A Study on the Relationships of Residential Electricity Consumption and Automobile Energy Consumption with Urban Forms Using GIS

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Summary
In this Paper, we explored the relation between the electricity consumption in residential sector and the automobile energy consumption in transportation sector in accordance with the location of city by employing Geographic Information System (GIS). We found in the study that the electricity consumption per capita has a tendency that is higher in city center and lower in suburbs in Utsunomiya city. It is also noted that there is little difference among total consumption between city center and suburbs, despite the fact that the density of electric appliances tends to increase in a small size house of city center and the amount of automobile energy consumption from residence is lower in city center than in suburbs.

1 Introduction
With the background of intensifying global environment problems and depletion of fossil fuel in recent years, it is an urgent issue to reduce excessive energy consumption. For the pursuit of the sustainable development goal, it is important to plan the city with low energy consumption. In general, energy is classified into three sectors. These are a private sector, a transportation sector, and an industrial sector. Especially, the energy consumption in the private sector and the transportation sector has been significantly increasing in recent years, and it is the key factor to reduce the consumption in those sectors. The private sector can be divided into residential sector and business sector. In the residential sector, the energy is mainly used for air conditioning, hot water, cooking, and lighting. As a result, the electricity consumption in residential sector consists of about 40 percent of the total energy consumption and it remarkably increases compared with other energy consumption such as gas and kerosene. On the other hand, in transportation sector, about 95 percent of energy is dominantly consumed by automobile (=Automobile energy consumption). Therefore, the electricity consumption in residential sector and automobile energy consumption in transportation sector are crucial indicators to know energy consumption structure. In this study, we focused on how the change of lifestyle influences the key indicators: the electricity consumption in residential sector and automobile energy consumption in transportation sector. We also explore the relationship between the energy consumption and city type by employing Geographic Information System (GIS).For a case study, we chose Utsunomiya city. Utsunomiya is a regional capital city with population of half a million and is located 100 km north of Tokyo. We examined the influence of city type and change of lifestyle on energy consumption to plan the city with low energy consumption. According to existing studies, the increase of floor space and household size influences on the amount of energy consumption in residential sector. However, there are few studies that discuss the energy consumption in residential sector by considering the effects of type of city and/or type of household. In transportation sector, it is well known that there is a difference of automobile energy consumption in accordance with city type. The objective of this study is the overall examination of the trend of the energy consumption by matching not only the private sector but also the transportation sector. Especially, the energy consumption in city center and

suburbs are compared in order to investigate the difference of the proportion between energy consumption for household and automobile. For the objective, we collected the energy consumption distribution within a city in residential sector to know detailed variation of energy consumption. Then, we took household type and lifestyle into consideration. Detailed distribution of automobile energy consumption is also calculated in this study.

2 City sprawl for suburbs and change of lifestyle

Since automobiles are frequently used recently because of the city sprawl for suburban area due to the progress of motorization, the automobile energy consumption in transportation sector increases. In private sector, the change of lifestyle such as the increase of single household and small families leaded the increase of a number of families, which caused the increase of electricity consumption. The schematic relationship between the sprawl for suburbs and the change of lifestyle shows in Figure 1. The process of city sprawling is the following:

First, the small families in city center moved to suburbs. Second, the migration leaded the increase of small families in suburbs. Third, those small families in suburbs turned out to be the single household of the young in city center and the middle age families in suburbs, and the middle age families became the senior families. This process continues endlessly, thus, family houses in suburbs continuously are increasing, which is causing a problem, because the increase of the floor space has significant impacts on electricity consumption growth. Considering those phenomena, which are now happening, we focus on the house size and unit household population, which are related to the lifestyle and analyze the relationship between electricity consumption and city type.

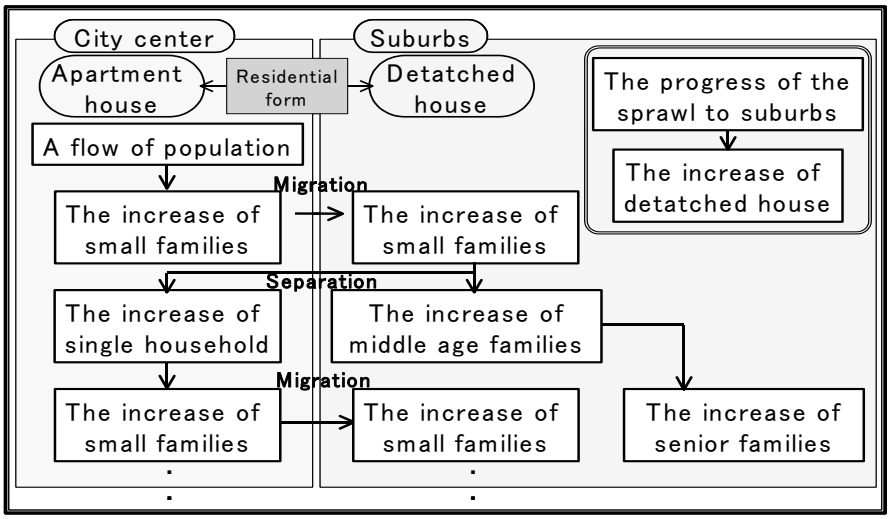

Figure 1. City sprawl for suburbs and change of lifestyle

3 The present condition of energy consumption in residential sector

In General, energy consumption in residential sector consists of heating, air-conditioning, hot water, cooking, and lighting and it is correlative with the growth of population and household income, which has been gradually increasing in recent years. The portion of electricity in total energy consumption has been increasing mainly because electric power is more convenient than other power sources to use in household. The transition of energy consumption per family in residential sector at Kanto region is shown in Figure 2. Comparing this to the data in 30 years ago, it is obvious that the consumption per family increases, especially electricity became more

important in household during 30 years. The composition of energy consumption in residential sector in 1999 is shown in Figure 3, showing that energy consumption for lighting, hot water and heating are dominate. The ratio of energy source in use in residential sector in 2000 is shown in Figure 4.

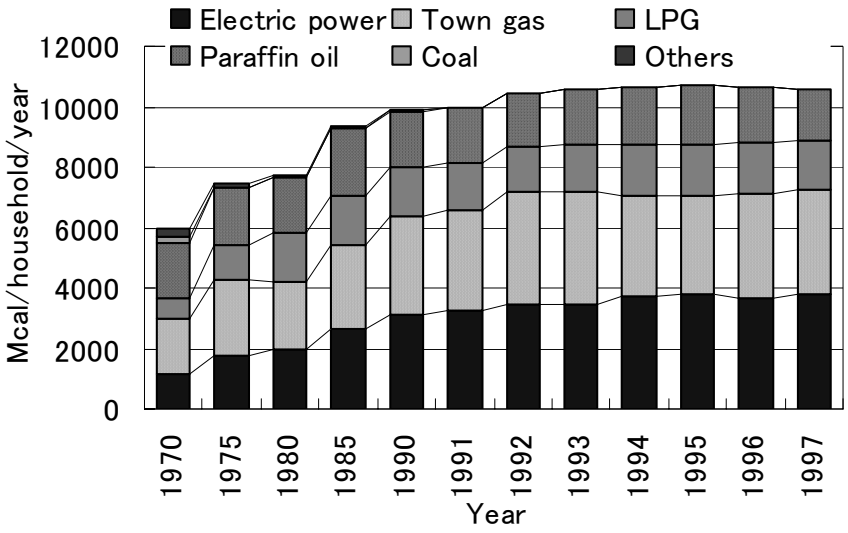

Figure 2. The transition of energy consumption per family in residential sector at Kanto region

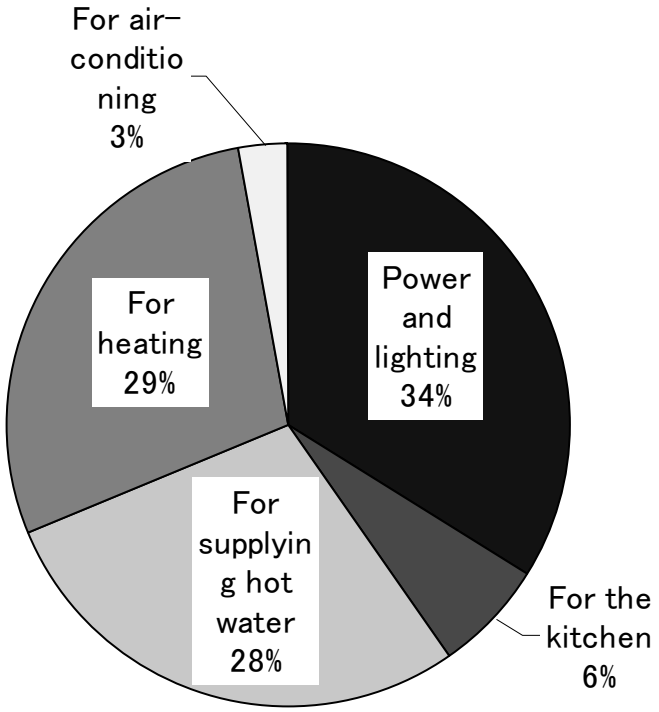

Figure 3. The ratio of each usage in 1999

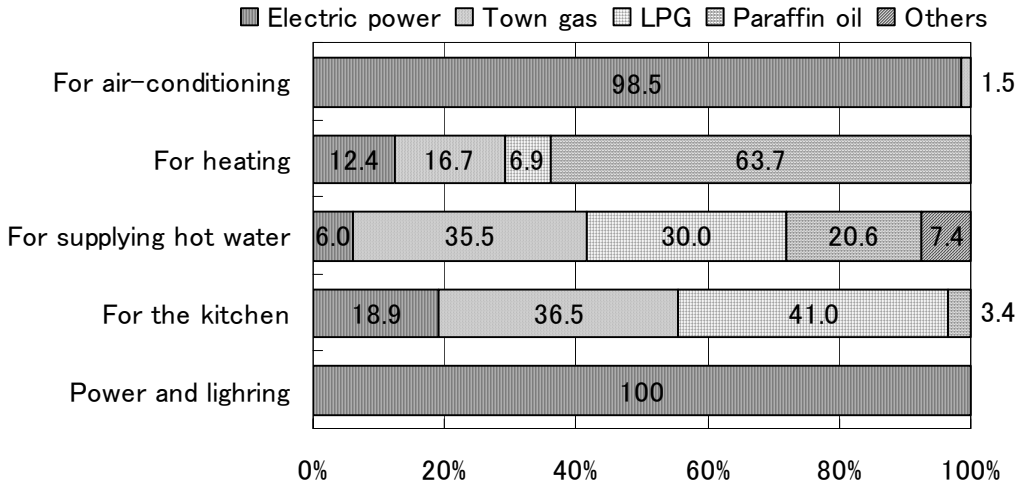

Figure 4. The ratio of energy source in each usage of residential sector in 2000

According to those figures, it is clear that the portion of electricity is getting larger than other power sources, especially for lighting, air-conditioning and heating. This tendency is related to the penetration of convenient and rich lifestyle, the progress of aging, the spread of information related equipment and shifting from stoves to air conditioners and heating carpet for more comfortable and safe way of life. Clearly, this tendency is expected to continue because people are getting more demanding for better way of life.

4 The Electricity consumption of Utsunomiya city

4.1 The Electricity consumption of each district in Utsunomiya city

For analysis of electricity consumption distribution in Utsunomiya city, we used the data of electricity consumption of Lighting Type A and B in Utsunomiya city (2002). Lighting Type A and B are price options provided by the power company. Since those two options are usually contracted by general residence, electricity consumption by Lighting Type A and B can be considered as electricity consumption in residential sector. By calculating electricity energy consumptions per capita of each 248 districts in Utsunomiya, we have found the average value of 1,562 (kWh/capita). Electricity energy consumption of residential sector in Utsunomiya city is shown in Figure 5 by setting the rate of relative shift so that the average value is to be unit. It shows higher value in city center or suburbs where 10km or further from city center.

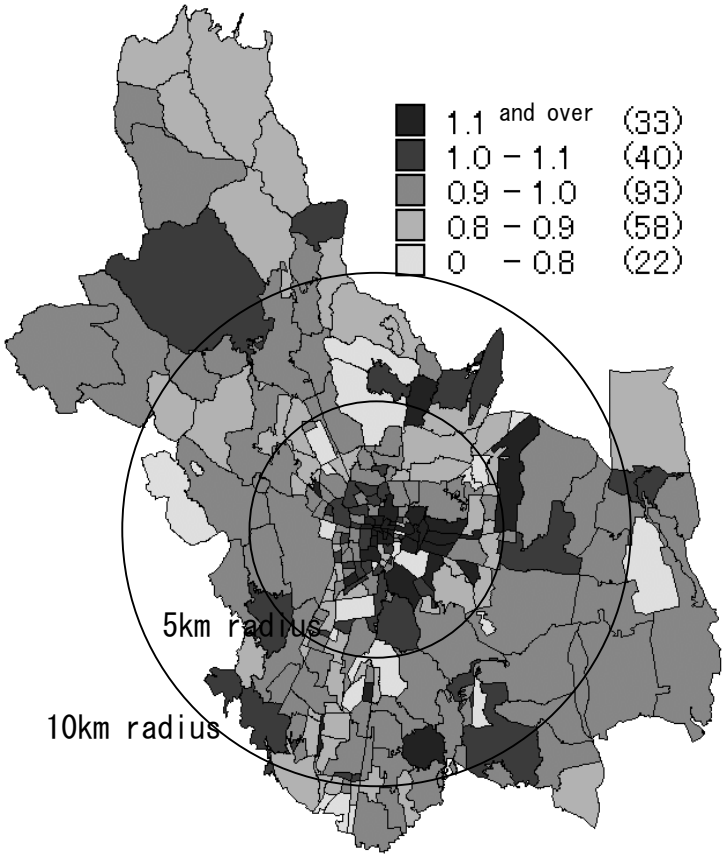

Figure 5. The rate of relative shift of electricity energy consumption per capita

4.2 Distance from city center and electricity consumption

Electricity energy consumption per capita: e_i (kWh/capita) is calculated by using consumptions of Lighting Type A and B in each districts, and the relationship between distance from city center (km) and the rate of relative shift of e_i (kWh/capita) which is the average of every each distance of 1km to 10km from city center point is shown in Figure 6. e_i (kWh/person) shows higher value in city center than in suburbs. Comparing electricity consumption and residential type in the city, the following three indices are sequentially numbered as elements which influence e_i (kWh/capita).

1. House size: s_i (m^2/household)
2. Household size: h_i (capita/household)
3. Electricity consumption per unit floor space of residence: u_i (kWh/m^2)

These indices have the relationship such as $e_i=u_i*s_i/h_i$. The relationship between distance from city center and these indices is shown in Figure 7 by using the rate of relative shift as well as e_i (kWh/capita)

According to those figures, house size is decreasing in range of less than 3km from city center then increasing toward to suburbs. This is because there are many small apartment houses in city center. In the range between 3km and 4km from city center, there is a boundary between the Urbanization Promotion Area and the Urbanization Control Area configured by the local authority. Under the related laws, buildings cannot be constructed in the Urbanization Control Area. Therefore, the sprawl for suburbs is limited within the Urbanization Promotion Area

where the building can be constructed and this causes overcrowding of apartment house and small-scale houses in the Urbanization Promotion Area. In suburbs, there are a lot of farmhouses whose size is larger due to the exception of construction restriction in the Urbanization Control Area. As a result household size in suburbs is larger. Summarizing those tendencies, it is clear that single household and small families are mainly located in city center and farmhouses and three-generation family homes mainly in suburbs. Due to the fact that the house size and household size is smaller in city center, electricity consumption per unit floor space of residence is larger in suburbs and larger in the range of less than 4km from city center.

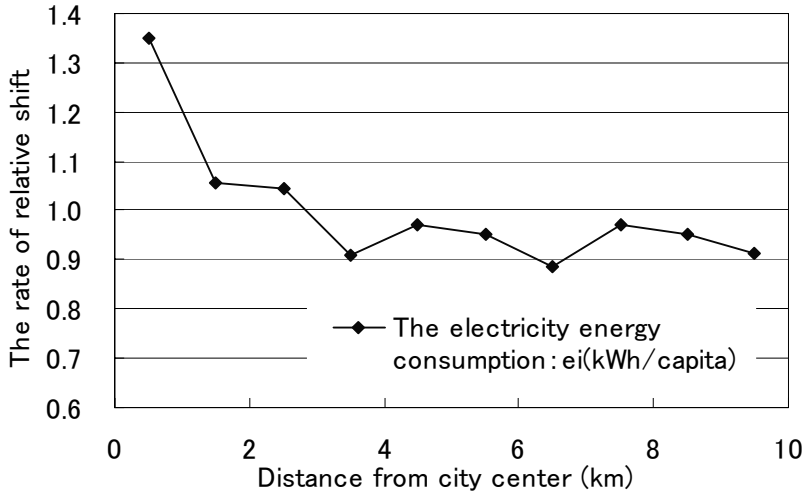

Figure 6. Distance from city center and electricity consumption

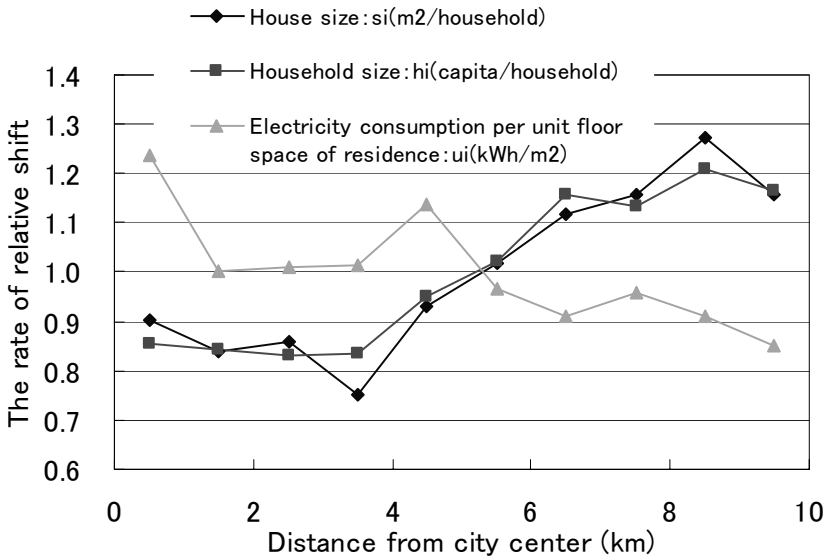

Figure 7. Distance from city center and three indices

Focusing on distance from city center and the proportion of family house and apartment house (Figure 8), the proportion of the family house is getting larger in suburbs. Comparing with Figure 7, it is clear that house size is positively related to the ratio of family house.

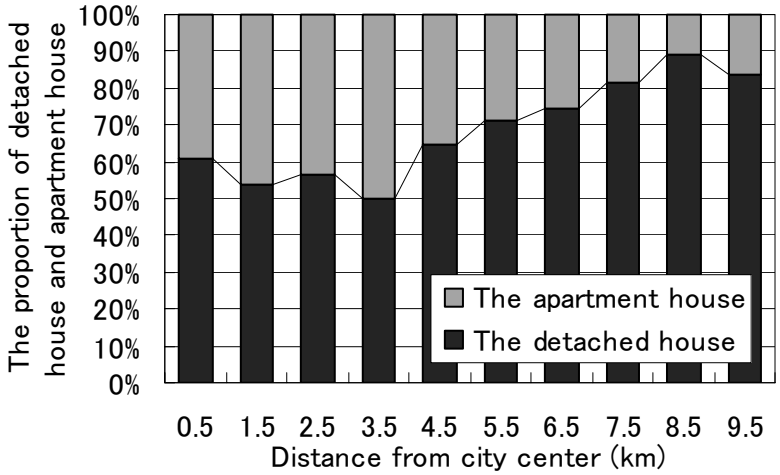

Figure 8. Distance from city center and the proportion of detached house and apartment house

4.3 Distance from city center and floor space of residence per capita

In Figure 7, house size and household size are showing the similar tendency, which is low value in city center and high value in suburbs. Focusing on floor space per capita, the relationship between distance from city center and floor space of residence per capita is shown in Figure 9. Thus, it is clear that these show higher values in city center and suburbs and they are the similar values.

On the contrary, it is found in Figure 6 that electricity consumption per capita is higher in city center and lower in suburbs. As a conclusion, in a present Utsunomiya city, this is might because electricity consumption per capita is lower at living in a large-size house in suburbs by many households than at living in a small-size house in city center by small household.

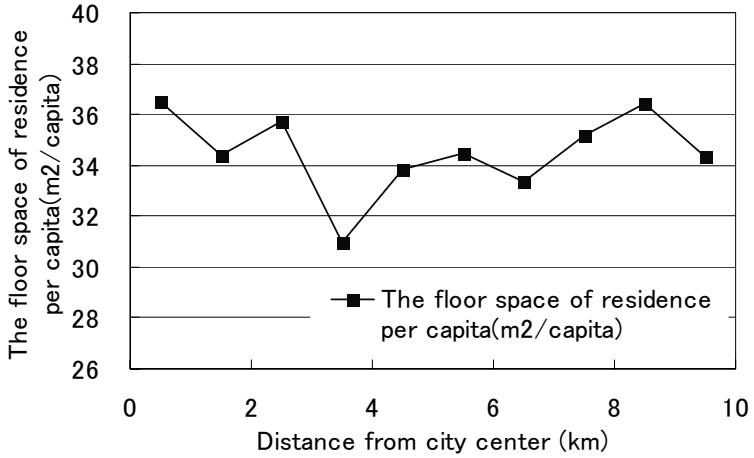

Figure 9. The relationship between distance from city center and floor space of residence per capita

5 The energy consumption of transportation sector in Utsunomiya city

5.1 The state of traffic in Utsunomiya city

Now, the transportation characteristic in Utsunomiya city is heavily dependent on automobile use. As a result of calculation of energy consumption in transportation sector by the Utsunomiya Person Trip Survey (1999), the total consumption per day of all transportation mode amounts to 7,872(kcal/capita) which contains 7,587(kcal/capita) for automobile, 193(kcal/capita) for railway and 92(kcal/capita) for bus. In a word, the majority of the energy consumption of transportation sector is automobile energy consumption, and it occupies about 96.4%. Then, we pay attention to the amount of automobile energy consumption, and analyze the relationship between automobile energy consumption and city form.

5.2 The method to calculate the amount of automobile energy consumption

The amount of automobile energy consumption is estimated by trip length calculated using the data of Utsunomiya Person Trip Survey (1992). The energy consumption of auto trip generated from each 44 zone was calculated according to expression , and these were divided by each population to calculate per capita.

$$\sum_j t_{ij} = \sum_j G_{ij} \times T_{ij} \times S \times e \qquad \cdots ①$$

t_{ij} : The automobile energy consumption from ***i*** zome to ***j*** zone (kcal)
G_{ij} :The number of automobile trips
T_{ij} : The average moving time by automobile(h)
S : The average speed of automobile (km/h)
e : Automobile energy consumption per unit [763.1(kcal/km)]

5.3 The distance from city center and automobile energy consumption

In order to clarify the relationship between the automobile energy consumption per capita and the distance from city center, we classified 44 zones into several groups depending on the distance from city center and integrated average values (see Figure 10). Similar figures are developed for six trip purposes, namely, ‘ all purposes’, ‘go to office’, ‘go to school’, ‘back home’, ‘private matters’ and ‘business’. Since we focus on the energy consumption from residence, trips with purposes of ‘go to office’, ‘go to school’, ‘private matters’ and ‘business’ are calculated from departure points, and the purpose of ‘back home’ is calculated from arrival point, and the ‘all purpose’ is the sum of all trips. The energy consumption induced by the trip with purposes of business and private matters show high values in city center. The reason why trips with business purpose show high value is that there are many business facilities in city center. In the trip with purpose of private matters, it is thought that there are a lot of movements not only from suburbs to city center but also within city center, and these movements affect the high value in city center. On the other hand, the values of the purposes of ‘go to office’ and ‘back home’ are low in suburbs and high in city center. Moreover, in the ‘all purposes’ category, it shows high value in city center and low value in suburbs because of influence of the trip with purposes of private matters and business.

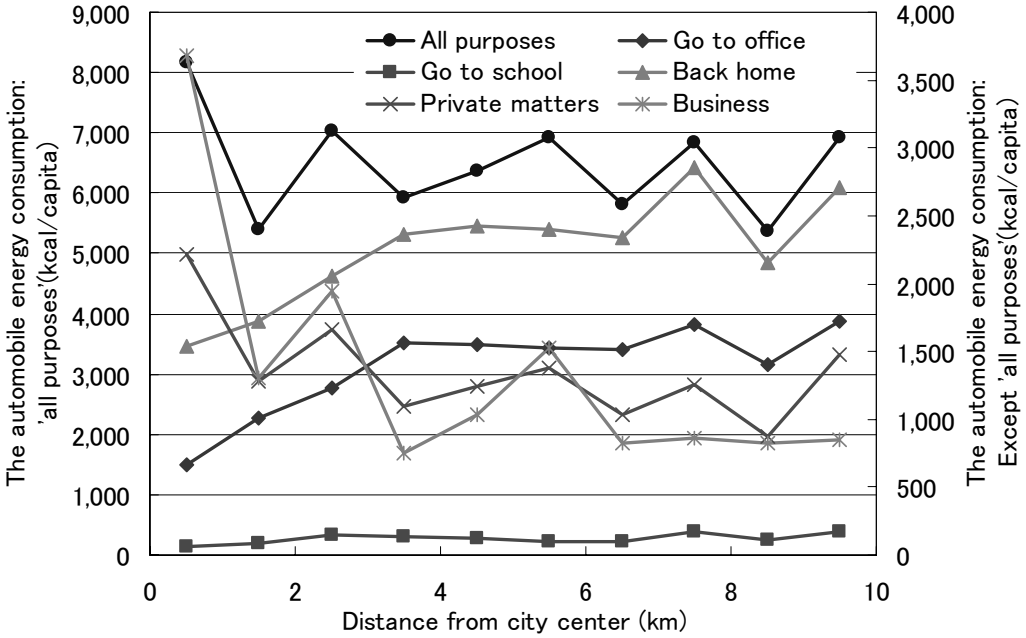

Figure 10. The distance from city center and automobile energy consumption

5.4 Automobile energy consumption from residence

In this research, since we pays attention only to automobile energy consumption from residence, the total automobile energy consumption induced by the trip with purposes of going to office, going to school, coming home and private matters is defined as automobile energy consumption in the following discussion. When the results are shown geographically using GIS, the trend is seen most clearly (see Figure 11). It shows low consumption in city center and high consumption in suburbs. In the Figure 12, we compare the automobile energy consumption with electricity consumption in terms of distance from city center.

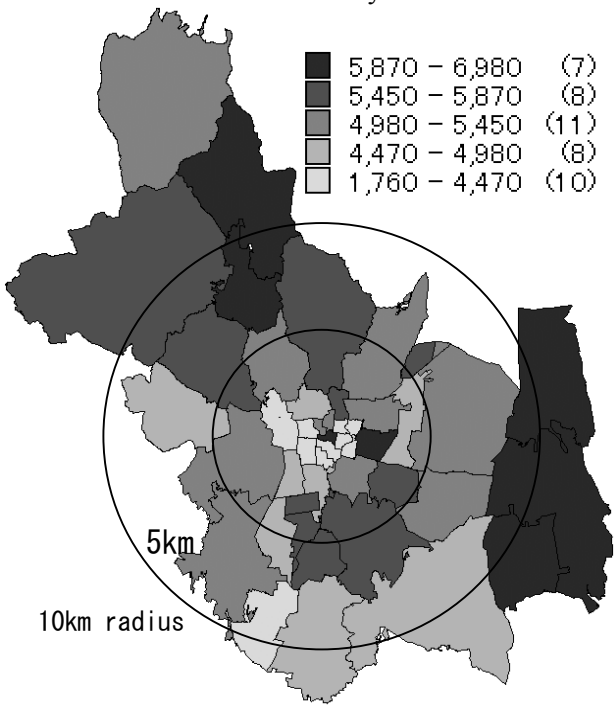

Figure 11. Automobile energy consumption from residence per capita (kcal/capita)

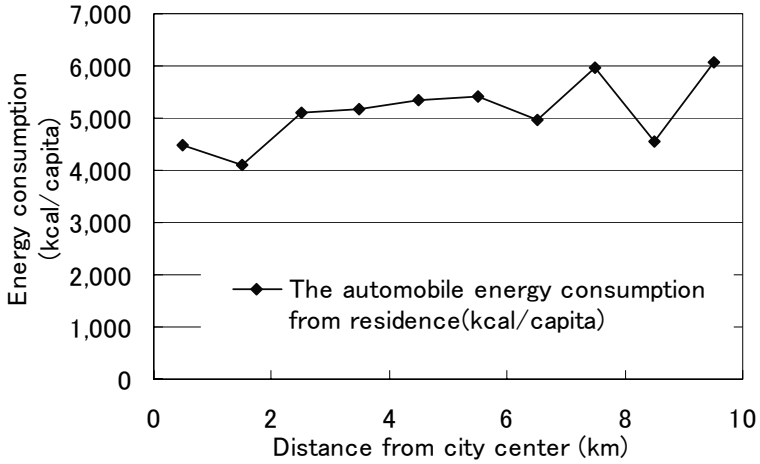

Figure 12.The distance from city center and automobile energy consumption

6 The amount of energy consumption from residence

6.1 Electricity consumption and automobile energy consumption

The electricity consumption in residential sector is calculated for 44 zones as well as automobile energy consumption, and it is shown the relationship between the amount of the automobile energy consumption from residence and electricity consumption in Figure 13. From that, it is noted that there is no correlation between the two. In other words, it might be possible to say that the change in either amount of consumption does not directly influence on the other.

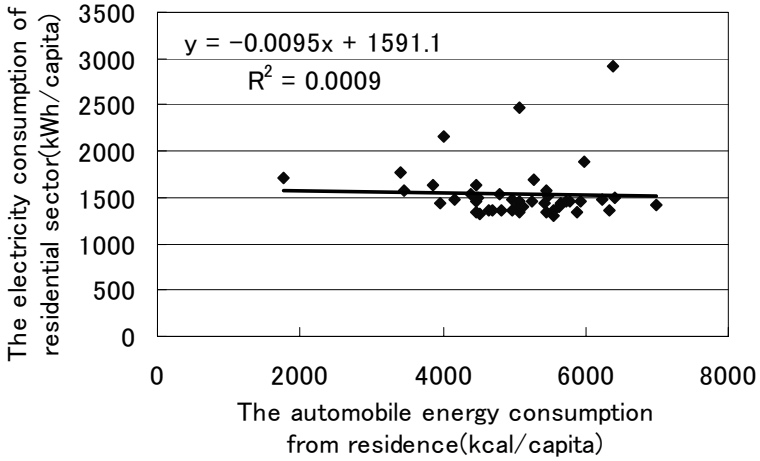

Figure 13. The relationship between electricity consumption and automobile energy consumption

6.2 Distance from city center and energy consumption

Converting the unit of electricity consumption per capita, the total of the two types of energy consumption is shown on Figure 14, by distance from city center. From that, it is noted that one person consumes about 8000(kcal/day) to 9000(kcal/day). Electricity consumption shows high ratio in city center and automobile energy consumption shows high ratio in suburbs. And, there is little difference among total consumption between city center and suburbs though there is difference in ratio. There is no location where the amount of both energy consumptions is small. This is because there may be missing energy consumption in the city, which is not taken into account in this study. To clarify this point, more detailed examination is required.

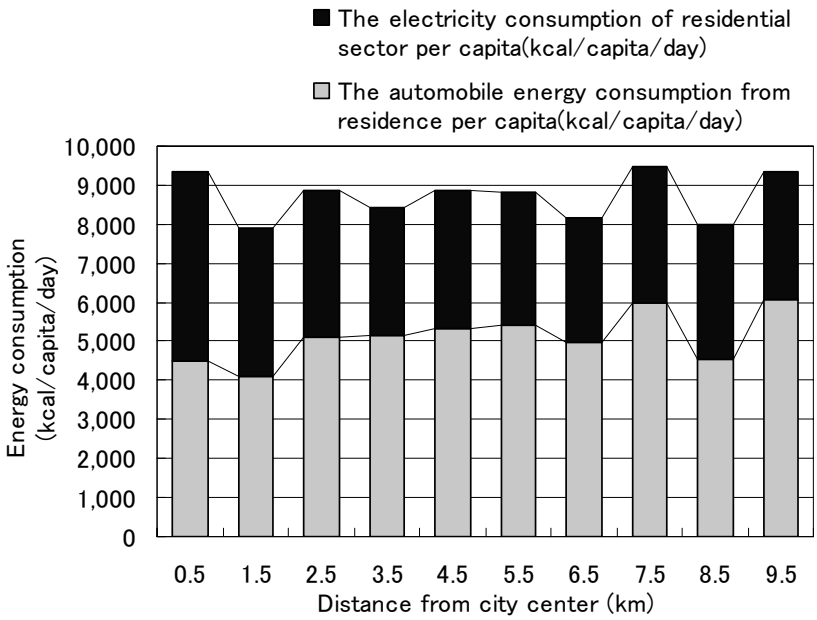

Figure 14. The distance from city center and energy consumption

7 Conclusions

The electricity consumption per capita has a tendency that is higher in city center and lower in suburbs. On the contrary, it is found that the automobile energy consumption from residence has the tendency that is lower in city center than in suburbs. But, there is little difference among total consumption between city center and suburbs. This shows that residence in city center is energy efficient in automobile energy consumption, but not in electricity consumption. This is because many single household and small families are located in city center and there are still many three-generation family homes in suburbs. The density of electric appliances tends to increase in a small size house of center city. In addition to this, the efficiency of energy consumption can be larger in such condition. Recently, the compact city concept draws attention as an ideal urban form for energy efficient consumption and high density housing in city center. However, energy saving can not be accomplished only by the effort of city center residents, and it is necessary to promote small size houses and the common use of living space together with development of energy saving technology. In addition, the more reduction of energy consumption is expected by the conversion from automobile to public transport. As an issue in future, we suggest to examine the energy consumption not only electricity but also gas such as LNG and LPG. In addition to that, it is necessary to analyze the mechanism of energy consumption by arranging characteristics of the city which influences on the energy consumption in residential sector.

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