Study on Energy Consumption of Hotel Based on Extended STIRPAT Model

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Abstract: Energy consumption of hotel can be a hot topic in smart city. To find the key impact factors of energy consumption to realize the energy saving target. This paper examined the impact factors of occupancy rate, unit area of revenue, temperature factor and unit revenue of energy consumption. However, the current study on energy consumption of hotel is limited to the relationship with the single impact factor at home and abroad. In this paper, by taking the energy consumption data of a five-star hotel as a case, we explored the impact factors of occupancy rate, unit area of revenue, temperature factor and unit revenue of energy consumption on energy use intensity (EUI) change based on the extended STIRPAT model. Empirical results indicate that factors such as occupancy rate, unit area of revenue, and unit revenue of energy consumption can cause an increase in energy consumption of the hotel, but temperature factor can lead to a decrease in energy consumption of the hotel. The empirical results also reveal that the extended STIRPAT model can be used to predict and evaluate energy consumption of hotel. Finally, the study can provide managerial reference according to the regression results for energy saving management of hotel.

Key Words: impact factors, energy use intensity, STIRPAT model, energy saving

1 INTRODUCTION

With the development of society and the improvement of quality of life, the awareness of energy saving is getting more and more attention all over the world. The energy consumption of hotel has become a large part of the social consumption. So the study on energy consumption of hotel is an increasingly necessary problem to study. Studying on energy impact factors can help hotel managers find the focus of energy saving and make up the lack of the theory of energy consumption and energy saving management.

Current research on the energy consumption of hotel is almost to study the relationship between the energy consumption and the single factor at home and abroad[1]. However the impact of the energy consumption of hotel has a series of factors, and there is no substantial progress in the study of multiple factors effect on the energy consumption of hotel. In this paper, the extended STIRPAT model is applied to study the relationship between energy consumption of hotel and the energy impact factors. Because the hotel energy impact factors mainly include static factors and dynamic factors. The static factors refers to the location, hotel orientation, architectural feature, etc[2]. Once the hotel is built, we could not change these static factors. Therefore this paper considers main dynamic factors that can impact the energy consumption of hotel, the dynamic factors include occupancy rate, unit area of revenue, temperature factor, and unit revenue of energy consumption.

This paper is organized as follows: Section 2 introduces the extended STIRPAKT model and applies this model to study the energy consumption of hotel; The rationality of the extended STIRPAT model applied to study energy consumption is verified by a case in Section 3 . The conclusions and policy implications are summarized in Section 4.

2 APPLICATION THE STIRPAT MODEL TO STUDY ENERGY CONSUMPTION

2.1 STIRPAT Model

In order to quantitatively reveal the impact of population, economic development and the science & technology on the environment, the famous American demographers Ehrlich and Holden proposed IPAT model in 1971[3], the equation is expressed as:

$$I = PAT. \tag{1}$$

Where I represents environmental impact, P refers to the population, A refers to affluence, T is technical level. Left side of equation (environment impact) can represents different indicators, such as energy consumption, CO_2 emissions and so on[4].

IPAT model works by changing one factor, while holding other factors no changing to analyze the problem. Thus the obtained results is equal proportion impact on the dependent variables, which is the biggest limitation of the model. Therefore STIRPAT model is established based on IPAT model[5], the equation is expressed as:

$$I = \alpha P^a A^b T^c e. \tag{2}$$

Where I, P, A and T have the same meaning as in the IPAT model, α is coefficient of the model, a , b and c are parameters to be estimated, and e represents the random error. The IPAT model can be regarded as a special form of STIRPAT, wherein $\alpha = a = b = c = e = 1$.

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Compared with IPAT model, The STIRPAT model has better expansibility[6]. Not only could it be used to analyze the influence of one independent variable on the environmental pressure, but also to examine the effect of each independent variables on the environmental pressure. Furthermore, it is the non-linear model, and the introduced parameters in the model can be used to analyze the impact factors of non-proportional impact on the environment.

2.2 Extended STIRPAT Model Applied To Study Energy Consumption Of Hotel

According to the above analysis of IPAT model and STIRPAT model, we can know these two models can represent the relationship between environmental pressure and the factors. Environmental stress can be represented by energy consumption of hotel. The air-condition and heating can consume a large portion of energy consumption of hotel [7]. In this paper , the temperature factor is the absolute value of outdoor temperature minus indoor comfort temperature. In other words, temperature factor indicates the need to adjust the degree by air-condition and heating. So on the basis of the STIRPAT model, we introduce the temperature factor as an important factor. Then we establish the following extended STIRPAT model for energy consumption of hotel, the equation is expressed as:

$$I = \alpha P^a A^b K^c T^d e, \tag{3}$$

$$\frac{energy\ consumption}{construction\ area} = occupancy\ rate \times \frac{operation\ revenue}{construction\ area} \times temperature\ factor \times \frac{energy\ consumption}{operation\ revenue}$$

Where the occupancy rate is dimensionless, and the temperature factor is converted to dimensionless by dividing the unit temperature, I represents energy consumption(expressed as the monthly average total energy use intensity(EUI))[8], P refers to the population factor(expressed as monthly average occupancy rate), A is affluence factor(expressed as unit area of revenue), K represents temperature factor, T is technical factor (expressed as unit revenue of energy consumption).

Compared with the traditional STIRPAT model, the extended one with its supplementary variable of temperature factor allow much more factors of energy consumption to be examined.

3 EMPIRICAL ANALYSIS

This empirical analysis is based on a five-star hotel, the hotel total construction area being 43580 square meters, with 308 rooms. Occupancy rate reached 57 percent in general. Table 1 shows the energy consumption original data in recent years: x_1 refers to monthly average occupancy rate, x_2 represents to unit area of revenue, x_3 is the temperature factor, x_4 refers to unit revenue of energy consumption and y refers to the monthly average total energy use intensity(EUI).

Table 1 Original data

month	x_1	x_2	x_3	x_4	y
Jan.	0.4036	5.8	25	1.6643	9.6528
Feb.	0.4512	6.1	22	1.5445	9.4213
Mar.	0.5345	6.6	17	1.6177	10.6768
Apr.	0.5088	6.4	10	1.5450	9.8879
May.	0.5867	6.8	4	1.6718	11.3685
Jun.	0.7023	8.5	1.5	1.6078	13.6664
Jul.	0.6687	7.7	3	1.6301	12.5521
Aug.	0.6456	7.4	4.5	1.6685	12.3466
Sept.	0.6889	7.6	2.5	1.7272	13.1269
Otc.	0.6545	7.3	5	1.5120	11.0378
Nov.	0.5343	6.3	13	1.6774	10.5679
Dec.	0.4712	6	21	1.6627	9.9762

Data source: The original data is obtained based on a five-star hotel. The monthly average occupancy rate is obtained by combining with annual average occupancy rate of the hotel and tourism in high seasons and low seasons; Unit area of revenue is obtained by way of monthly operation revenue divided by construction area; The temperature factor is the absolute value of outdoor temperature minus indoor comfort temperature, and dividing the unit temperature; The monthly average outdoor temperature is found on the web of the Chinese weather network, indoor comfort temperature is set to 20 degree; Unit revenue of energy consumption is obtained by way of monthly energy consumption divided by construction area; Monthly average total energy use intensity (EUI) is obtained by way of monthly energy consumption divided by construction area.

3.1 Analysis of Original Data

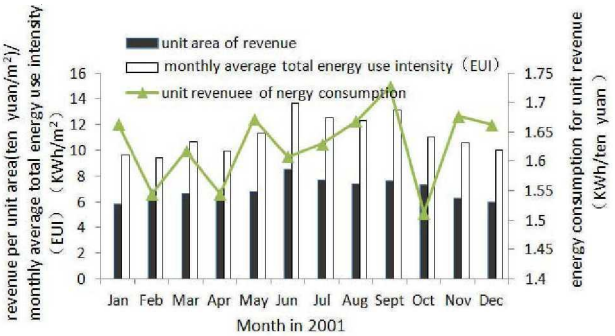

Fig.1. monthly average total energy use intensity(EUI), unit revenue of energy consumption, and unit area of revenue

From Fig.1, we can see that the change trend of the monthly average total energy use intensity(EUI) and unit revenue of energy consumption is almost consistent. And with the growth and decline of the monthly average

total energy use intensity(EUI), unit area of revenue is consistent with growth and decline. We can get the conclusion that unit revenue of energy consumption and unit area of revenue are driving impact on the monthly average total energy use intensity(EUI).

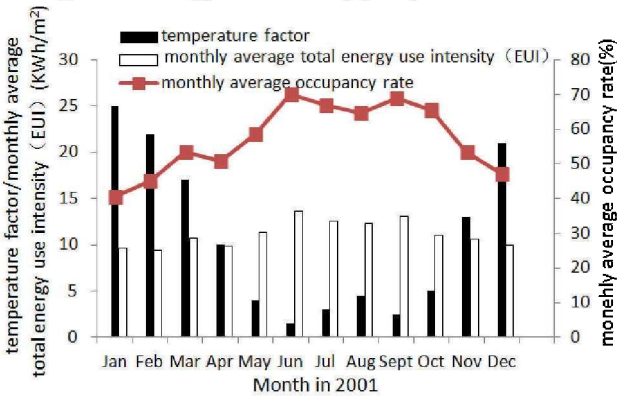

Fig.2. monthly average total energy use intensity(EUI), temperature factor, and monthly average occupancy rate

The relationships between the monthly average total energy use intensity(EUI) and weather conditions have been studied by many researchers. In this paper, we introduce temperature factor replace weather conditions. From Fig.2 we can see that temperature factor value is relatively higher at November, December, January, February, March, but the monthly average occupancy rate of the five months is relatively lower, and there is no obvious relationship in other months. So it is difficult to judge the impact of temperature factor on energy consumption of hotel. We need to establish the extended STIRPAT model to analyze the impact of temperature factor on the energy consumption of the hotel.

3.2 Data Preprocessing

This paper is based on the extended STIRPAT model, we add the temperature factor to the model, and establish the eq(3) which is applied to energy consumption of hotel.

In order to facilitate the processing of mathematics, The nonlinear model is converted to linear model[9]. In empirical studies, Eq.(3) may be converted to logarithm form

$$\ln I = a\ln P + b\ln A + c\ln K + d\ln T + \ln e \text{ .(4)}$$

3.3 Multicollinearity Testing

Multicollinearity refers to a situation in which two or more independent variables in a multiple regression model are strongly and linearly related. The multicollinearity of independent variables in the regression model is examined by OLS regression and evaluating their VIF. In general, a VIF greater than 10 indicates severe multicollinearity[10]. Our current work will determine whether there is multicollinearity among the independent variables or not. Based on these preprocessed data, we use the SPSS software to analyze the four independent variables. The results show in Table 2.

Table 2:OLS regression analysis and VIF test of Multicollinearity

Variable	Unstandardized coefficients	t-Statistic	Sig.	VIF
Constant	0.02	1.226	0.137	--
x_1	0.01	2.881	0.078	12.230
x_2	0.999	1694.06	0.001	18.155
x_3	0.00006	0.472	0.915	13.174
x_4	1.000	2289.41	0.000	1.161
R^2	1.000	F-Statistic	16464053	
Adjust R^2	0.999	Sig.	<0.001	

We can get the regression results through table 2, the regression results show the adjustment R^2 is 0.999, F-Statistic is 16464053, Sig. is less than 0.001. The regression equation through the significance test, but three VIF of the four independent variables are greater than 10, this situation indicate there is a serious multicollinearity among those variables.

3.4 Ridge Regression Estimation

There are three main methods for solving the regression equation that has serious multicollinearity under the condition of not removing the independent variables. The three methods include partial least square method, principal component analysis and ridge regression. This empirical analysis chooses the ridge regression method[11]. Although the ridge regression is a biased estimation method, there is no necessary to remove independent variables. Compared with the ordinary least squares method, we can get more significant regression results. Applying ridge regression to regression fitting by the preprocessed data, we set the K value to [0,0.2], and the step size is 0.01 to get the ridge trace.

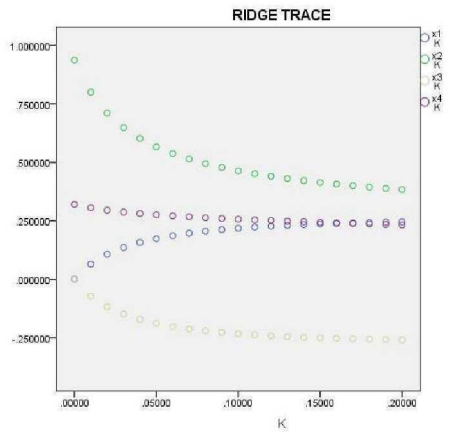

Fig.3. Ridge Trace

As we can know from the Fig.3, When $K = 0.12$, the regression coefficients is almost stable. Thus $K = 0.12$ was selected for performing ridge regression on

our data. As R square is 0.9848, the overall fit is very good. The VIF of each variable is much less than 10. Therefore , the fitted ridge regression equation is

$$\ln y = 1.2772 + 0.1558\ln x_1 + 0.4694\ln x_2 - 0.0358\ln x_3 + 0.78413\ln x_4 \quad (5)$$

3.3 Results Analysis

According to the regression eq(5) , we can get the results of the monthly average total energy use intensity(EUI) from January to December. Table 3 shows the data.

Table 3 regression results and error

month	Actual EUI	Regression EUI	Error
Jan.	9.6528	9.4421	0.0218
Feb.	9.4213	9.3204	0.0107
Mar.	10.6768	10.393	0.0266
Apr.	9.8879	9.9933	0.0107
May.	11.3685	11.556	0.0165
Jun.	13.6664	13.256	0.0300
Jul.	12.5521	12.384	0.0134
Aug.	12.3466	12.134	0.0172
Sept.	13.1269	13.024	0.0078
Otc.	11.0378	11.142	0.0094
Nov.	10.5679	10.562	0.0006
Dec.	9.9762	9.8818	0.0095

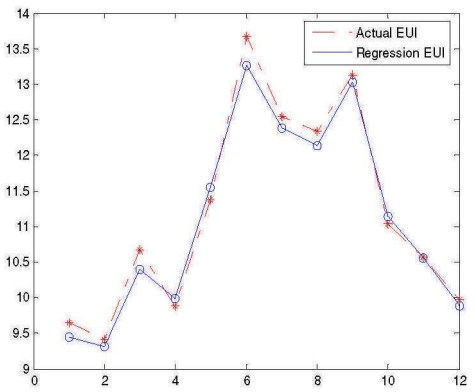

Fig. 4. Comparison Figure Between Actual EUI and Regression EUI

Error analysis: We can get the average error is 1.415% through table 3. The relative error is less than or equal to 3%. From fig.4 we can obviously see the value of actual monthly average total EUI and regression monthly average total EUI. These two aspects could obtain that the regression results are good.

4 SUMMARY

In this paper, the extended STIRPAT model is applied to study the energy consumption of hotel[12]. It breaks the traditional practice of studying the relationship of energy consumption of hotel with a single impact factor at home and abroad. Because the energy consumption of hotel can be connected with many factors. This extended model shows the change of energy consumption under the impact of multiple factors working together. The extended STIRPAT model is used to study the relationship between energy consumption with energy impact factors of a five-star hotel, using ridge regression method to get the fitting equation. Through the error analysis, we can see that the error can be controlled within 3%. Empirical results reveal that the factors such as occupancy rate, unit area of revenue, and unit revenue of energy consumption can cause an increase in energy consumption of the hotel, but temperature factor can lead to a decrease in energy consumption of the hotel. The empirical results also indicate that the extended STIRPAT model can be used to predict and evaluate energy consumption of hotel. Managers can realize the energy saving target of hotel based on the extended STIRPAT model.

Because a series of factors could affect energy consumption of hotel[13]. The factors include static factors and dynamic factors, and each of which contains a lot of factors. This paper gives four main dynamic factors, but lack of other factors effect energy consumption of hotel. So we need to further explore more factors that have effect on energy consumption of hotel.

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