Geographical Distribution of Energy Consumption in Western Japan

Kazuhiro Fukuyo
Graduate School of Innovation and Technology Management
Yamaguchi University
Tokiwadai 2-16-1, Ube, Yamaguchi
JAPAN

Abstract: - We estimated from recent statistical data the consumption per household over a 12-month period of electricity, gas, and kerosene in nineteen cities across the islands of Honshu, Kyushu, and Okinawa in western Japan. The result showed that there were clear differences in gas and kerosene consumption among cities while there is little difference in electricity consumption. We analyzed the effect of geographical factors on gas consumption and successfully developed a simple model for predicting monthly gas consumption per household was presented. This model can be used to help determine future strategies for reducing energy consumption.

Key-Words: - Energy consumption, Electricity, Gas, Statistics, Air temperature, Population density

1 Introduction

Reducing energy consumption and strategies to achieve this are now on every government's agenda. While energy consumption in the Japanese industrial sector has increased slightly since 1970 to date, that of the household sector has doubled. This is partly due to the upgrading of home appliances [1]. The doubling of energy in the household sector means that the first step toward establishing any energy-saving strategy is to determine the current status of the residential energy consumption.

We have been investigated in the residential energy consumption in Japan [2 – 4]. This paper shows a recent geographical distribution of energy consumption in western Japan. The weather sensitivity in electricity and gas consumptions is also analyzed.

2 Estimation Method

Data on energy consumption per household is not provided by government or public organizations, so it had to be estimated by using statistical data on family income and expenditures and retail price surveys provided by the Statistical Bureau of Japan [5]. For this paper, a standard household is defined as a place where two or more people live but excludes places where people live on a farm or fishery..

Monthly energy consumption per household in nineteen cities across the Japanese islands of Honshu, Kyushu, and Okinawa was estimated using a previously validated method [4]. The method involves dividing utility expenditures by the corresponding retail prices.

The names of the cities for which household energy consumption was estimated are shown in Fig. 1. Their populations and population densities are listed in Table 1. Tokyo, Yokohama, Osaka, Nagoya, Hiroshima, Kitakyushu, and Fukuoka are megalopolises with populations of over one million. Tokyo is a capital city of Japan.

Fig. 1 Locations of cities in Japan

Table 1 Population of each city in 2005

City	Population [person]	Population density [person/km^2]
Tokyo	8,396,594	13518
Yokohama	3,559,867	8209
Shizuoka	703,150	512
Nagoya	2,122,977	7887
Osaka	2,633,819	11936
Tottori	201,650	263
Matsue	194,631	367
Okayama	638,110	1243
Hiroshima	1,146,063	1546
Yamaguchi	191,195	262
Kitakyushu	1,006,635	2068
Fukuoka	1,391,146	4084
Saga	206,973	583
Nagasaki	452,091	1113
Kumamoto	663,095	2490
Oita	446,147	890
Miyazaki	309,358	518
Kagoshima	604,367	1105
Naha	313,414	8038

3 Energy Consumption in Japan

Figure 2 shows the estimated annual total energy consumption per household in 2004 for each of nineteen cities under consideration. Electricity is widely used for lighting, cooking, heating, cooling, and supplying hot water. There are two types of gas that are mainly used for cooking, heating, water heating. City gas is distributed by gas pipe networks. Propane gas is delivered to households in gas cylinders. Kerosene is limited to use in heaters in most cases.

The composition of energy consumption depends on the city. Kerosene is seldom used in Tokyo, Yokohama, and Osaka metropolitan area because the gas distributing networks are well developed in these cities. Figure 2 shows that propane gas is not used in Nagoya and Osaka.

Figure 2 also shows that there is a little difference in electricity consumption among cities. It ranges from 16355 to 19817 MJ per year. However, clear differences in gas and kerosene consumption can be seen, with city gas consumption ranging from 4425 to 22354 MJ per year and kerosene consumption ranging from 1057 to 8804 MJ per year.

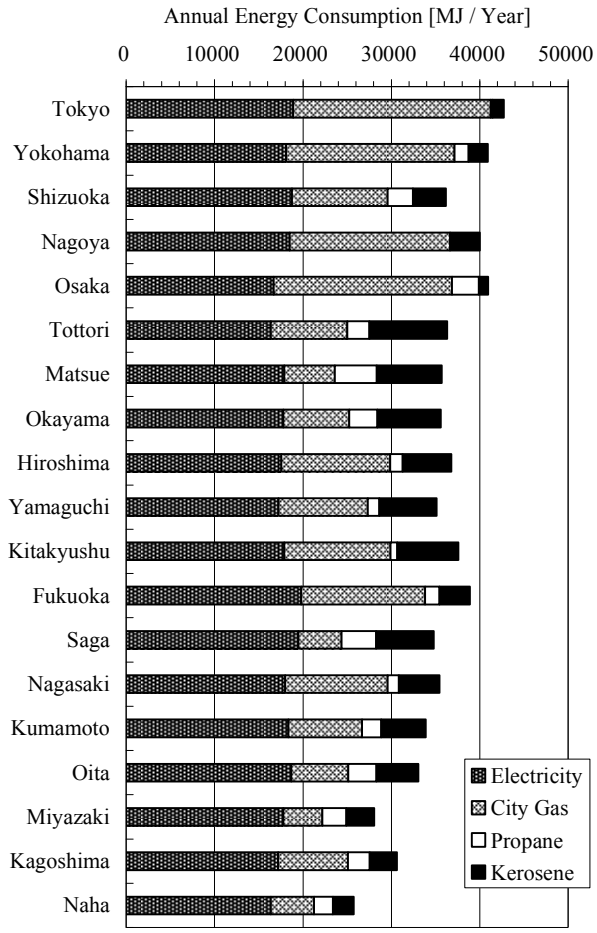
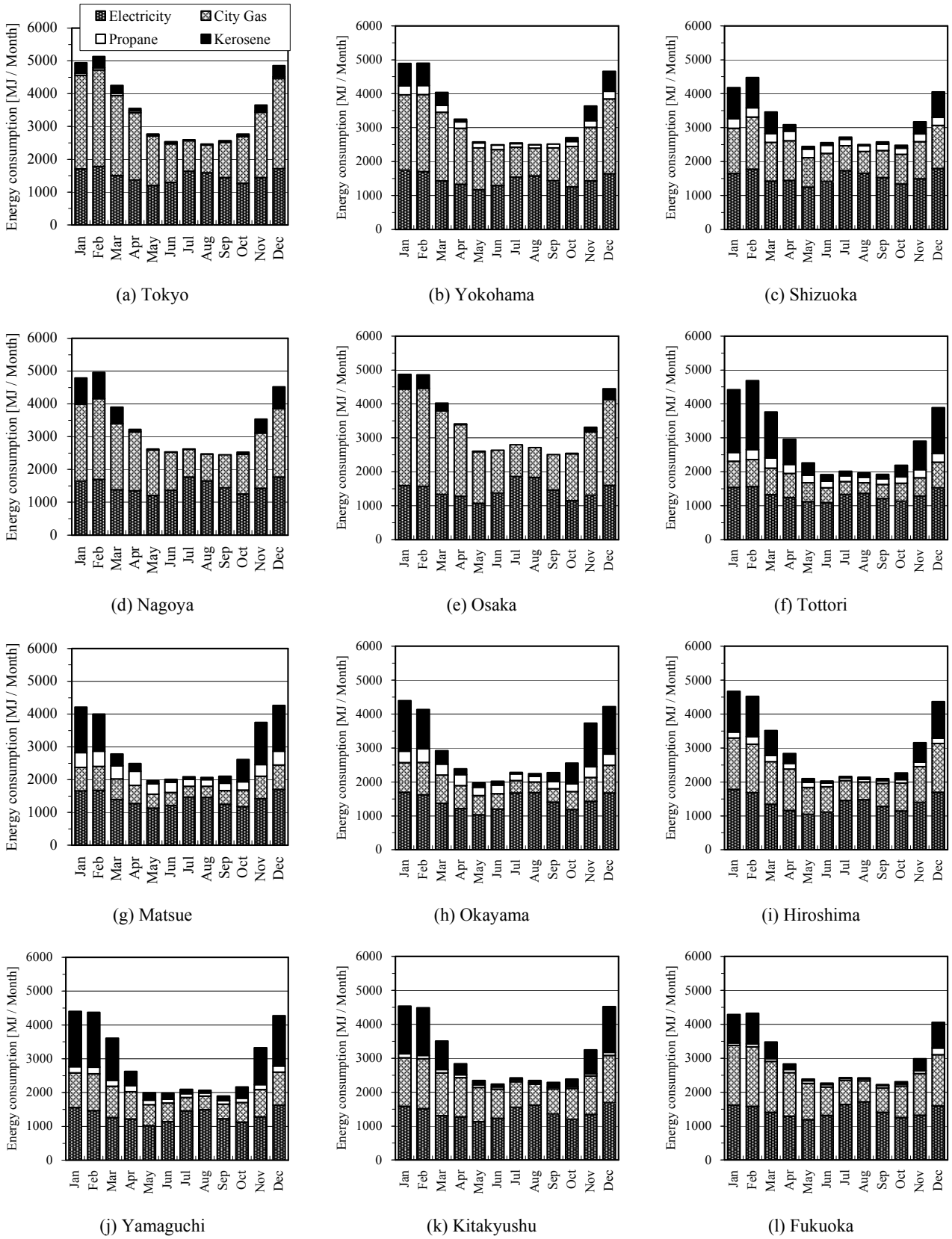


Fig. 2 Annual total energy consumption per household in 2004

Figure 3 shows the estimated monthly average total energy consumption per household. The values are determined using the average value per household per month between 2000 and 2004. With the exception of Naha, the figure shows that electricity increases in winter and summer in all cities. The increase was due to electricity being used for heating and cooling. Electricity is not used for heating in Naha because the city is located in a subtropical zone. Gas and kerosene consumption increased in winter in every city because they are used for heating.

Figure 2 suggests that the gas and kerosene consumption are affected by the geographical factors. Figure 3 suggests that energy consumption depends on the season or weather. Based on these suggestions, we applied a regression approach to the gas consumption with geographical and weather variables as explanatory variables.



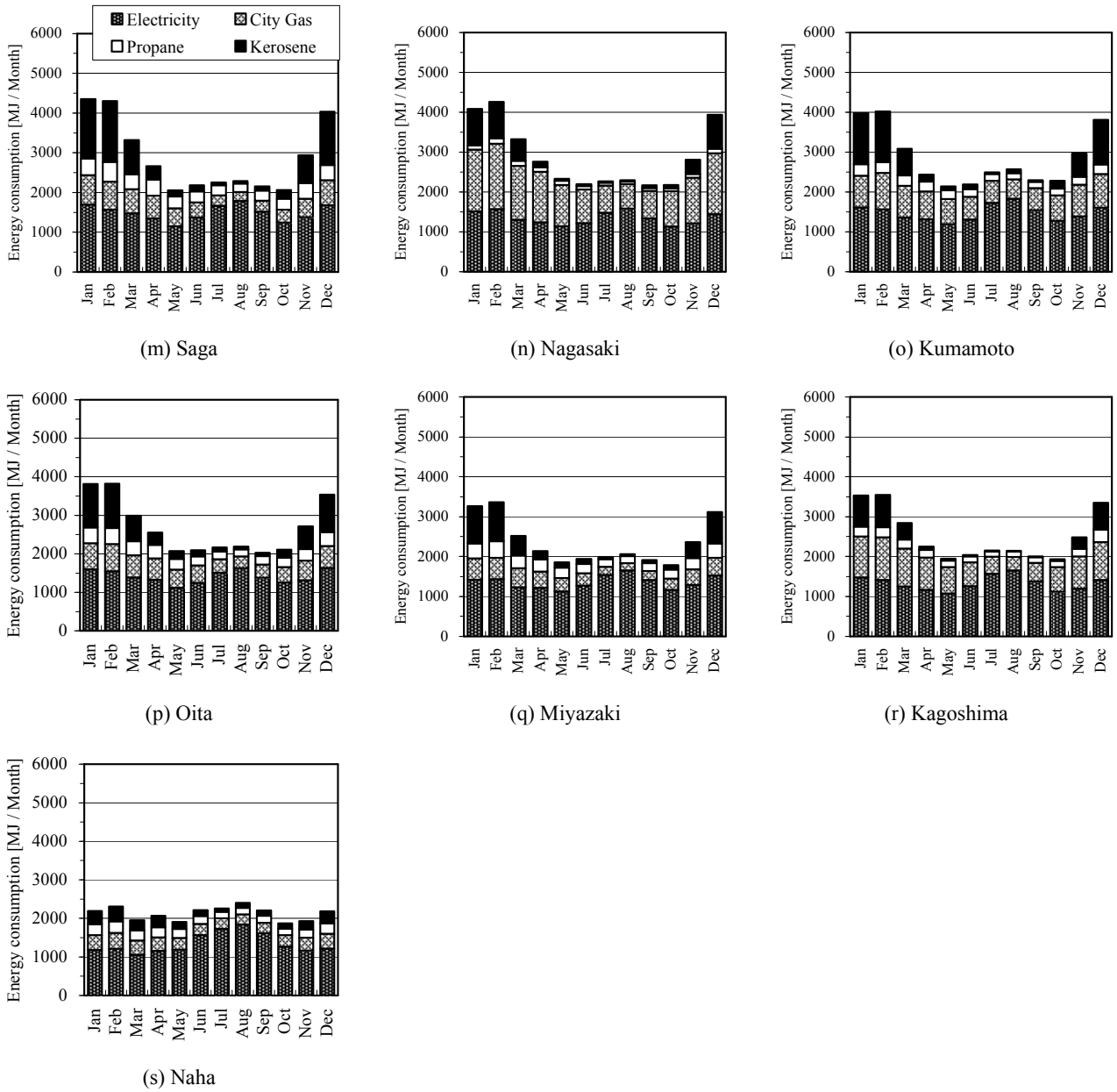
(a) Tokyo (b) Yokohama (c) Shizuoka

(d) Nagoya (e) Osaka (f) Tottori

(g) Matsue (h) Okayama (i) Hiroshima

(j) Yamaguchi (k) Kitakyushu (l) Fukuoka

Fig. 3 Monthly total energy consumption per household. These values are average ones between 2000 and 2004



(m) Saga (n) Nagasaki (o) Kumamoto

(p) Oita (q) Miyazaki (r) Kagoshima

(s) Naha

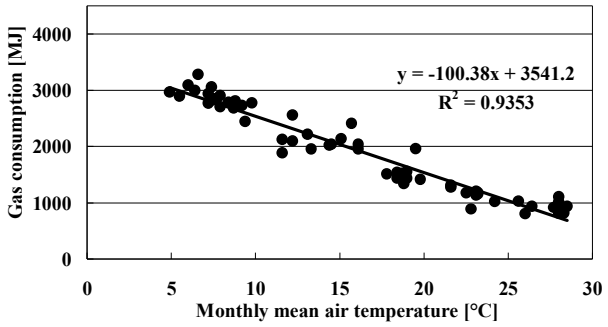
Fig. 3 (continued) Monthly total energy consumption per household.
These values are average ones between 2000 and 2004

4 Air-temperature Sensitivity in gas consumption

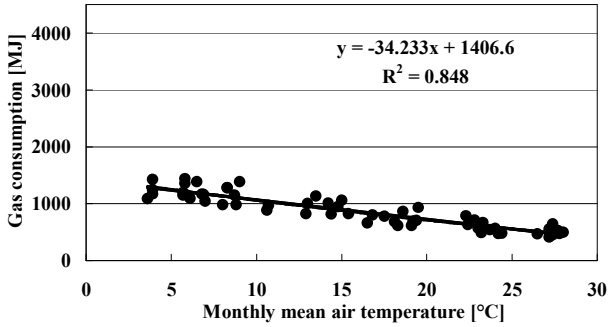
Two examples of the graphs showing the relationship between temperature and gas consumption in Tokyo and Yamaguchi are shown in Fig. 4. Here, the gas consumption is the sum of the city gas and propane consumptions. These graphs show that the gas consumption is linearly associated with air temperature. We thus assumed the following regression formula for gas consumption.

$$E_g = -g_1 t + g_2, \qquad (1)$$

where E_g is the monthly gas consumption per household [MJ] and t is the monthly mean temperature [°C]. g_1 and g_2 are the coefficients. The regression results are shown in Table 2. Comparing the coefficients of the equations shown in Table 2 with the population densities in Table 1, we find a relationship that the higher the population density becomes, the higher the coefficient g_1 does. We thus carried out the multi-regression analysis in the next chapter.



(a) Tokyo



(b) Yamaguchi

Fig. 4 Monthly mean air temperature vs. Gas consumption

Table 2 Regression formula for gas consumption

City	Formula	R^2
Tokyo	E_g = -100.4 t + 3541	0.935
Yokohama	E_g = -81.2 t + 2991	0.936
Shizuoka	E_g = -39.7 t + 1927	0.748
Nagoya	E_g = -66.4 t + 2661	0.945
Osaka	E_g = -87.3 t + 3320	0.910
Tottori	E_g = -25.1 t + 1193	0.648
Matsue	E_g = -30.1 t + 1335	0.849
Okayama	E_g = -33.0 t + 1447	0.877
Hiroshima	E_g = -46.9 t + 1914	0.902
Yamaguchi	E_g = -34.2 t + 1406	0.848
Kitakyushu	E_g = -39.1 t + 1801	0.838
Fukuoka	E_g = -53.7 t + 2153	0.876
Saga	E_g = -30.5 t + 1331	0.754
Nagasaki	E_g = -50.0 t + 2088	0.845
Kumamoto	E_g = -21.0 t + 1279	0.793
Oita	E_g = -26.3 t + 1242	0.722
Miyazaki	E_g = -27.1 t + 1132	0.844
Kagoshima	E_g = -40.8 t + 1700	0.855
Naha	E_g = -21.4 t + 1060	0.809

5 Regression Analysis

The multi-regression analysis was applied to the monthly gas consumption from 2000 to 2004 in all cities, excluding Naha. Here, the gas consumption is the sum of the city gas and propane consumptions. Total number of individual items of data on monthly gas consumption is 1080 (= 18 (cities) X 5 (years) X 12 (months)).

Past researches [6, 7] show that air temperature has a very strong influence on energy consumption. The other research [4] shows that the population density affects gas consumption because of the following relationship: the higher the population density becomes, the more the people select to live in the collective housings, where the use of kerosene is not safe or convenient; therefore, gas is preferred.

Thus, the monthly mean air temperature and population density in each city were selected as explanatory variables in this multi-regression analysis.

The following formula was obtained:

$$E_g = -(0.0054\,p + 28.6)\,t + 0.174\,p + 1352\,, \qquad (2)$$

where p is the population density [person / km^2]. The multiple coefficient of determination R^2 of Eq. 2 is 0.856. A comparison between original values and those calculated using Eq. 2 is shown in Fig. 4. The broken lines indicate errors of plus/minus twenty percent. The calculated values show good agreement with the original values.

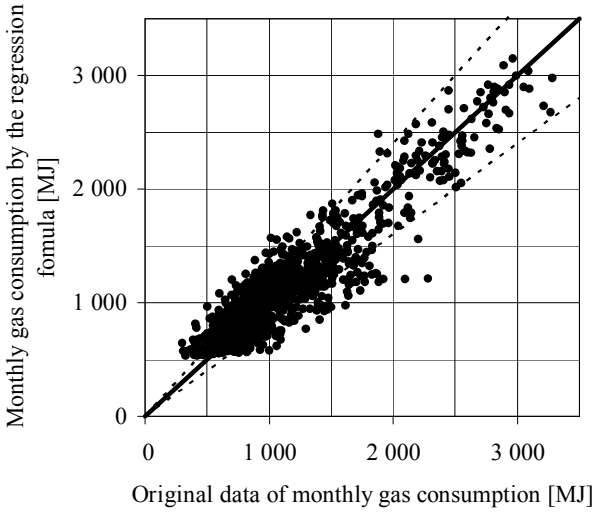


Fig. 5 Comparison between the original data and those calculated by the regression formula (Eq. 2)

This result (Eq. 2) will be used in architectural and energy fields. For example, Eq. 2 can be used to decide the maximum capacity of gas equipments at the stage of the residence services planning.

6 Conclusion

Our estimate of the electricity, gas, and kerosene consumption per household in nineteen cities across the Japanese islands of Honshu, Kyushu, and Okinawa using statistical data showed that there are clear differences in gas and kerosene consumption among cities while there is little difference in electricity consumption. Taking into consideration geographical factors, we determined that air temperature and population density affected gas consumption. Thus, with air temperature and population density as explanatory variables, we successfully used regression analysis to derive a simple model for predicting monthly gas consumption per household. This model may be helpful for determining future strategies for reducing energy consumption.

Acknowledgement

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