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Comparison of Residential Energy Consumption in China, Japan, Canada and USA

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Abstract

There have been very few researches on the energy consumption of residences in China because it is difficult to collect the data of energy consumption for district heating. In this study, the energy for district heating was estimated based on the heating load, and the annual unit energy consumption (UEC) for the residences in the main cities of China was calculated. The relationship between the UEC and heating degree-days was examined for China, Japan, Canada and the United States.

Keywords: residential energy consumption; UEC; energy for district heating

Introduction

Energy consumption in the residential sector in the developing countries is increasing dramatically due to the improvement of living standards. Therefore the energy conservation for residences, along with the establishment of a sustainable life style has become important tasks for both developed and developing countries. In order to promote energy conservation in the residential sector, and to predict the CO2 emission, it is important to realize the energy consumption in different countries, and to exchange information about residential energy consumption.

The residential energy consumption in Japan (Sawachi et al., 1994; Ishida, 1997; and Miura, 1998), the USA (DOE, 1999) and Canada (Office of Energy Efficiency, 2000; Canadian Residential Energy End-use Data and Analysis Center, 2000) has been reported in several studies. Nevertheless, the energy consumption for dwellings in the Chinese locations has rarely discussed. Yoshino and Lou (Yoshino and Lou, 2002) have been trying to elucidate the energy performance in dwellings of some Chinese cities by surveying, which sheds light on the trend of energy consumption in dwellings. There are some difficulties with this method. First, some residents do not know the monthly energy consumption due to lack of records. Another difficulty in data collecting is the regional heating system where usually no meters are used for heat flow to each dwelling unit.

In this study, consumption of liquefied petroleum gas, natural gas, coal gas and electricity for 28 main Chinese in 1996 was made clear by analyzing the data from statistical yearbooks. The energy for district heating was estimated with the heating load from the previous studies of the authors. The annual energy consumption per household was calculated by adding energy for district to gases, electricity and coal. The energy consumption for each household in China was compared with that of Japan, the USA and Canada. Furthermore, regression equations of energy consumption for each household against the heating degree-days were developed for the four countries.

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Residential Energy Consumption in Chinese Locations

Consumption of Gases, Coal and Electricity

The data of consumption of electricity, coal gas, liquefied petroleum gas (LPG) for the main Chinese cities in 1996 can be obtained from the Urban Statistical Yearbook (State Statistical Bureau, 1997). The fuel for households in the Chinese cities is changing rapidly from coal to gas; therefore the kinds of energy used in households are quite different according to places and the year concerned. Using the gas-using ratio among all the numbers of households for each city, we can obtain the population ratio for each kind of fuel as shown in Fig.1. In 1996, natural gas is mainly used in Chengdu, Shenyang, Zhengzhou, Tianjin, while coal is only consumed by a small number of households in Shanghai, Ulumuqi, Harbin etc.

Consumption of electricity for dwellings in the main cities of China is shown in Fig.2. The consumption of electricity in warm regions like Guangzhou, Changsha, Fuzhou is larger than the cold locations due to space cooling. Fig.3 shows the relationship between power

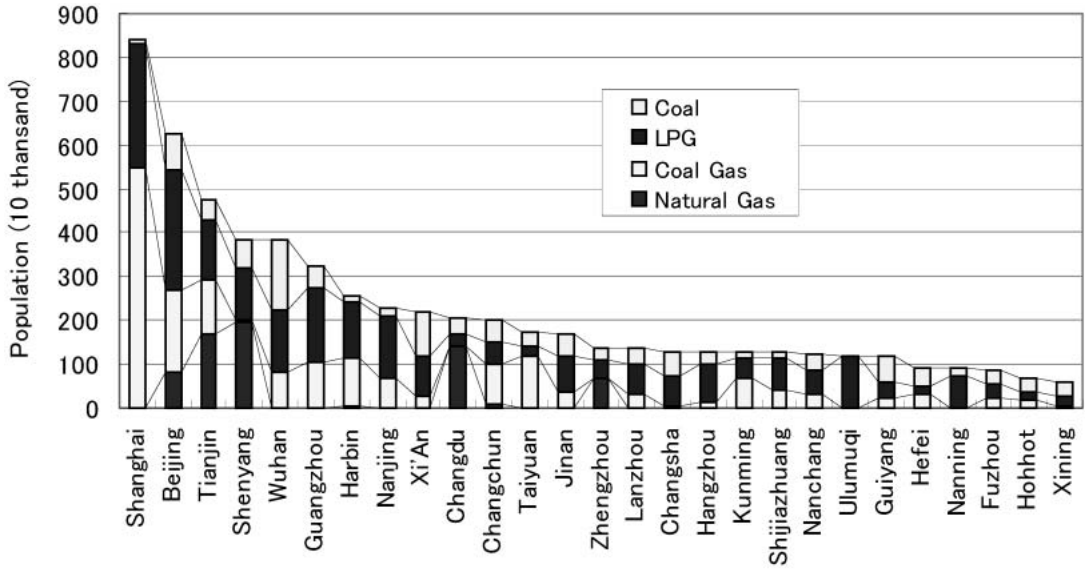

Fig.1. Population Using Coal, LPG, Coal Gas and Natural Gas (1996)

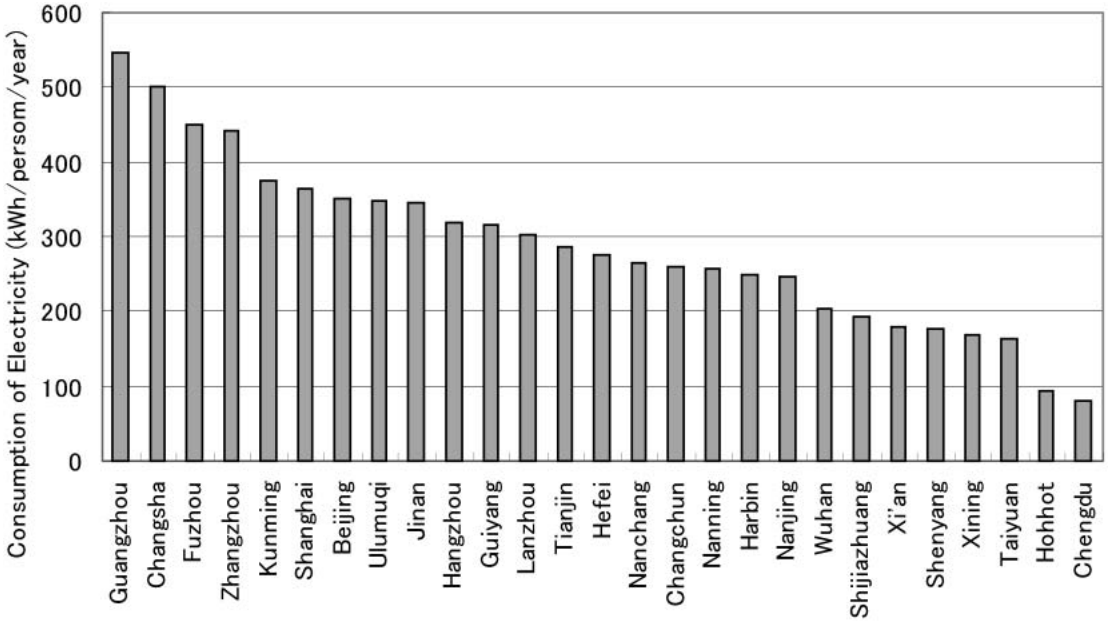

Fig.2. Annual Consumption of Electricity per Capita

consumption and cooling degree-hours,which indicates that power for air-conditioners in households is related to the cooling degree-days, but there may be other factors influencing the total power consumption.

Estimation of Energy Consumption of District Heating

In China, one of the difficulties in estimating energy consumption for households is that there are very few data on energy consumption for each household for district heating. Usually the heating energy for each household is paid annually with a fixed fee, no matter how much energy is used. In the southern part of China, district heating is not commonly available; therefore the energy for individual heating is already included in the energy consumption in the forms of coal, gas or electricity.

For this reason, it is necessary to estimate the energy consumption by district heating for each household. Fortunately, the authors have calculated the heating loads of two model houses in most Chinese locations, with three residents in each dwelling unit (Zhang et al., 2001). The average heating load per square meter of floor area

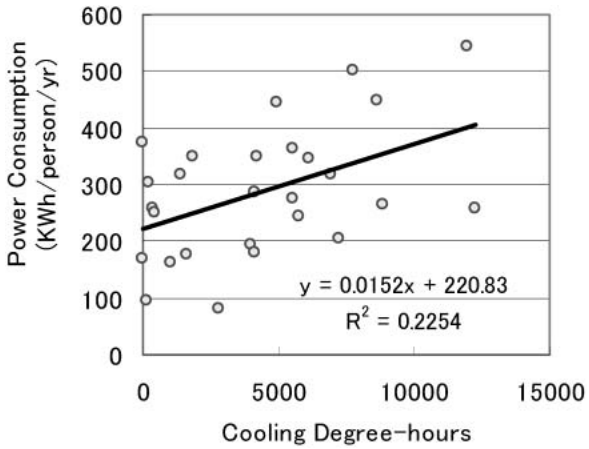

Fig.3. Relation between Power Consumption and Cooling Degree-hours

of the two model houses is considered as the heating energy of district heating for each household, multiplied by the percentage of households making use of district heating. This percentage was obtained by a survey conducted previously (Zhang, 2002). Therefore, the annual consumption per capita for district heating is calculated as follows:

$$E_h = L_h \cdot \eta \cdot A_h / N_h$$

where Eh is the annual energy consumption per capita for district heating, GJ/person; Lh is the heating load per square meter of floor area in GJ/m^2/year; is the ratio of household using district heating; Nh is the resident number in each household. According to the State Statistical Bureau (State Statistical Bureau, 2002), the average family number per household in the main cities is about three. Ah is the average floor area for each household in 1996, which is shown in Fig.4 (Sohken, 1999). According to this figure, the city with the largest floor area in each household is Hangzhou, and the smallest is Nanning among the 28 cities in 1996.

The total energy consumption per capita can be obtained by adding the energy consumption for district heating to the consumption of gas, coal and electricity. The annual energy consumption per household (which is called the annual unit energy consumption or UEC hereafter) can be calculated by multiplying three to the energy consumption per capita.

The values of UEC of the main cities in China are shown in Fig.5. The houses in the cold climate like Harbin, Hohhot, Changchun consume more energy than the houses in warm regions, because space heating is the dominant factor in the total energy consumption in north China. The UEC of houses in the south of Yangtze River is less than 15 GJ/household/year, mainly because very little energy is used for space heating in these provinces.

Comparison of Residential Energy Consumption in China, Japan, the USA and Canada

Having clarified the UEC of the residences in the main cities of China, we have been able to compare the UECs of residences in China with that in Japan, Canada, and the USA.

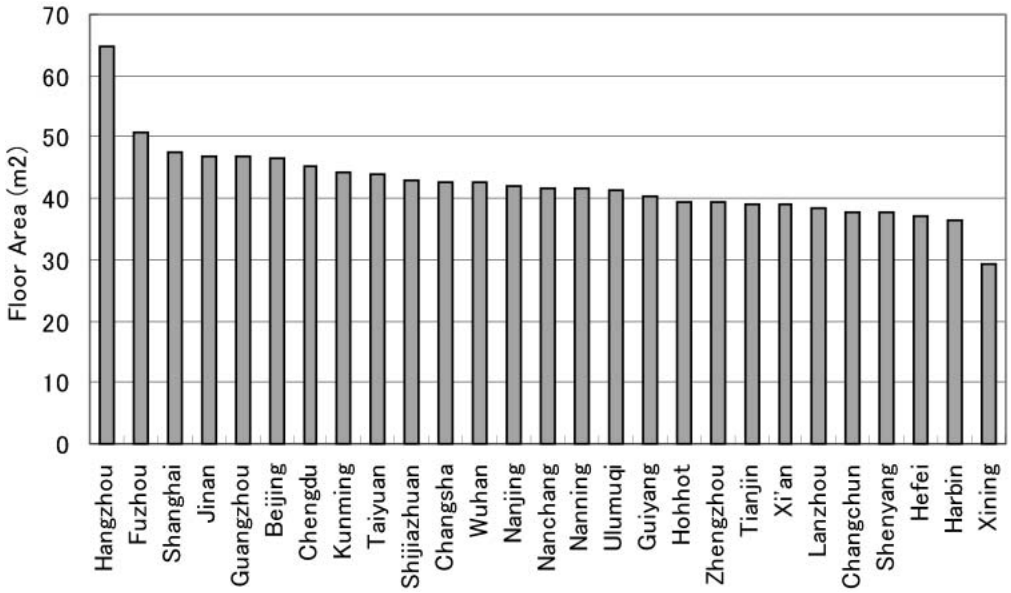

Fig.4. Average Floor Area in Residences

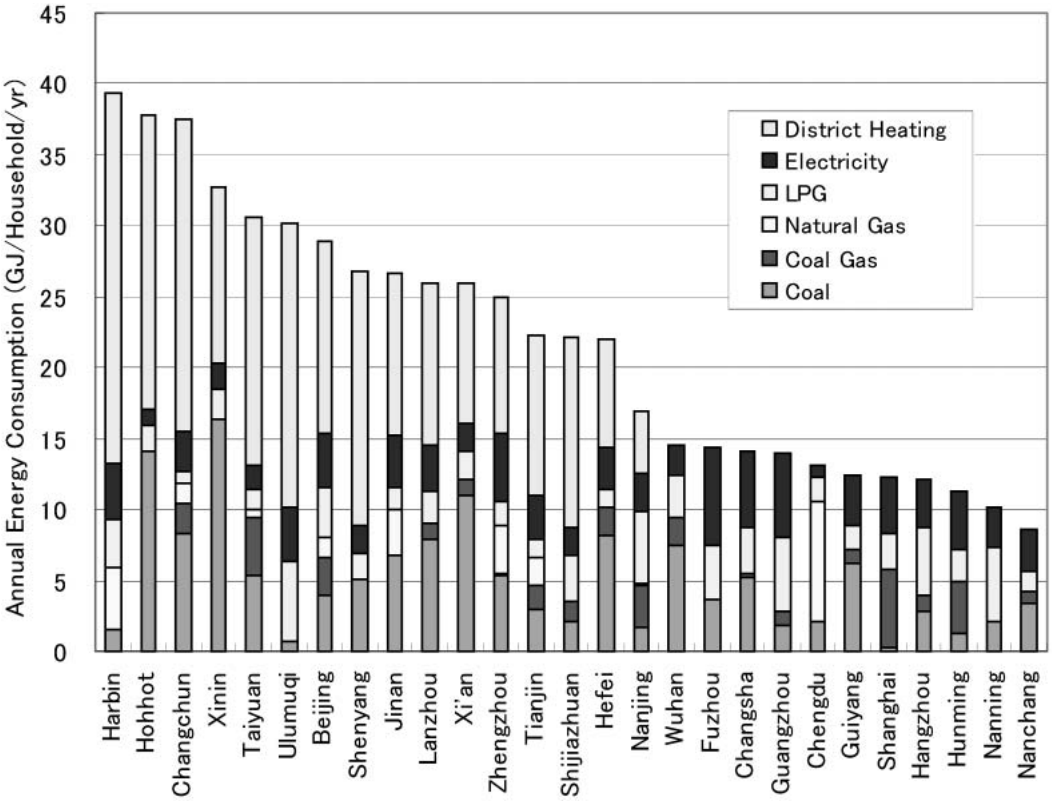

Fig.5. Annual Unit Consumption for the Chinese Locations

Energy Consumption for Residences in the USA

The Department of Energy of the USA conducted a survey throughout the country on energy consumption in the residential sector in 1997 (U.S. Department of Energy, 1999). In this report, the United States was divided into four regions by their climatic characteristics. The average heating degrees-days over the Northeast, Midwest, South and West regions and the UECs of the corresponding regions are shown in Table 1.

Table 1. Heating Degree-days and UECs in the US

Regions	Heating Degree-days	UEC (GJ)
NE USA	3461	127
MW USA	3626	141
S USA	1628	89
W USA	2379	79
Average	2542	107

* Data in this table was originally from Ref. 2) and rearranged by the authors

Energy Consumption for Residences in Canada

The Natural Resources, Canada made a nation-wide survey on the living environment and building equipment for dwellings in 1997 (Office of Energy Efficiency, 2000). The UEC was predicted with simulations and analyses (Canadian Residential Energy End-use Data and Analysis Center, 2000). The predicted UECs of the residences in the main provinces and the heating degree-days are shown in Table 2. The province with the smallest UEC is British Colombia, and the largest is Saskatchewan.

Table 2. Heating Degree-days and UECs in Canada

Province	Heating Degree-days	UEC (GJ)
NFLD	5033	157
NS	4270	150
NB	4774	146
QUE	4915	127
ONT	4284	144
MAN	5943	182
SAS	6019	194
ALB	5482	171
BC	3344	111
Average	4586	143

* Data in this table was originally from Ref. 1) and rearranged by the authors

Energy Consumption for Residences in Japan

In Japan, there have been several studies on residential energy consumption. Sawachi et al. (Sawachi, 1994) conducted a survey on the energy consumption and

indoor environment in the main cities of Japan, according to the categories of houses. Ishida (Ishida 1997) examined the residential energy consumption in detached houses, and obtained the UECs regionally; Miura (Miura, 1998) calculated primary energy consumption in 47 Japanese cities using the results of the family income and expenditure survey conducted by the Statistical Bureau of Japan.

In this study, we convert Miura's UEC value from primary energy basis to secondary energy or site energy basis, in order to compare the UEC values with other countries.

Relations between Energy Consumption and Heating Degree-days

One of the dominant factors in the UEC is the climatic characteristics of the location of a house because air-conditioning load is dominated by the weather conditions. Of energy consumption for heating and cooling, heating is more energy consuming. Therefore, we select the heating degree-days to describe the climatic characteristics of a region. The relationship between the UECs and heating degree-days for locations in China, Japan, the USA and Canada is shown in Fig.6. It is clear that the energy consumption in residences is strongly related to the heating degree-days for all the four countries. Nevertheless, the values of UEC may be quite different even if the heating degree-day is the same when the location is in a different country. This fact implies that energy consumption is influenced by energy policy, energy price, building structure, as well as life style of the residences etc.

According to Fig.6, the regression lines for Canada and the USA are close to each other, with almost the same inclines, which implies that both the structure of the houses and life style of the residents in the USA and Canada are similar. Nevertheless, the characteristics of residences in Japan and China are quite different from that in the US and Canada. The following regression equations can be obtained for the four countries.

UEC =0280HDD+32.18 (GJ/household/year) (for the USA)

UEC =0.0274HDD+19.31 (GJ/household/year) (for Canada)

UEC =0.0148HDD+16.52 (GJ/household/year) (for Japan)

UEC =0.0063HDD+6.195 (GJ/household/year) (for China)

where HDD is the heating degree-days.

The average UECs of the USA, Canada, Japan and China are 107, 143, 44 and 22 GJ/household/year respectively, which is to say, the energy consumption in the USA, Canada and Japan is about 5.0, 6.5 and 2.0 times as large as that of China as shown in Fig.7. The main reasons for this are: first, the ratio of apartment houses is very high and apartment houses are more energy-saving than detached houses; second, space heating is still not commonly adopted in warm regions in China and this reduces energy consumption significantly; the size of residences as well as the heating time within a day (continuous or intermittent heating) may be other factors affecting the residential energy consumption.

It should be noticed that the values of UECs for the USA and Canada are the average of all the residences within a region, while that for Japan and China are only the average of residences in urban areas.

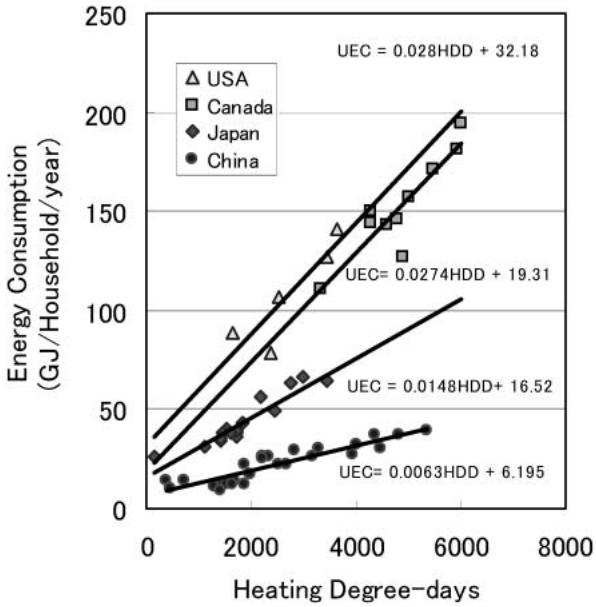

Fig.6. Relationship between Energy Consumption and Degree-days

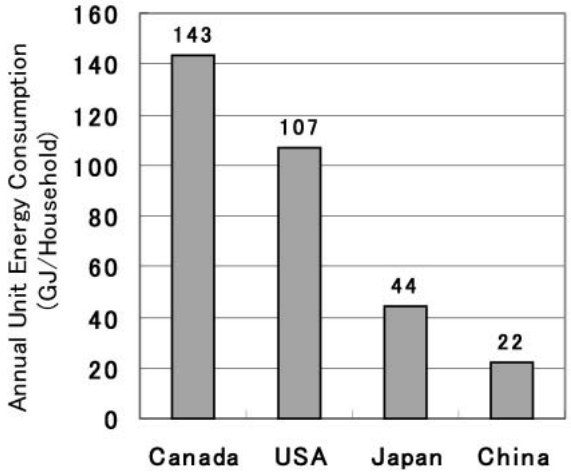

Fig.7. UECs of Canada, USA, Japan and China

Conclusions

In this study, the annual unit energy consumption of residences in the main cities of China was examined, and was compared with Japan, Canada and the USA. The conclusions of this study are as follows:

1. The UEC for the main cities of China was obtained by adding the heating load to the energy consumption for other purposes. The values of UEC for the main cities of China are between nine and 39 GJ/household/year.
2. The regression equations of UEC over heating degree-days for residences in the USA, Canada, Japan and China were developed using the data of 1996 - 1997.
3. In 1996, the average UECs of the USA, Canada, Japan and China are 107, 143, 44 and 22 GJ/household/year.

Acknowledgments

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