B-12.2 Analysis of Energy Consumption Structure in Urban Area

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Total budget for FY1990 - 1992 14,493,000 Yen

Abstract Energy consumption in urban area depends on socio-economical factors, life style, level of country's development and climate. Urban energy consumption in household, commercial and office, transportation and manufacturing sectors were estimated in Sapporo, Tokyo, Yokohama, Nagoya, Osaka, Kobe and Fukuoka. Household energy consumption per person in Sapporo was significantly high due to cold climate, whereas other cities showed rather small variation. Energy consumption in these 7 cities had fairly good correlation with regional GDP. Per capita energy consumption in large cities was higher than other area in China, though energy consumption per GDP was rather low in cities. Much higher energy was consumed in Bangkok than nation's average. Increase both in population and in per capita energy consumption with the change of life cycle would surely bring tremendous increase of energy consumption in expanding urban area in developing countries. Effect of temperature on energy consumption in Japan and China was estimated from available energy consumption data. Kerosene consumption in Japan and coal consumption in China showed good correlation with heating degree month (standard temperature: 18℃). Japanese cities in cold region is much more sensitive to temperature change than Chinese cities/regions. Expected decrease in heating energy consumption was high in Japanese cities in cold region due to high sensitivity against temperature. A computer simulation system was developed to evaluate feasibility and effectiveness of use of waste heat for heating/cooling in urban area to minimize energy consumption. Geographical information of Tokyo Metropolitan area was used to calculate energy demand as well as production of sewage and solid waste, which are energy source.

Keywords Energy consumption, simulation, urban area, waste heat recovery, climatic impact

1. Introduction

As around 70% of population live in urban area in Japan, cities have great responsibility for emission of carbon dioxide through energy consumption as well as other greenhouse gases. Energy consumption in urban area has significantly increased with industrialization since the industrial revolution. Activities in developed nation such as Japan deeply lean on substantial amount of energy consumption. Saving energy is strongly required in the developed country in which per capita energy consumption is far higher than developing countries. Reduction or at least stabilization of energy consumption as well as use of less carbon intensive fuel is without doubt necessary. On the other hand, energy used in cities in developing country is expected to increase tremendously. Energy consumption in urban area, which reflects the nation's activity, should be minimized to approach the sustainable world. Beside the effort of energy saving in each unit technology, improvement of urban system to minimize energy consumption is also needed. Feasibility and effectiveness of reuse of waste heat through district heating/cooling system should be evaluated.

2. Objectives

Particular objectives of this research were as follows:

- to establish method of estimating energy consumption in city scale,
- to identify dependency of energy consumption on socio-economical factors and on climate in cities both in Japan and other countries, and
- to develop simulation system to examine the feasibility and effectiveness of waste heat recovery system in urban area for reduction of fossil fuel consumption.

3. Energy consumption in Japanese cities

Energy is consumed in city for very wide range of purposes from household use to commercial or industrial use. The energy consumption in urban area was categorized here into four sectors, namely, household, commericial and office, transportation, and manufacturing. Share of each sector in Tokyo (23 wards) is shown in Fig. 1 as an example.

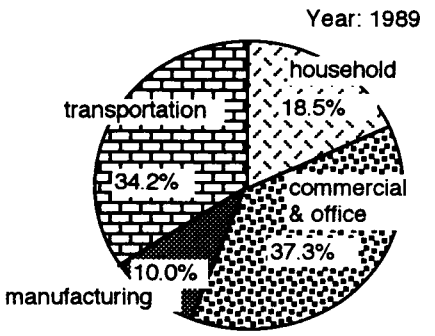

Fig. 1. Energy consumption in each sector in Tokyo (23 wards)

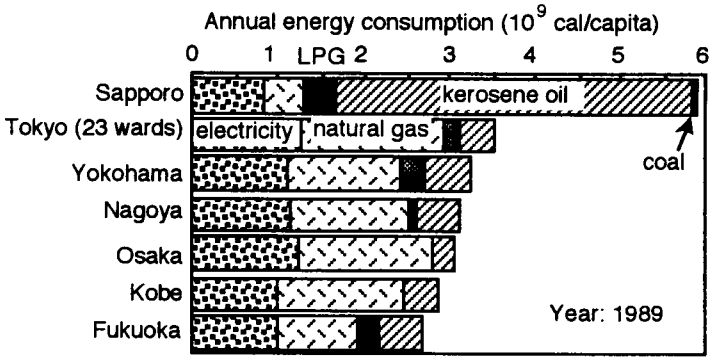

Fig. 2. Per capita annual energy consumption for household use in Japanese cities (1989)

Commercial and office sector and transportation sector which support urban activities, were two major contributors followed by household sector. Energy consumption in the transportation sector depends on urban planning elements such as size and density of urban area, and public transportation service. There is room of reducing energy consumption through reorganizing urban planning. Household energy consumption depends on life style, floor space of house, and climate. As Japanese society is very uniform, life standard of people has small variation. Floor space and climate are major factors to decide per capita household energy consumption which is shown for seven major cities in Japan in Fig. 2. Sapporo shows significantly higher value than other six cities because of cold climate. This fact indicates that energy consumption in Japanese cities in cold region is sensitive to climate, and that urban waste heat recovery for heating would be effective.

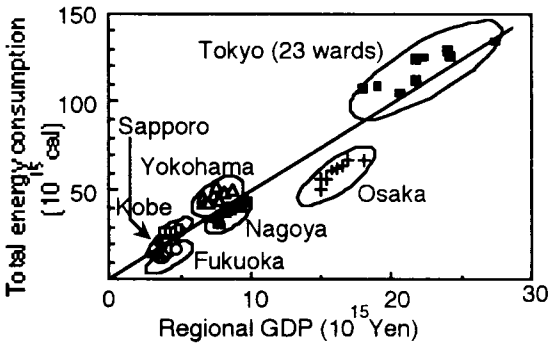

Fig. 3. Total energy consumption and GDP in Japanese large cities

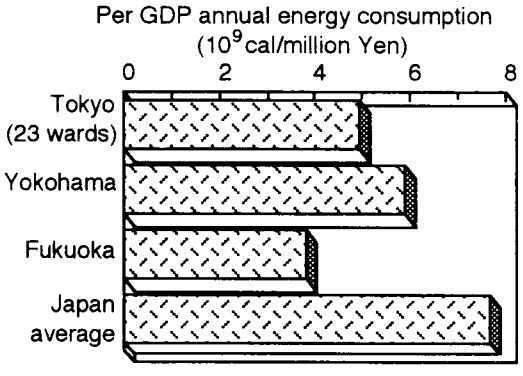

Fig. 4. Per GDP annual energy consumption in urban area

Although major activities of these seven cities are not identical, GDP (Gross Domestic Product) of each city showed good correlation with energy consumption as shown in Fig. 3. Economic growth and increase in energy consumption in each city fell into a straight line. The energy consumption in all seven cities is expressed fairly well as:

Energy consumption (10^9 cal) = (4 to 6.5) x GDP (million Yen 1985)

Urban area consumes less energy to yield GDP due to its commercial oriented activity than non-urban area as shown in Fig. 4 which compares majors cities with average value in Japan.

4. International comparison of urban energy consumption

Energy consumption in urban area heavily depends on social and economic circumstances and life style. The method established for Japanese cities was applied to foreign cities, especially cities in China. Collection of various kinds of statistics and interviews in Energy Research Institute in China were conducted through a survey trip.

Per capita energy consumption and per GSP (Gross Social Product) energy consumption for provinces and large cities in China are shown in Fig.5. Beijing, Shanghai and Tianjin obviously show high per capita consumption with low consumption per GSP. It indicates that increase in energy consumption with urbanization contributed to GSP in rather efficient way in terms of energy. This seems to be a typical change accompanying urbanization in developing countries.

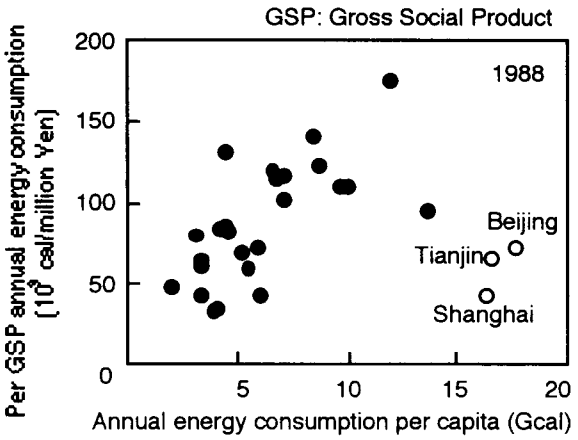

Fig. 5. Correlation between per capita and per GDP energy consumption in China.

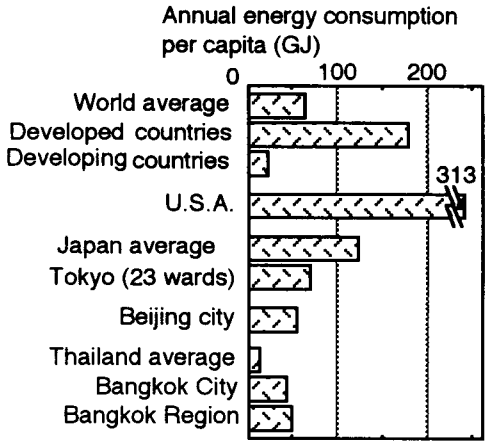

Fig. 6. Per capita energy consumption in developed and developing countries.

Progressive urbanization is expected in many developing countries in the future. Carbon dioxide emission through energy consumption in such countries is major contributor to the global warming. Fig. 6 shows per capital energy consumption in urban area and other area both in developing and developed countries. Energy consumption in urban area is less than non-urban area in developed countries as shown in the case of Tokyo. On the contrary, energy consumption is significantly higher in Bangkok or Bangkok Region than average value in Thailand. Bangkok region consumes 60% of nation's energy while the share of population is less than 20%. This clearly show that urbanization in developing country brings significant increase in energy consumption. This is probably due to changes in life style of people. Rather high per capita energy consumption value in Beijing also supports this tendency.

5. Dependency of energy consumption on climate

Energy consumption for heating or cooling is affected by climate as shown in the case of Sapporo city (Fig. 2). Furthermore, its sensitivity depends on socio-economical factors. Estimation of temperature effect from available data of energy consumption was attempted for

Chinese and Japanese cities. Temperature effect for heating demand is represented by heating degree month (HDM) based on standard temperature of 18℃. Correlation between HDM and consumption of various types fuel was examined. Kerosene consumption in Japan and coal consumption in China showed best correlation with HDM. Fig. 7 shows that heating demand in Japan is very sensitive to HDM in the area with HDM higher than 70 deg-month, whereas heating demand in China are less sensitive to temperature. Correlations are expressed as

Per capita annual kerosene consumption (Mcal) = 3.6×10^{-6} $HDM^{4.4}$ – 391 (Japan),

Per capita annual coal consumption (Mcal) = 53.46 $HDM^{0.7}$ – 139.2 (China),

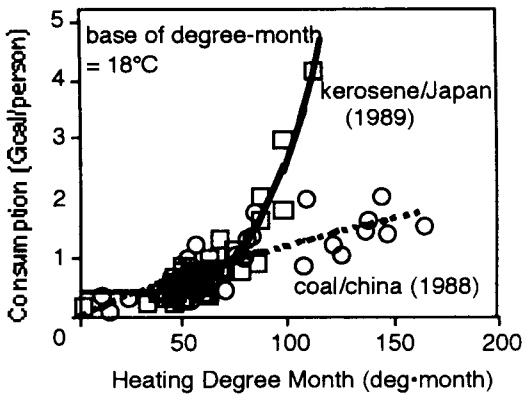

Fig. 7. Dependency of per capita energy consumption on temperature.

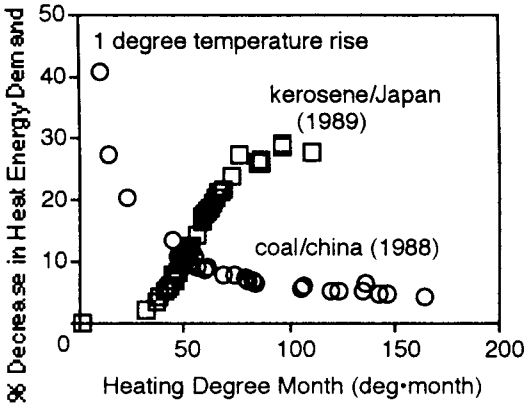

Fig. 8. Sensitivity of heat demand against temperature rise.

Potential impact of climate change on heating demand can be calculated based on these equations. Fig. 8 shows decrease in heat energy demand in area with various cities in Japan and China with temperature rise of 1℃. Expected decrease of heating energy consumption in cold cities in Japan is as high as 25%.

6. Effective use of waste heat in urban area

Most of the used energy in urban area turns to heat and emitted to the atmosphere, wastewater or solid waste. Such waste heat should be used to minimize energy consumption in urban area. Although all types of energy demand cannot be replaced with such waste heat, heating or cooling demand of energy can be saved by utilizing such waste heat. Technology for recovering heat from sewage or solid waste and its use through district heating/cooling system is almost established. However, encountering problem in application of such technology to actual urban area is spatial and temporal distribution of waste heat source and heating/cooling demand. Computer simulation system was developed to estimate feasibility and effectiveness of heat recovery and reuse. Geographical information matrix data (size: 250 m x 250 m) of Tokyo Metropolitan area were used to calculate energy demand and amount of sewage and solid waste. Floor space of various types of building obtained from data on type of land use and stories of the building was used to calculate energy demand. Fig. 9 displays, as examples of output, density of energy demand in day time or night time in winter and oil consumption in winter.

7. Summary

Method of estimation of urban energy consumption both in developed and developing countries was established. Socio-economical factors are very important in developing countries in which urban area consumes higher energy per person than non-urban area. Decrease in heating demand by temperature rise is expected to be large in cities in cold climate in Japan. Computer simulation system was developed to evaluate feasibility and effectiveness of waste heat recovery system in urban area.

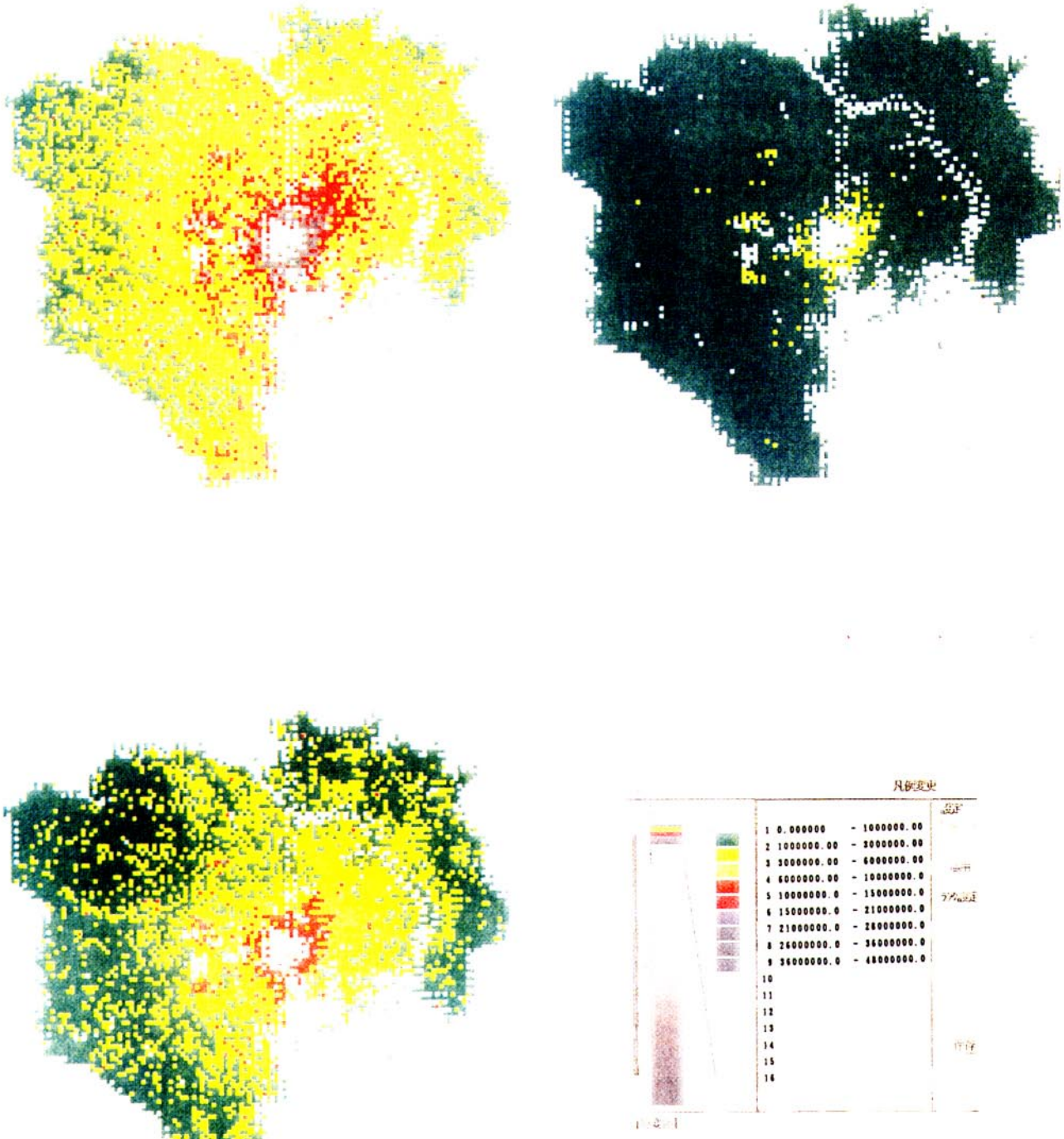

Fig. 9. Examples of output of simulation.
(Energy consumption density in Tokyo (23 wards))
Left top: day time in winter
Right top: night time in winter
Left bottom: day time in winter (oil for heating only)
Right bottom: legend