor area ($m^2$); $X_2$ denotes the annual per capita income ($).

**Table 4.** Model summary

| $R$ | $R^2$ | Adjusted $R^2$ | Standard error |
|---|---|---|---|
| 0.892 | 0.796 | 0.787 | 140.51959 |

**Table 5.** ANOVA

| | Sum of squares | *df* | Mean square | *F* | Sig. |
|---|---|---|---|---|---|
| Regression | 3621451.218 | 2 | 1810725.609 | 91.702 | 0.000 |
| Residual | 928050.538 | 47 | 19745.756 | | |
| Total | 4549501.756 | 49 | | | |

**Table 6.** Coefficients

| Item | Unstandardized coefficients | | Unstandardized coefficients | *t* | Sig. |
|---|---|---|---|---|---|
| | *B* | Standard error | | | |
| (Constant) | 313.993 | 79.309 | | 3.959 | 0.000 |
| Floor area | 12.186 | 1.827 | 0.604 | 6.670 | 0.000 |
| Annual income | 0.074 | 0.003 | 0.362 | 4.002 | 0.000 |

**4.1.3 Energy consumption quota of a typical nuclear family**

$X_1$ and $X_2$ were equal to 30.62 m$^2$ and $ 4534.6, respectively, whereas the result of Equation 1 was 1022.69 kWh, which is the annual per capita energy consumption for a nuclear family.

**4.2 Result of energy simulation**

The result of energy simulation showed that the amounts of energy consumption of domestic appliance, lighting, heating, cooling, and domestic hot water were 2301.78, 237.14, 128.15, 373.94, and 436.19 kWh; thus, the per capita energy consumption was 1159.08 kWh.

**4.3 Analysis of the difference between two results**

The energy consumption for heating, cooling, and domestic hot water might be the cause for the difference between the two results. The household survey showed that cooling equipment was not available, including fans, in all the families; the space was cooled through natural ventilation during summer. The average energy consumption for heating was only half of the simulation result, because part of the space of the family was heated by electric heaters with people inside wearing heavy jackets, which was proved by the site survey (shown in Figure 6).

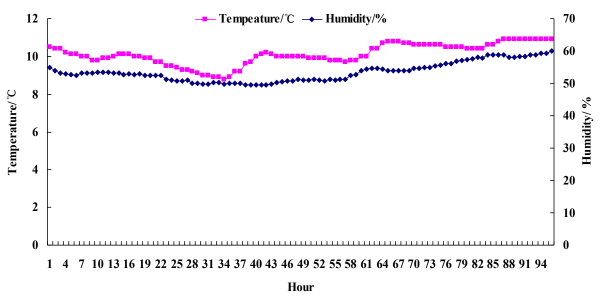


**Fig. 6.** Hourly temperature and humidity of the living room of a family from February 6 to 7, 2016

Furthermore, heating equipment was used only for the occupied room and was turned off during sleeping time. Finally, solar domestic water heating system was used almost in every family; thus, energy consumption for domestic hot water could be cut in half when setting the solar fraction to 50%.

**4.4 Error analysis of the results**

Based on the previous analysis, if the energy consumption for cooling, heating, and domestic hot water were adjusted to 0, 64, and 218 kWh from the actual situation, respectively, the simulation result could be revised to 2820.92 kWh, and the annual energy consumption per capita would be 940.31 kWh. Thus, using the regression analysis result of 1022.69 kWh as a reference would lead to a relative error of 9.7%.

**4.5 Establishment of the quota**

Some deficiencies exist for both methods; thus, a suitable way to determine the quota is combining both results from the actual situation of residential buildings. The final quota was established based on the energy simulation result but should be adjusted according to the site survey data. Energy consumption was adjusted as follows:

(1) Energy consumption for domestic appliance, lighting, and heating remained unchanged.

(2)Energy consumption for cooling was changed to zero, because natural ventilation is effective in Kunming, which belongs to mild region.

(3) Energy consumption for domestic hot water was modified to 218.1 kWh, because the solar hot water system is popular in this district.

Finally, the adjusted energy consumption and ultimate quota were 2885.52 kWh and 951.84 kWh, respectively.

**5. Conclusions**

Regression equation was built based on household survey to establish the energy consumption quota of residential buildings in Kunming. In addition, energy simulation was conducted to compare the two results, thereby determining the quota. The main conclusions based on the analysis are drawn as follows:

(1) Statistic analysis proved that annual per capita energy consumption is positively related with per capita floor area and annual per capita income; per capita floor area is insignificantly related with annual per capita income.

(2) The site survey indicates that three facts made the value of energy simulation higher than that of regression analysis: the room was cooled via natural ventilation in summer; only a part of the room was heated through electric heater with people inside wearing thick cloth; and solar hot water system was popular in Kunming.

(3) After energy consumption for cooling, heating, and hot water was acquired using energy simulation and corrected exactly according to the actual situation obtained from the site survey, the difference between both values obtained through the two methods is 9.7 %.

(4) The modification was based on the assumption that ventilation was the only means of cooling and indoor comfort during winter. After this modification was satisfied, the value of energy simulation was determined to be the

final quota, which is lower than that of the regression analysis.

This study is valuable for the government for the implementation of tiered pricing for electricity consumption. Nonetheless, accuracy should be improved, because the information about subentry energy consumption and household behavior is lacking. Further study is required to solve this problem by obtaining more specific household survey data.

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