Decomposing the Impact Factors of Energy Consumption of Hotel through LMDI

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***Abstract*—**Energy consumption of a hotel can be a hot topic in smart city; it is difficult to evaluate the contribution of impact factors to energy consumption of a hotel. Therefore, grasping the key impact factors has great effect on the energy saving management of a hotel. Based on the SPIRTPAT model, we establish the identity with the impact factors of occupancy rate, unit area of revenue, temperature factor, unit revenue of energy consumption. In this paper, we use the LMDI (Logarithmic Mean Divisia Index) to decompose the impact factors of energy consumption of hotel from Jan. to Dec. in 2001. The results indicate that the occupancy rate and unit area of revenue are the main factors that can increase unit area of energy consumption, and the unit revenue of energy consumption is the main factor to restrain the growth of unit area of energy consumption. When the energy consumption of hotel can appear abnormal, the hotel manager can carry out energy saving management and control according to the contribution value of impact factors.

***Keywords*—**Smart city, SPIRTPAT model, LMDI, saving management and control.

I. INTRODUCTION

AFTER consulting a large amounts of data, we find that many scholars use LMDI decomposition approach to research the change of energy consumption and environmental economy [1]-[7], and they have made some progress in these study.

When the World Bank study the relationship of economic growth and CO_2 emission in India [1], the study comparatively analyzed the world of CO_2 emission, population growth, economic development, energy structure and energy consumption based on LMDI decomposition approach. Ou Yuhui and Miu Fumin research the growth of energy consumption by LMDI decomposition approach [2], [3]. Wei Ziqing found industrial energy efficiency is the main reason for reducing energy intensity by using LMDI decomposition approach in Jiangsu Province [4]. Wang Junsong analyzed the CO_2 emission by using LMDI decomposition method in China from 1990 to 2007. The study pointed out that the effect of economic growth is major factor which lead to the increase of CO_2 emission, and impact of energy use intensity is the main reason for suppressing CO_2 emission [5]. Wang Yuan estimated the amount of implied carbon in China International Trade, the influence factors of the net transfer of carbon can be decomposed into strength effect, scale effect and structure effect through LMDI method. Among these factors, the contribution rate of intensity effect and scale effect was

positive, the contribution rate of structural effect was negative [6]. Jiang Lu introduced LMDI decomposition approach into virtual water trade, and the amount of change in virtual water can be divided into scale effect, structure effect and intensity effect, and we can quantitative calculate the contribution value of various effects [7]. We can see that LMDI decomposition approach is mostly used in the change of energy and environmental economy, but the approach is less used in energy consumption of hotel. Considering energy consumption of hotel also belongs to a part of energy consumption, we analyze the impact factors of energy consumption of hotel by using LMDI decomposition approach, and then analyze the contribution value of the factors.

II. LMDI DECOMPOSITION APPROACH APPLY TO STUDY THE ENERGY USE INTENSION OF HOTEL

A. LMDI Decomposition Approach

The basic idea of index decomposition could decompose the change of a target variable (such as energy consumption) to the combined of several impact factors, then we can get the impact degree of the various factors. In the case of available data, this decomposition proceeds layer by layer, and ultimately a variety of factors that influencing the target variable are distinguished. We use the following mathematical language describe the basic model of index decomposition:

Assume V is the sum of m sections, that is $V = \sum_i V_i$. In n-dimensional space, The target amount V can be decomposed to product of n factors, which is denoted as $V_i = x_{1,i} x_{2,i} \cdots x_{n,i}$. Within the time period $[0,T]$, the target amount is changed from $V^0 = x_{1,i}^0 x_{2,i}^0 \cdots x_{n,i}^0$ to $V^T = x_{1,i}^T x_{2,i}^T \cdots x_{n,i}^T$. The basic form of index decomposition is as follows:

Additive decomposition:

$$\Delta V_{tot} = V^T - V^0 = \Delta V_{x_1} + \Delta V_{x_2} + \cdots + \Delta V_{x_n} + \Delta V_{rsd} \quad (1)$$

Multiplicative decomposition:

$$D_{tot} = V^T \big/ V^0 = D_{x_1} D_{x_2} \cdots D_{x_n} D_{rsd} \quad (2)$$

where $D_{x_k}, \Delta V_{x_k}$ represent decomposition amount of factor x_k, $D_{rsd}, \Delta V_{rsd}$ are decomposition residuals.

In 1924, a French mathematician Divisia proposed Divisia index [8]. The purpose of Divisia index is to decompose the various factors as continuously differentiable functions of t by

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time derivative, and then we can get the effect of the various factors. The two common Divisia index decomposition method are AMDI and LMDI.

According to the definition of Divisia decomposition method, we do time differential by the target amount V:

$$dV^t/dt = \sum_k \sum_i x_{1i}^t, x_{2,i}^t \cdots x_{k,i}^t \cdots x_{n,i}^t \, dx_{k,i}^t/dt$$
$$= \sum_k \sum_i V_i^t \, d(\ln x_{k,i}^t)/dt \qquad (3)$$

Do time derivative in (3) on both sides at the same time:

$$\int_0^T dV^t/dt = V^T - V^0 = \sum_k \int_0^T \sum_i V_i^t \, d(\ln x_{k,i}^t)/dt \qquad (4)$$

According to the additive decomposition:

$$\Delta V_{x_k} = \int_0^T \sum_i V_i^t \, d(\ln x_{k,i}^t)/dt \qquad (5)$$

Divide (3) by V^t, integrated by the time:

$$\int_0^T \frac{1}{V^t} dV^t/dt = \ln(V^T/V^0) = \sum_k \int_0^T \sum_i \omega_i^t \, d(\ln x_{k,i}^t)/dt \qquad (6)$$

Exponential operation of e in (6), according to the multiplicative decomposition, we can get:

$$D_{x_k} = \exp\left\{ \int_0^T \sum_i \omega_i^t \, d(\ln x_{k,i}^t)/dt \right\} \qquad (7)$$

It is difficult to calculate (5) and (7), so we usually use approximation algorithm. B.W. Ang and F. Q. Zhang analyze the field of energy by the decomposition method [9], [10], comparing with specific examples, they get a completely LMDI decomposition approach finally, which is more suitable for the areas of energy research. The model of LMDI decomposition is as:

Additive decomposition:

$$\Delta V_{x_k} = \sum_i L(V_i^T, V_i^0) \ln(x_{k,i}^T/x_{k,i}^0) \qquad (8)$$

Multiplicative decomposition:

$$D_{x_k} = \exp\left\{ \sum_i \frac{L(V_i^T, V_i^0)}{L(V^T, V^0)} \ln(x_{k,i}^T/x_{k,i}^0) \right\} = \exp\left\{ \frac{\Delta V_{x_k}}{L(V^T, V^0)} \right\} \qquad (9)$$

Among them:

$$L(x, y) = y - x/\ln(y/x).$$

B. LMDI Decomposition Approach Decompose the Impact Factors of Energy Use Intension of Hotel

The LMDI decomposition approach is widely used in analyzing the impact factors of energy use intension. Based on the SPIRTPAT model, this paper establishes the identity with the impact factors [12], and the STIRPAT model is as:

$$E = \alpha P^a A^b K^c T^d e \qquad (10)$$

In the time period $[0, T]$, the energy use intensity of hotel changes from E^0 to E^T, the change quantity is ΔE_{tot}, the change of the ratio is expressed as the population factor (P), the affluence factor (A), the temperature factor (K) and the technical factor (T). The contribution of factors can be decomposed by the index method. Additive versus multiplication forms are as:

Additive decomposition:

$$\Delta E_{tot} = E^T - E^0 = \Delta E_p + \Delta E_A + \Delta E_K + \Delta E_T + \Delta E_{rsd} \qquad (11)$$

Multiplicative decomposition:

$$D_{tot} = E^T/E^0 = D_P D_A D_K D_T D_{rsd} \qquad (12)$$

where $\Delta E_P(D_P)$, $\Delta E_A(D_A)$, $\Delta E_K(D_K)$, $\Delta E_T(D_T)$ represent the contribution to energy use intensity, ΔE_{rsd}, D_{rsd} represent decomposition residuals. It has been proved that the residuals of LMDI decomposition are zero [11].

Using the LMDI model to decompose the impact factors of energy use intension of hotel, the results are as:

Additive decomposition:

$$\Delta E_P = \frac{E^T - E^0}{\ln E^T - \ln E^0} \ln(P^T/P^0) \qquad (13)$$

$$\Delta E_A = \frac{E^T - E^0}{\ln E^T - \ln E^0} \ln(A^T/A^0) \qquad (14)$$

$$\Delta E_K = \frac{E^T - E^0}{\ln E^T - \ln E^0} \ln(K^T/K^0) \qquad (15)$$

$$\Delta E_T = \frac{E^T - E^0}{\ln E^T - \ln E^0} \ln(T^T/T^0) \qquad (16)$$

Multiplicative decomposition:

$$D_P = \exp\left\{ \frac{\ln(E^T/E^0)}{E^T - E^0} \Delta E_P \right\} \qquad (17)$$

$$D_A = \exp\left\{ \frac{\ln(E^T/E^0)}{E^T - E^0} \Delta E_A \right\} \qquad (18)$$

$$D_K = \exp\left\{ \frac{\ln(E^T/E^0)}{E^T - E^0} \Delta E_K \right\} \qquad (19)$$

$$D_T = \exp\left\{ \frac{\ln(E^T/E^0)}{E^T - E^0} \Delta E_T \right\} \qquad (20)$$

It can be proved that LMDI is a complete decomposition method without residuals. Add the two sides of (13)-(16), the results are as:

$$\Delta E_P + \Delta E_A + \Delta E_K + \Delta E_T$$
$$= \sum_i \frac{E_i^T - E_i^0}{\ln E_i^T - \ln E_i^0} \left\{ \ln(\frac{P_i^T}{P_i^0}) + \ln(\frac{A_i^T}{A_i^0}) + \ln(\frac{K_i^T}{K_i^0}) + \ln(\frac{T_i^T}{T_i^0}) \right\}$$
$$= \sum_i \frac{E_i^T - E_i^0}{\ln E_i^T - \ln E_i^0} \ln(\frac{P_i^T A_i^T K_i^T T_i^T}{P_i^0 A_i^0 K_i^0 T_i^0})$$
$$= \sum_i \frac{E_i^T - E_i^0}{\ln E_i^T - \ln E_i^0} \ln(\frac{E_i^T}{E_i^0})$$
$$= \sum_i (E_i^T - E_i^0) = E_{tot} \qquad (21)$$

That is to say:

$$E_{tot} = \Delta E_P + \Delta E_A + \Delta E_K + \Delta E_T \qquad (22)$$

Evidenced by the same token:

$$D_{tot} = D_P D_A D_K D_T \qquad (23)$$

III. EMPIRICAL ANALYSIS

The empirical analysis is based on the relevant data of 10 five-star hotel in a particular place; the hotel average construction area is 43580 square meters, with 308 rooms. Monthly average occupancy rate reached 57 percent in general. Table I shows the original data in 2001: x_1 refers to monthly average occupancy rate, x_2 represents to unit area of revenue, x_3 is temperature factor, in this empirical analysis the temperature factor is the absolute value of the temperature difference between outdoor temperature and indoor comfort temperature. x_4 refers to unit revenue of energy consumption and y refers to the monthly average total energy use intensity (EUI).

TABLE I
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

A. SPIRPAT Model Establishment

According to the data of Table I, we use the SPIRPAT model to establish the identity. Based on these data, firstly we should make a multiple linear diagnosis[13]. The multicollinearity of independent variables in the empirical analysis is examined by

OLS regression and evaluating their VIF, The diagnosis results indicate there is a serious multicollinearity among those variables. In this paper, we choose the ridge regression method to regression fitting. By looking at the ridge trace, we can get the K value when the ridge trace tends to be stable, regression equation through F test and T test, as R square is 0.9848. The regression equation is as:

$$\ln y = 1.5402 + 0.1725 \ln x_1 + 0.3694 \ln x_2$$
$$- 0.0344 \ln x_3 + 0.6698 \ln x_4 \qquad (24)$$

B. Decomposing the Impact Factors of Energy Use Intension of Hotel

In this empirical analysis, we use the LMDI decomposition approach to study energy use intension of hotel form Jan. to Dec. in 2001. We decompose the impact factors of energy use intension by additive decomposition of LMDI decomposition approach. ΔE_{tot} represents the change of unit area of energy consumption, ΔE_P refers to the contribution value of monthly average occupancy rate to unit area of energy consumption, ΔE_P represents the contribution value of unit area of revenue to unit area of energy consumption, ΔE_K refers to the contribution value of temperature factor to unit area of energy consumption, ΔE_T represents the contribution value of unit revenue of energy consumption to unit area of energy consumption. Table II shows the LMDI decomposition results of the impact factors of energy use intension.

TABLE II
THE LMDI DECOMPOSITION RESULTS

Time	ΔE_{tot}	ΔE_P	ΔE_A	ΔE_K	ΔE_T
Jan.-Feb.	-0.1217	0.1629	0.2221	0.0429	-0.5496
Feb.-Mar.	1.0725	0.2599	0.3642	0.0908	0.3576
Mar.-Apr.	-0.3995	-0.0782	-0.1473	0.1935	-0.3675
Apr.-May.	1.5628	0.2387	0.3062	0.3526	0.6654
May.-Jun.	1.7002	0.3470	1.2977	0.4347	-0.3792
Jun.-Jul.	-0.8720	-0.0979	-0.5947	-0.3178	0.1384
Jul.-Aug.	-0.2498	-0.0671	-0.2287	-0.1778	0.2239
Aug.-Sept.	0.8900	0.1272	0.1574	0.2644	0.3410
Sept.-Otc.	-1.8818	-0.0962	-0.2280	-0.2990	-1.2585
Otc.-Nov.	-0.5810	-0.3430	-0.7505	-0.3709	0.8833
Nov.-Dec.	-0.6800	-0.2000	-0.2341	-0.1753	-0.0705
Total	0.4398	0.2532	0.1644	0.0380	-0.0158

C. Decomposition Results

From Table II, we can see that the unit area of energy use intension increases by 0.4398 from Jan. to Dec. in 2001. Occupancy rate and unit area of revenue contribution value is relatively larger than other factors; the contribution value is 0.2532 and 0.1644. The unit revenue of energy consumption can be used to decrease the energy use intensity of the hotel; the impact of temperature factors on the energy use intensity of the increase is relatively small. In this empirical analysis, the occupancy rate and the unit area of revenue refer to population factor and affluence factor. The two factors will drive the increase in the energy use intensity of the hotel, and the unit

revenue of energy consumption represent technical factors, the improvement of the technical factor is obviously reduce the energy use intensity of the hotel, which is accord with fact.

IV. SUMMARY AND SUGGESTION

In this paper, firstly we introduce the theory of the decomposition model, and give the additive decomposition and multiplicative decomposition. This paper analyzes the method of the Divisia index, and we combined with the research of the former scholars. We choose the LMDI decomposition approach which has no residuals as the main model of this paper.

In this paper, STIRPAKT model is used to construct the identity with the impact factors of energy consumption, and using the LMDI decomposition approach decompose the impact factors of energy consumption of the hotel. We can get the contribution value of the impact factors of energy consumption, then we can get the factors that can play a role in promoting or inhibiting. So we could get which factors lead energy consumption of hotel to abnormal. The study can provide managerial reference for energy saving management of hotel.

Because there are many factors that could affect energy consumption of hotel [14], this paper only gives four main factors that affect energy consumption of hotel, although it can be more obvious that the four factors contribute to the changing of energy consumption of hotel, we need to further explore the impact factors of energy consumption. So we will be able to get more accurate decomposition results of the impact factors of energy consumption.

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