

# Comparative Study on Method for Determining the Benchmark of Office Building Energy Consumption in Xi'an

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**Key words:** office building; multiple regression analysis; simplified calculation; the benchmark of energy consumption

**Abstract.** The methods of multiple regression analysis and simplified calculation were used to predict the benchmark of office building energy consumption, the features and the applicabilities of the two methods were discussed based on the comparison of predicted results, and the benchmark of office building energy consumption was determined by combining the two methods. The problems for setting up the benchmark of building energy consumption in China were pointed out, and several suggestions for improving the two methods were suggested.

## Introduction

As China's economy develops, the energy consumption of the public buildings has been increased and made up to about 30% of the total social energy consumption. Many countries have established and continue to improve building energy benchmarking system and many energy baseline assessment methods as well as management systems has been developed to guide the energy-saving. At present, multivariate statistical regression method has been widely used in the area of building energy assessment. As established by Sharp and published in 1996, the stepwise linear regression model<sup>[1]</sup>, has been modified and used for the US Energy Star Benchmarking Tool ("Energy Star" Building Energy Benchmarking tool) theoretical basis<sup>[2]</sup>. Joyce Carlo, Roberto Lamberts et al have studied on the relationship between commercial building envelope structure and its electricity consumption in Brazil. The linear regression relationship between envelope structure factors, such as the window-wall ratio, building scale and so on and electricity consumption indicators relationship have been established to judge the level of the energy saving of envelope structure<sup>[3]</sup>. William Chung, YV Hui et al. have divided the nine factors which ones impact the building energy consumption into four categories, which are building age, scale, users' behavior and energy-using equipments. Based on the categories, multiple regression models were established to estimate the energy consumption of Hong Kong's 30 supermarkets<sup>[4]</sup>. In 1994, the Germany government has released VDI3807 evaluation system, which was considered to a representative method based on simplified simulation to determine the building energy benchmarking. Besides, the neural network method<sup>[5]</sup>, neural network combined with energy simulation<sup>[6]</sup>, linear regression combined with data envelopment binding method<sup>[7]</sup> and statistical regression combined with data mining techniques method<sup>[8]</sup> were also developed for building energy benchmarking. In this study, multivariate statistical regression and to simplified calculation methods were used to evaluate the energy consumption of office buildings in Xi'an respectively, compared to the actually statistical data, differences in applicability between the energy consumption benchmarks obtained from the two methods were analyzed and discussed.

## Application of multiple linear regression

The (electric energy use intensities) was considered as the dependent variable and the energy consumption influencing factors as independent variables to fit the regression equation by stepwise regression method <sup>[9]</sup>. All the energy consumption influencing factors derived from the statistical data of office buildings in Xi'an were selected by partial F statistic method and the factors have little effect on EUIs were excluded. Since the equation was established, the energy consumption and the energy efficiency of buildings were discussed by comparing the actual and the evaluated EUIs values.

**2.1 Establishment and test of the models.** Multiple linear stepwise regression method was used to establish the model by considering eight energy consumption influencing factors initially, which ones are glass type  $x_1$ , weekly run time  $x_2$ , window-wall ratio  $x_3$ , orientation  $x_4$ , building ages  $x_5$ , number of computers  $x_6$ , total power of the air-conditioning system  $x_7$  and air conditioning type  $x_8$  respectively. During the regression, the multiple linear models were optimized by introducing the eight factors into the regression equation successively and four models were finally obtained. Total power of the air-conditioning system  $x_7$ , number of computers  $x_6$ , building ages  $x_5$  and window-wall ratio  $x_3$  as factors were introduced into the regression equation successively. As the number of variables increased, the determination coefficient ( $R^2$ ) gradually increased; explaining ability of the model was enhanced. The  $R^2$  of the model with four variables reached to about 0.881 and 86.7% of the total variance can be explained. So the regression equation which reflects the relationship between EUIs and the energy consumption influencing factors is as follow:

$$y = 10.537 + 0.611x_7 + 0.3x_6 + 0.221x_5 + 38.96x_3$$

The significance of obtained regression equation and the regression coefficients were tested and the diagnosed by the statistical methods of F test and the T test respectively. The Sig value (significance level) of the model is 0.000, indicating that the regression equation is significant. It is shown in Table 1 that the significance level of constant term and the all variables of the model are all less than 0.05, indicate that the regression coefficient got statistical significance. Scatter distribution in Figure 1 is irregular that indicate the reasonability of the assumption based on which the model was established.

Table1. T test of model

Model	Non standardized Coefficients	Standard error	Standard coefficient	t	Sig.
constant	10.537	4.550		2.316	0.027
$x_7$	0.611	0.154	0.400	3.968	0.000
$x_6$	0.030	0.006	0.496	4.798	0.000
$x_5$	0.221	0.068	0.206	3.259	0.003
$x_3$	38.960	13.944	0.200	2.794	0.009

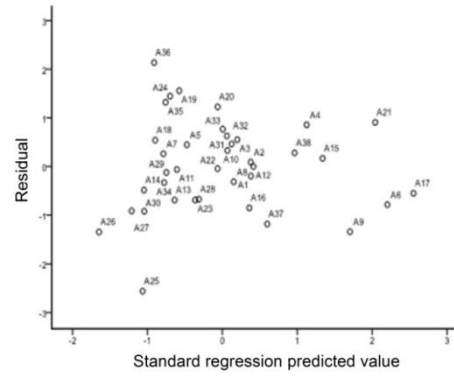


Fig1. The standardized residual plot

**2.2 EUIs prediction and Analysis.** The difference of EUIs value predicted by the model ( $Y_{01}$ ) and actual EUIs value ( $Y$ ) were listed in Table 2: use the predicted value as the reference of energy consumption of each building, so the differences in energy efficiencies of the buildings could be distinguished by comparing the residuals value. As shown in Figure 2: the higher the residual value is, the higher the building energy consumption above the reference value is, and the building got less energy saving capability.

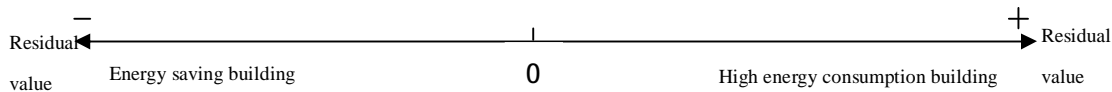


Fig2. Axis of Building energy consumption evaluation

Table2. The value of Residual

No.	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10	A11	A12	A13	A14	A15	A16	A17	A18	A19
	-1.4	0.7	3.9	6.1	3.2	-5.5	1.9	-2.2	-9.5	2.3	-0.4	0.0	-4.9	-3.4	1.2	-6.0	-3.9	3.8	11.0
No.	A20	A21	A22	A23	A24	A25	A26	A27	A28	A29	A30	A31	A32	A33	A34	A35	A36	A37	A38
	8.7	6.4	-0.3	-4.9	10.2	-18	-9.5	-6.4	-4.7	-0.9	-6.5	4.5	3.3	5.4	-2.3	9.3	15.1	-8.3	2.0

## Simplified Calculation Method

The key on application of simplified calculation method is to determine the standard building operation mode including equipment uptime and load factor by combine public building energy efficiency standards and the actual operation situation. First, a unified energy consumption sub-structure was established according to the office building equipment systems, the total energy consumption was calculated by plus energy consumption of building subsystem.

**3.1 Energy Consumption of Air Conditioning System.** Since the conditioning system is complex, so it is necessary to analysis and calculate its energy consumption independently. As for the central air conditioning system, in most of the time the system is operated under the partial load condition <sup>[12]</sup>. According to *The heating and ventilating design manual*<sup>[13]</sup>, in the standard operating mode, the equivalent full load running time ( $\tau_R$ ) of air conditioning system are 560h. In the cooling season, the time in which the system was operated was counted by 86 days and for 11 hours per day <sup>[10]</sup>. In the transition season, the operation time of the system was counted by 60 days and for 11 hours per day. The formula for calculation is as follow:

$W=)$ ++

Where,  $W$  represents the total power consumption of air conditioning systems;  $P$  represent the rated power of the refrigerator, cold water and cooling water pumps, cooling towers as well as fans;  $T$  represent the totally operation time of the refrigerator, cold water and cooling water pumps, cooling towers as well as fans.  $a$  represents the loading rate which means the ratio of the equivalent full load running time to the actual running time.  $\Delta t$  represents the difference between the loading rate of water pump or fan with refrigerator;  $t_e$  represents the equivalent full load running time;  $n$  for the number of equipment units.

As for fission air-condition, according to the measurement, the air-conditioning set temperature is 26 °C, power factor of about 0.7. The formula is:  $W=P \cdot T \cdot a$ .  $W$ : Energy consumption of fission air condition;  $P$ :rated power;  $T$ : operation time in cooling season;  $a$ : power factor.

**3.2 Energy consumption of other systems.** The run-time of lighting and indoor electrical equipment was set as the standard run-time of each subsystem except the air conditioning system<sup>[10]</sup>. Since the subsystems such as elevators, pumps and electric water heaters were seldom operated in rated power, the start and stop of the system and the power changes are frequently and were in great randomness. So the load factors of the systems were set according to "2010 Annual Report on China Building Energy Efficiency"<sup>[11]</sup> and the "annual equivalent full load operating hours" were obtained. The load factors and the operating hours of each system were listed in Table 3. The formula for calculation is as follow:  $w=p \cdot t \cdot c$ .  $w$ : Energy consumption for subsystem;  $p$ : rated power;  $t$ : annual equivalent full load operating hours;  $c$ : load factor.

Table3 The load factors and the operating hours of each system

Sub system	lighting	Office equipment			Elevator	Pump
		computer	printer copier	Electric boiling water heater		
Standard running time/h(t)	9.45	8.85	8.85	8.85	10.45	9.45
Loading coefficient	1	1	0.2	0.08	0.2	0.01

The value of energy consumption obtained by simplified calculation ( $Y_{02}$ ) and the actual value of ( $Y$ ) are shown in Table 4. As shown in Table 4, the values of the predictions are similar to the actual value, indicating that it can be used as the energy consumption reference value for each building.

Table 4 difference between simplified calculated value and actual energy consumption value

No.	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10	A11	A12	A13	A14	A15	A16	A17	A18	A19
$Y-Y_{02}$	4.79	7.17	3.24	25.4	7.48	7.77	4.28	-1.2	-5.4	6.65	1.9	5.62	-2.4	-1.8	3.4	12.8	11.5	1.03	-11
No.	A20	A21	A22	A23	A24	A25	A26	A27	A28	A29	A30	A31	A32	A33	A34	A35	A36	A37	A38
$Y-Y_{02}$	14.8	58.3	37.1	17.0	20.7	-3.7	-10	-11	-2.2	16.0	-2.5	-3.0	6.55	3.99	-1.2	35.6	1.7	-6.1	50.5

## Results and discussion

The prediction results of energy consumption of the two methods both could be used as the benchmarking for each building and the disadvantages of the two methods were discussed. Generally, when used as the benchmarking, the values which were predicted by regression method were usually higher than that predicted by simplified calculation. This may attribute to the

difference between the characteristic of the two methods. As for the regression method, the prediction was based on the statistical data, so the regression results may be closed to the actual energy consumption values, which could be higher than that of the reasonable energy saving buildings. The simplified calculation was based on the ideal assumptions, so the predicted values were lower than that of the actual buildings. By comparing the prediction results of the two methods, it is found that it is necessary to combine the two methods together to provide a reasonable predicted benchmarking of building energy consumption for energy saving.

The benchmarking of energy consumption of each building, which ones are obtained by the predictions of the regression and simplified calculation method, could be corrected under the following rules to avoid the disadvantages of the two methods.

- (1) When the actual value of building energy consumption was in the range between the predicted values of two methods, namely  $Y_{02} < Y < Y_{01}$ , and if  $\delta_1 / Y < 20\%$  exists, indicate that there are considerable potential on the building for energy saving and the benchmarking takes  $Y_{02}$ ;
- (2) When the building energy consumption is higher than the value obtained from regression model but lower than the predicting energy consumption of simplified calculation method, namely  $Y_{01} < Y < Y_{02}$ , indicate that the building is basically operated in a reasonable energy saving state, and the benchmarking takes  $Y_{01}$ ;
- (3) When 50% of the building energy consumption is in the range of  $[Y_{02}, Y_{01}]$ , namely  $Y_{02} < 50\% Y < Y_{01} < Y$ , indicate that the building is in a high-energy consumption running state. In this situation, according to the building energy efficiency targets ruled in the "Design standard for energy efficiency of public buildings GB 50189-2005" the expected amount of building energy savings are of the 50% of the current energy consumption, the benchmarking takes 50%  $Y$ ;
- (4) When the building energy consumption is less than both values obtained from the two methods, namely  $Y < Y_{01} < Y_{02}$ , the building is in energy-efficient state.

The corrected benchmarking based on the four rules mentioned above are shown in Tables 5 and energy-saving buildings were marked by "☆".

Table 5. The corrected benchmarking based on the four rules

No.	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10	A11	A12	A13	A14	A15	A16	A17	A18	A19
Y	59	61	61	80	48	88	41	54	75	57	42	61	37	31	79	54	96	41	54
Bench- marking	54.2	53.8	57.1	54.6	40.5	80.2	36.7	☆	☆	50.3	40.1	55.3	☆	☆	75.6	41.2	84.4	☆	40.9
No.	A20	A21	A22	A23	A24	A25	A26	A27	A28	A29	A30	A31	A32	A33	A34	A35	A36	A37	A38
Y	61	97	52	42	51	16	14	25	43	39	28	59	59	59	37	49	52	56	73
Bench- marking	46.2	48.5	26	25	30.3	☆	☆	☆	☆	23	☆	54.5	52.5	53.6	38.2	29.5	36.9	☆	36.5

## Conclusion

In this study, the energy efficiency of 38 office buildings in Xi'an was studied. By stepwise regression method, four energy consumption influencing factors, which ones are air-conditioning system, number of computers, building ages and window-wall ratio, were derived from eight factors to establish the regression model. The building energy consumption of 38 buildings was predicted by both regression models and simplified calculation methods, and the predicted values were used as benchmarking of the building energy. However, both benchmarking determined by two methods

have certain limitations: the benchmarking was either higher or lower than the reasonable value, making the number of energy efficient buildings among the 38 samples were 18 and 12, respectively. By comparing the two benchmarking to the actual values of energy consumption of each building, the benchmarking was corrected by four reasonable rules, making the number of energy efficient buildings were 11. The corrected results were more reasonable and useful.

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