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A Design of the Evaluation and Prediction of Power Energy Consumption of Office Buildings based on Multivariate Linear Regression

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Abstract

In recent years, with the rapid increase of office buildings and the requirements to improve the office environment, office building energy consumption has increased significantly. That has brought great pressure to the user, environment and city power supply and demand. The electric energy consumption of office building conservation is the most important way to reduce the energy consumption. Simulation is a major method to understand about office building power consumption. At present domestic and foreign computer software simulation technology cannot work without a lot of professional parameters. And the obtained results is so professional that cannot give the management decision auxiliary. This paper presents a holistic statistical distribution instead of complex thermodynamic iterative computation model, and the analysis method. Using the mode "facing to the whole" for analysis of power energy consumption of office buildings, without more intricate parameters, and can be iterative adjusted according to the difference between measured data and the prediction.

***Keywords**: Office building, electrical energy consumption, power consumption simulation, power consumption prediction*

1. Introduction

In the field of Simulation analysis for the office building energy consumption, in "Current building energy consumption in China and effective energy efficiency measures[1]" Jiang Yi and his colleague who analyzed the situation of building energy consumption in our country. Starting from energy characteristics of buildings, they came out a new classification of buildings and building energy pathway, provided all kinds of status quo, problems and potential energy savings. And confirmed the feasibility and effectiveness of simulation-based analysis of building energy optimization design. Pan Yiqun and his colleagues who proposed building energy simulation tools are essential to support building energy saving described the simulation software and modeling methods including forward and reverse modeling. Other studies have been developed mainly using simulation software, such as DOE-2, DeST and EnergyPlus, to analysis the index of the building under a specific status, within qualitative and quantitative conditions. In some other researches, authors suggest that their study mathematics or thermodynamic model. But using these professional analysis software, highly professional basic data is always obligatory. And the output data that is obtained are also highly specialized and difficult to use directly, or to provide an intuitive decision-making support.

Many scholars abroad for building energy analysis and modeling conducted in-depth research. These studies broadly divided into two directions, the first direction is mainly in the building structure for the study, using software or method of hourly energy consumption simulation, which are mainly built on the thermodynamic theory,

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considering the disturbance inside and outside interference factors, and list thermodynamic equations to solve. Research in this direction has played a significant supporting role in the architectural design stage. However, in the use stage, due to the use of user behavior uncertainty, there are much discrepancy between results and actual data. Another direction is focused on the analysis of data on energy consumption, such as Le Comte D M., Manish Ranja who used artificial intelligence, data mining algorithms and other ways to find the relationship between energy consumption data and influencing factors, building energy analysis and forecasting.

In this study, along the second direction of thinking, based on the acquisition of office building electricity consumption data, regarding energy consumption data in a period of time as the object of the research, establish a linear model, using office building electricity consumption factors (including behavioral factors users). Use regression algorithm to find the relationship between energy consumption data and influence factors. According to this relationship and indicators of the next period of time, we can predict the consumption in another period of time. The article first analyzes and screening out the most critical factors in typical office building electricity consumption, then use these factors to establish a linear regression model of factors and consumption. At last, we use actual energy consumption data for multiple regression analysis to verify the feasibility of the model in SPSS.

2. The Extraction of Influence Factors in the Model

In this study, instead of using energy or building professional analog mode, we study the relationship between the change of energy consumption and the change of variables of the building. Therefore no longer need to pay attention to the amount that will not change over time in a fixed architecture such as building area, orientation, shape coefficient, windows than walls, wall heat transfer coefficient, lamp type, and system architecture. Instead, the variables which be able to change over time are needed. These variables are divided into two kinds, of objective factors and human factors.

2.1. Objective factors

In this study, with the analysis of historical data, we select the objective factors collections, as shown in Table 1.

Table 1. Names and Meanings of Objective Factors Variable

Names	Meanings
outside temperature	The temperature of the natural environment
indoor temperature setting	Office building indoor temperature set
personnel density	The ratio of the number with the floor area of use

This section will analyze the variables, and the relationship between changes in these variables and changes in electricity consumption.

2.1.1. Outdoor temperature: The authors obtained 15 government office buildings in Beijing monthly energy consumption data in 2012, representing in a line chart in Figure 1.

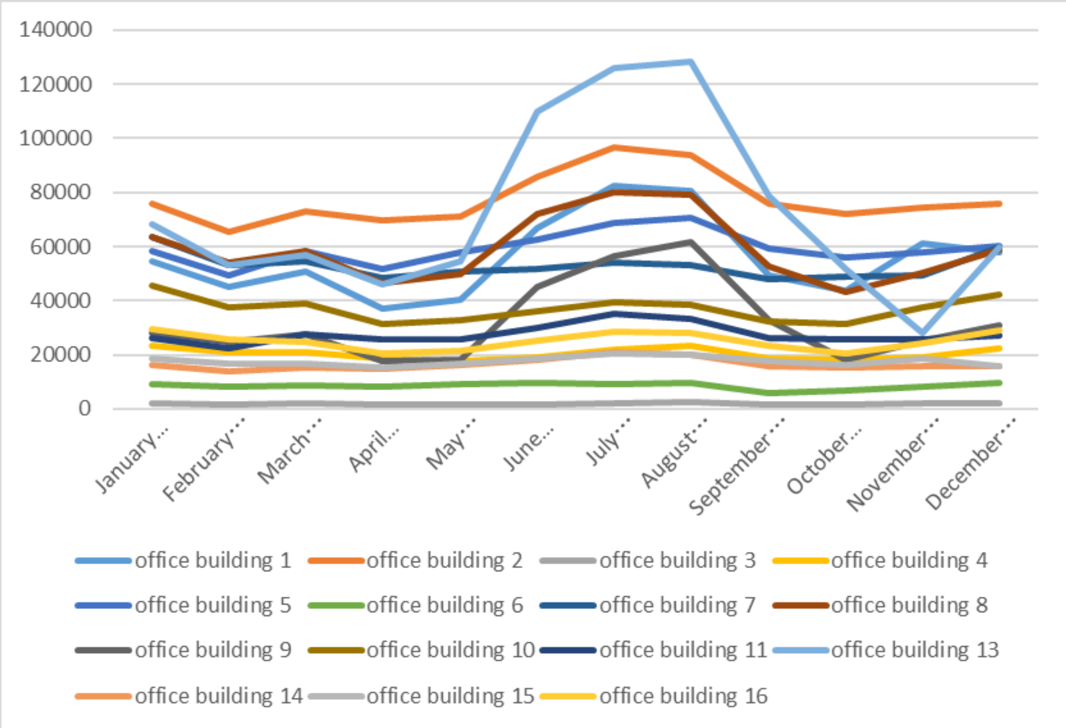

Figure 1. 15 Government Buildings in 2012 Electricity Consumption Line Chart in Beijing

Easy to see that, on the whole it shows the trend that higher summer, spring and autumn are lower, and winter centered. Mainly due to the high temperature of the hot summer, the summer air-conditioning power consumption has become the "main force". Because of suitable temperature, the use of air conditioning is less in spring and autumn, which consumes less power.

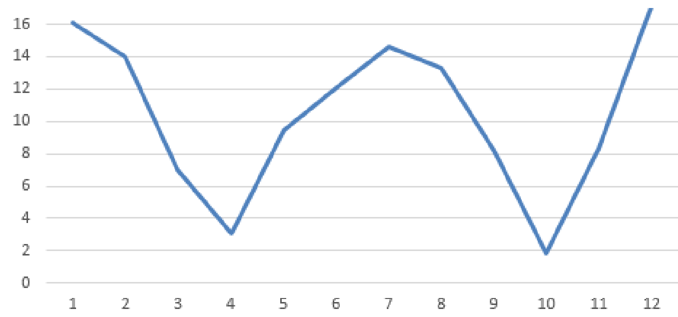

Figure 2. Absolute Value of the Temperature Difference between Monthly Average Temperature and 20 ℃ in Beijing

From Figure 1 and Figure 2, except November, December, January and February which have uniform heating, we can see clearly in general the power consumption are change with the change of absolute value of the temperature difference between monthly average temperature and 20 ℃, especially in the summer. So we can assume that there is a linear relationship between them, which provide ideas and theoretical basis for the following model.

2.1.2.Indoor temperature setting: In "Investigation of energy efficiency evaluation system for public building in Hunan area" researchers used simulation software eQUEST to establishment of a typical office building, and using the first idea mentioned in the introduction that regard the building structure as the object to Solve equations. This study demonstrates that there is a linear relationship between the building's energy consumption per unit area and the interior of the set temperature.

2.1.3. Personnel density: Usually the number of staff of an office building was not able to follow the will of the administrator to manually adjust. Although the total number of users may be due to changes in office operations or internal changes, but it is closer to be an objective change. In the air conditioning energy consumption, a linear increase in the user, will inevitably lead to air-conditioning heat load increases linearly. If we consider the efficiency of air conditioning equipment will not change because of the number of user. Then power consumption of air generated also show a linear increase. Similarly, consumption of power socket can also be considered by a linear increase in the number multiplied by a per capita remained unchanged "Device", so it's increase linearly. Therefore, the increase building energy consumption can be considered to have an approximate linear relationship with the increase in personnel, or personnel density.

2.2. Human Factors

In this study, the impact of human factors cannot be separated in influencing energy consumption. As shown in Table 2 is selected human factors in accordance with the characteristics of the building.

Table 2. Human Factors Variable Names and Meanings

Names	Meaning
Period of the lights	The period between lights on in the morning and the lights off at night in office building
Per capita illumination standards	The ratio of total office building interior illumination and number of user
Other equipment power	In addition to the air-conditioned and lighting power, other devices power in office buildings

2.2.1 Staff behavior patterns: One of the behavior patterns is period of the lights. In the composition of the power consumption in the building, lighting power is an important part separate from air conditioning and power socket. In large office buildings, there is a strong correlation between the time lamp turn-on and the time most people reach room. And so do the time lamp off and the time the last to leave the office.

The other behavior patterns is power consumption for lighting, has been widely recognized as an important part of the energy consumption. This part of the energy consumption has relatively simple purpose, which is to complete the construction of lighting tasks. However, the impact on electricity consumption for lighting is mainly determined by the use of personnel habits. Per capita lighting power is directly related to the building of the total electricity consumption. In the past, the study found that changes in lighting energy consumption is mainly affected by personnel schedule while less impact from the outdoor illumination situation, such as "Data Analysis and Modeling of Lighting Energy Use in Large Office Buildings" has suggested and proved. So the author classify illumination standards as human factors. In addition, as described above, the occupant density is classified as an independent factor. So per capita illumination standards is classified as a factor of power consumption, instead of total illumination. This is done to avoid the overlap between personnel density.

2.2.2. Other equipment power: Equipment runtime is undoubtedly an important factor of power consumption. Equipment power here refers to total power of the electrical equipment in the building in addition to the air-conditioning equipment, lighting equipment. The reason why it is singled out, partly due to the different uses of electricity, another very important aspect is air-conditioning equipment, lighting equipment under normal circumstances has been fixed, the number of devices, the total power has been determined at the time of building design and construction; however "equipment" power may also change significantly in normal use. Such as computers, server device, equipment used to control the water supply and drainage and power control equipment and so on.

3. Build Models

The analysis of these factors, provide the basis for multivariate linear regression of power consumption in office building.

3.1. Independent Variables Selection

When performing the regression analysis, independent variables selection is the basis, in general two principles should be considered. Independent variables must be closely related to the dependent variable. Independent variables should be avoided strong linear relationship between. Considering the representativeness, completeness and availability of the independent variables, the selected are shown in Table 2.

Table 2. Linear Regression Variable Table

Names	Meaning
Y (dependent variable)	a monthly consumption of office building(kWh)
X_1 (independent variable)	(air conditioning) the difference between the outdoor temperature and the indoor temperature (℃)
X_2 (independent variable)	(lighting) The average length of time daily lights (h)
X_3 (independent variable)	(lighting)per capita illumination(W/person) = $\frac{\text{personnel density (person/m}^2\text{)}}{\text{illumination standards (W/m}^2\text{)}}$
X_4 (independent variable)	The average number of users monthly = $\frac{\sum_{i=1}^{i=\text{the number of days in the month}} \text{the number of users in the } i\,th \text{ day}}{\text{the number of days in the month}}$
X_5 (independent variable)	Total power of the device(W)

Among them, all the variables are numeric variables, the specific form of multiple regression model is:

$$Y = b_0 + b_1X_1 + b_2X_2 + b_3X_3 + b_4X_4 + b_5X_5 + \varepsilon$$

Where b_0 represents the linear relationship of constant, $b_i (i = 1, 2, 3, 4, 5)$ represents the coefficients of each independent variables (X_1—X_5), and ε indicates the error.

3.2. Model Building

The model above is used, with a set of sample data observed—Y_j、X_{1j}、X_{2j}、X_{3j}、X_{4j}、X_{5j} (j = 1, 2, 3……n) , n is the sample size.

Using analysis software SPSS linear regression function, we set five independent variables X_1、X_2、X_3、X_4、X_5(Independent(S)), and set Y is the dependent variable ("Dependent").In the main menu of "Regression" in "Analyze", select linear regression analysis in "Linear" item, and set these independent and dependent variables. The parameters in this analysis are shown Table 3.

Table 3. Parameters of Linear Regression

Parameter names	Parameter values
Stepping Method Criteria	Use probability of F
Entry	.05
Removal	.10
Include constant in equation	Yes
Missing Value	Exclude cases listwise
Regression Coefficients	Estimates
Model fit	Yes

The linear regression model can be finalized by these forms, the specific usage, and examples of the model obtained, will be given below in 3.3 model validation.

3.3. Model Validation

This study select power consumption data in 2014 of one office building from one University to validate the model. The data is from energy monitoring platform of this University. Data model validation required is shown in the following table.

Table 4. Power Consumption Model Validation Data

Date (monthly)	Temperature difference (℃) X_1	Average length of time lights (h) X_2	Average users monthly X_3	Consumption (monthly) (kwh) Y
January 2014	19.95	9	300	131229.8
February 2014	20.25	9	300	116657.25
March 2014	10.403	10	500	148273.15
April 2014	2.629	10	500	133086.03
May 2014	1.8545	10	500	153972.31
June 2014	5.35	10	500	152644.2
July 2014	8.129	7	400	147685.94
August 2014	5.9355	6	300	125582.12
September 2014	0.933	10	500	133778.3
October 2014	5.5841	7.5	375	131400.98

Wherein the table should be noted is that, the "temperature difference" is an absolute value of the difference between the average temperature of each month in Beijing and 20 ℃.

The reason for this choice is because the goal to adjust the room temperature is to make it comfortable. Heating when cold and cooling when hot. Because of this building is from school, in the winter and summer vacation the average length of time daily will reduce. Accordingly, the average number of users monthly will have analogous variation.

The results are listed in Table 5 - Table 8 using SPSS. The text below is to illustrate from the writer, not produced by software.

Table 5. Variables Entered/Removed

Model	Variables Entered	Variables Removed	Variables Removed
1	VAR00003, VAR00002, VAR00001a	.	Enter

a. All requested variables entered.

Table 5 is the case that the variable entry and removal. Independent variables which is decided to retain are listed in "Variables Entered". That is to say, there is a linear relationship between the independent variables and the dependent variable to some extent.

Table 6. Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.817a	.668	.502	882.502974

a. Predictors: (Constant), VAR00003, VAR00002, VAR00001.

In Table 6, multiple correlation coefficient and coefficient of determination will be listed in column "R" and "R Square". The greater they are, the better indicating regression model is.

Table 7. Anova[b]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	9.395E8	3	3.132E8	4.021	.046a
	Residual	4.673E8	6	7.788E7		
	Total	1.407E9	9			

a. Predictors: (Constant), VAR00003, VAR00002, VAR00001.

b. Dependent Variable: VAR00004

In Table 7 $Anova^b$, if Sig. (Significance probability) value is less than alpha (default is 0.05), indicating that the regression is significant.

Table 8. Coefficients[a]

Model		Unstandardized		Standardized		
		B	Std. Error	Coefficients	T	Sig.
1	(Constant)	87405.229	22529.462		3.880	.008
	VAR00001	1280.130	902.576	.710	1.418	.206
	VAR00002	-6811.692	4153.196	-.813	-1.640	.152
	VAR00003	239.372	93.017	1.777	2.573	.042

a. Dependent: VAR00004.

Table 8 shows the test of partial regression coefficients and standard partial regression coefficients. Extract the model Unstandardized Coefficients B value, as the coefficient of the final model.

So we get personalized power consumption model specific to this building as follows:

$$Y = 87405.229 + 1280.130X_1 - 6811.692X_2 + 239.372X_3$$

3.4. Use of Model

With this model, we can predict the consumption of next month by input the expected value of X_1, X_2 and X_3. This can provide reliable data and decision support for future energy distribution and prediction.

If we want to get the consumption of a certain period ,for (m)Year(n)Month--$Y_{m,\ n}$, we can use the data of $Y_{m-i,\ n}$、$X1_{m-i,\ n}$、$X2_{m-i,\ n}$、$X3_{m-i,\ n}$、$X4_{m-i,\ n}$、$X5_{m-i,\ n}$ (i=1,2,3,4,5) to be the basic data. With the same way to establish model and to predict. The data of year to year will enhance the accuracy inevitably.

For each simulation, with getting the data of last period of time, the model modify constantly. And the model are getting more and more close to real situation.

4. Conclusion and Outlook

This study is based on energy consumption data, explore the relationship between change in energy consumption of office buildings and change in the natural environment or change in personnel statistically. It save a lot of work of thermodynamic data collection, processing and computation. It select and screen out five with the most significant factor to be independent variables which have linear relationship with the consumption, and proved that experimentally.

This paper has established a model method. Using this method which can establish a special linear equation for each office building solve a problem that the impact of personality factors in different buildings cannot be predicted in unified model. As long as the expected value of independent variables are given, we could predict power consumption within a certain period of time. And models can be continually update and iterate based on actual data. The bigger the sample size is the more accurate the prospective energy predict will be.

Future research will focus on two dimensions. Horizontally, this way of model can be used to other types of construction. Vertically, for office building, continue to explore the laws of different kind of energy consumption and the relationship between them, for more in-depth exploration of the total energy consumption of all types of buildings.

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