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EFFECTS OF URBANIZATION ON GROUND SURFACE TEMPERATURE IN THE KANSAI DISTRICT, JAPAN - BASED ON METEOROLOGICAL DATA -

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Abstract

Heat island phenomena have become of major interest in many world-wide metropolitan cities in connection with global warming. The changes in temperature in the Kansai District, Japan are examined by analyses of meteorological data obtained during the past 100 years at 13 observatories and AMeDAS data of the last 15 years at 66 observation points. A remarkable heat island phenomenon can be observed near Sanda New Town where preparation of housing site has been under construction. The annual average minimum temperature in January is now 4°C higher than that observed over the past 15 years. The present study examines the effects of urbanization such as land utilization and energy consumption on the heat island phenomena in Osaka City.

KEYWORDS: *Urbanization, local meteorology, heat island, land utilization, energy consumption*

1. Introduction

Modern cities have developed in line with more efficient economic activities, supported by construction of factories enabling mass production of commodities and innovation of technologies facilitating transportation and delivery networks. The concentration of such functions, the growth of population as a labor force and the concentration of information and cultural opportunities have made cities more attractive, so modern cities keep expanding.

Saito (1992) reported that more than 70% of the population lives in cities in developed countries and that the percentage of the world population lived in big cities larger than four million was 17% in 1985; it is expected that it will reach 25% in 2025. According to a report by the United Nations, there were 42 cities with populations exceeding four million in 1985, and this will increase to 66 cities by 2025. With cities growing and expanding, it is impossible to ignore their effects upon the environment of their own and surrounding areas. In Japan, the

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urban population has increased by 15% over the last 20 years; about 70% of the population now live in urban areas. Urbanization takes place not only in developed countries but also in developing countries. The expansion of cities in developing countries impose serious problems on the environment because their urbanization is occurring at an accelerated rate.

Environmental problems due to urbanization have appeared in various forms. The expansion of urban areas causes a change in land utilization: a decrease in green zones, changes in the properties of the ground surface due to road paving and in ground configuration due to the construction of buildings, and changes in the materials used for urban structures. Industrial and daily human activities in cities discharge a huge amount of thermal energy. All these factors can lead to noticeable changes of local climate in urban areas. It has been noted from long ago that the temperature in cities increases depending on their growth in size. Duckworth and Sandberg (1954) studied the phenomenon of higher temperature in three cities in California and named it the "heat island phenomenon". This name originates from the isolated temperature distributions of cities and their surroundings in contrast with those of other areas. According to Matsumoto, *et al.* (1990), there is almost no differences between the maximum temperatures at Ote-machi in the center of Tokyo and Omi located in the suburbs and the annual average minimum temperature of Ote-machi has been rising. During the 10 years from 1976, the difference in average minimum temperature between the two locations increased from 2.4°C to 2.9°C. In addition, the difference in daily average temperature increased from 1.8°C to 2.1°C after 1985; and this trend seems to be continuing. The heat island phenomenon in the center of Tokyo has become manifest year by year.

In the present study, the changes in temperatures in the Kansai District in Japan are analyzed based on meteorological data during the last 100 years collected at 13 major meteorological observatories in the Kansai District and AMeDAS data collected between 1976 and 1980 at 66 observation points. The changes of meteorological values in time and space can be evaluated by using these observed data. The effects of changes in land utilization upon ground temperatures are examined in terms of the temporal changes of the albedo and the evaporation ratio appeared in the heat energy transfer at the ground surface to specify the factors that could cause the heat island phenomenon. In addition, the correlation between temporal changes in temperature and energy consumption in Osaka City is discussed.

2. Temporal Change of Temperatures in the Kansai District

2.1 Temporal changes of Temperature for the Past 100 Years Observed in Meteorological Observatories

The position of the Kansai District in Japan, and the locations of the meteorological observatories and AMeDAS stations are shown in Fig.1. There are thirteen meteorological observatories; five of them started operation between 1880 and 1897. Figure 2 shows changes in annual mean temperature, annual daily minimum temperature and the number of tropical nights in Osaka for the last 110 years. Thin lines represent annual data, bold ones the 5-year moving average and its 95% confidence limits and a horizontal solid line the average of the whole period of observation. Generally speaking, the temperature in the Kansai District up to 1945 was consistently low as compared with the average value for 110 years. It started to increase from 1946 and peaked in 1960. After that, during the 1970's it tended to decrease, only to rise again from the 1980's to the present. Remarkable periodic variations can be found

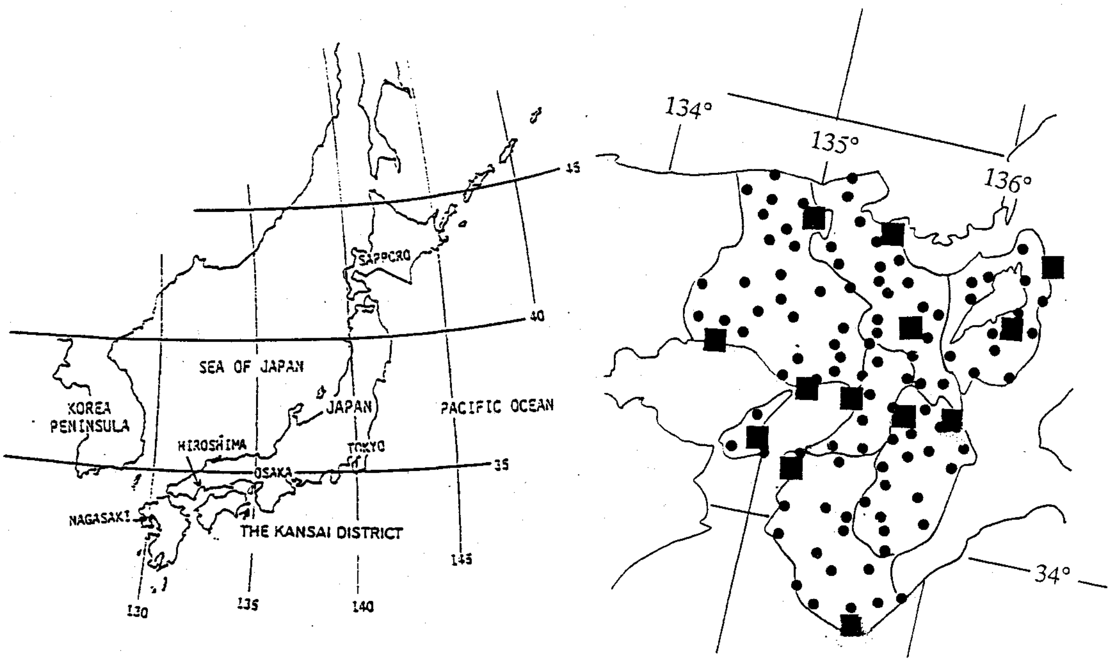

Figure 1. (a) Location of the Kansai District in Japan, (b) Location of meteorological stations (■) and AMeDAS stations (•)

about every 6 and 30 years. Temporal changes are formed by the combination of a long-term warming tendency and these periodic variations. According to Fig. 2, the daily average mean temperature of Osaka increased by about 2.0°C and the minimum temperature by about 2.5°C over the last 100 years. The number of tropical nights, which is defined to be a night with a minimum temperature of 25°C or higher, was around 10 times during the 1940's, but had reached 40 in 1985, and is still increasing.

The temporal change of temperature due to urbanization and those on a global scale are compared in Tables 1 and 2, where the rates of increase in annual mean temperature over 100 years are shown. The IPCC report (1990) based on observation data between 1950 and 1988 reports that the rate of global warming over the last 100 years is 0.6°C, commenting that this is a serious problem endangering the global environment. The rate of increase in annual average temperature is 1.34°C in Northern Asia, much bigger than that of the global level. Suzuki and Yamaji (1994) analyzed the observation data in the Kansai District between 1962 and 1992 and drew up Table 2 which indicates the rate of increase in annual average temperature in Osaka is 3.37°C during the last 100 years; and 2.58°C and 1.88°C in Kyoto and Kobe respectively. On the other hand, the observation data for Sumoto in Awaji Island facing the Osaka Bay show that the annual average temperature there has become lower. That of Cape Shionomisaki facing the Pacific Ocean shows an increase of 1.46°C. Overall, arming in urban areas in Kansai District has been progressing at a very much faster rate than global warming.

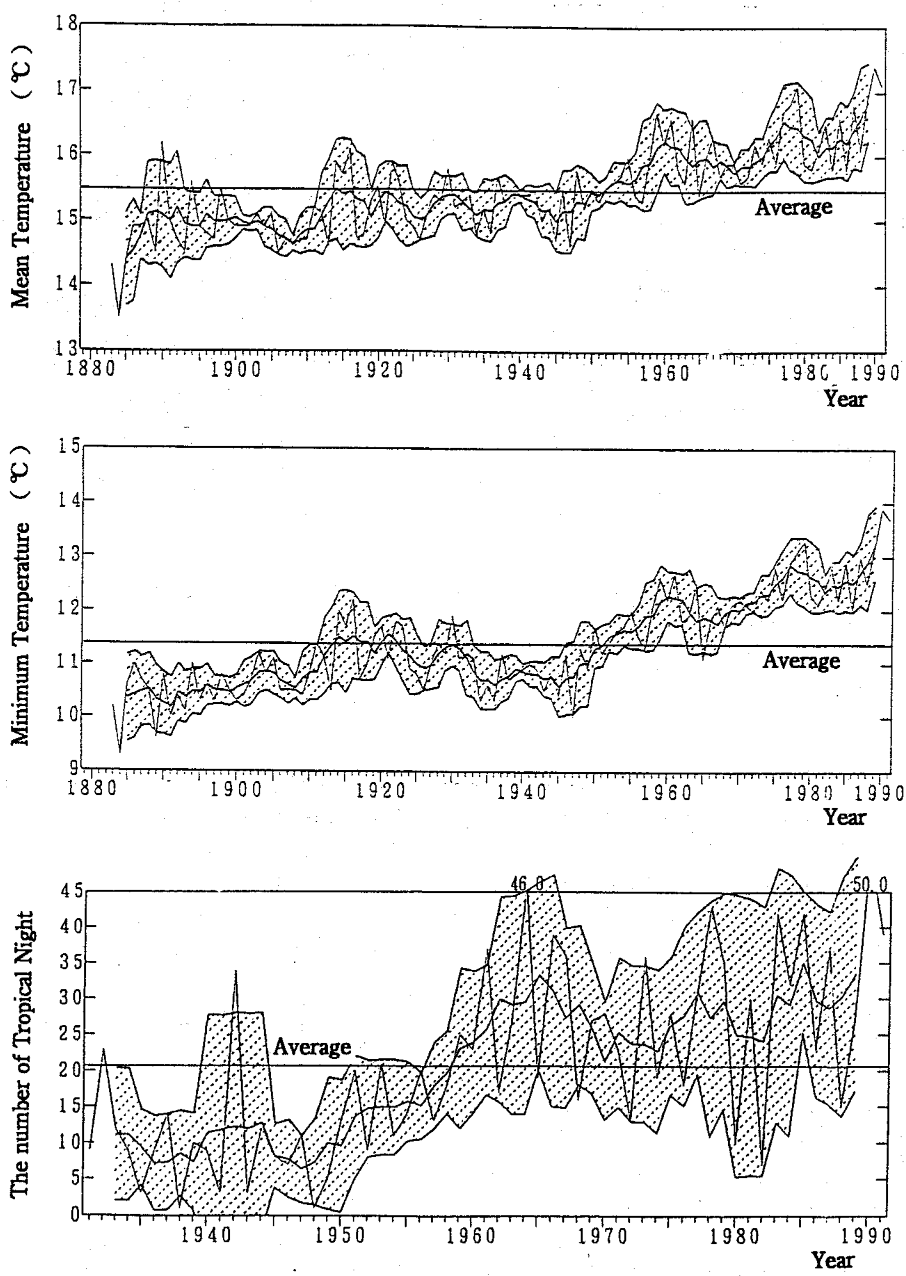

Figure 2. Variations of meteorological data obtained in Osaka City
(a) Annual mean temperature
(b) Annual minimum temperature
(c) Number of tropical nights

Table 1. Trend of annual mean temperature °C/100 years (from the report of IPCC (1991))

Area	Period 1950 - 1988
Earth	0.60
North Hemisphere	0.54
South Hemisphere	0.75
Northern Asia	1.34

Table 2. Trend of annual mean temperature °C/100 years (from Suzuki and Yamaji, 1994)

Meteorological Stations	Period 1962 - 1992
Kyoto	2.58
Osaka	3.37
Kob	1.88
Shionomisaki	1.46
Sumoto	-0.24

2.2 Temporal Change in Temperature for the Last 15 Years Observed in AMeDAS Observation Network System

The service of AMeDAS network system started from 1976 and its network throughout the Kansai District was completed at least in 1980. Now, 104 stations have already been set up in the Kansai District. AMeDAS system provides meteorological data every hour in normal operation. Three year average minimum temperature distribution between 1991 and 1993 is plotted in Fig. 3 using observation data obtained at the 66 AMeDAS stations. The reason why three year averaging was employed is that the abnormal temperature appearing in one particular year dominated by abnormal whether should be eliminated by using three- year average values. The interval of the isopleth is 0.2°C. Figure 3 reveals that the annual average minimum temperature on top of Mount Ikoma is around 8°C, while that of Osaka City is from 11.0°C to 12.0°C.

The difference between the three-year daily average minimum temperatures between 1980 and 1982 and those between 1991 and 1993 were calculated and the rate of change is plotted in Fig.4. The average minimum temperature has risen all over the Kansai District. It has risen by 1°C in Osaka City and by 0.2°C at top of Mount Ikoma, a somewhat smaller rise than that of Osaka City. What is conspicuous in Fig.4 is a temperature rise at Sanda City of more than 2°C, which is much larger than that of Osaka City.

Similar calculations were made for the average minimum temperature in January and a distribution of the difference in the average minimum temperature is plotted in Fig.5. A definite heat island can be found around Sanda with a rise of 4°C in a short period of 10 years. It can also be seen that the average minimum temperature in January in Osaka City increased by 2.5°C. Inhabitants in Sanda City often say that there has been less frost and snow in recent

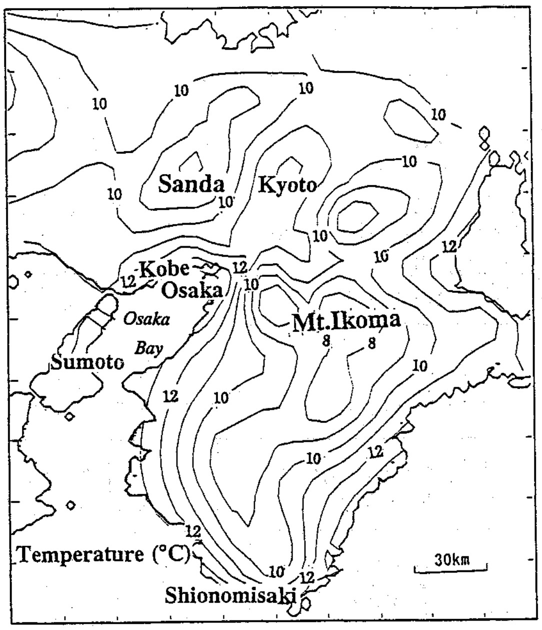

Figure 3. Distribution of three-year average minimum temperature between 1991 and 1993 in Kansai District

years. Their evidence supports the rapid change appeared in Fig.5. Figures 4 and 5 verify the theoretical argument that the heat island effects manifest themselves more clearly during winter rather than summer, and also appear the distribution of minimum temperatures rather than that of average and maximum temperatures.

3. Effects of Urbanization on Ground Surface Temperature

3.1 Factors Contributing to Generation of the Heat Island Phenomenon

Saito (1992) identified five factors that accelerate warming in urban areas:

(a) Paved roads, reduced area of greenery and a drop in the evaporation volume of water from urban areas;
(b) Large heat capacity of urban structures;
(c) Wind weakened by urban structures;
(d) Urban activities accompanied with huge energy consumption, such as the operation of factory boilers, air conditioning for buildings and exhaust fumes from vehicles; and
(e) Greenhouse effects due to carbon dioxide, steam and so on.

The heat island effect results from a complicated combination of the above factors. The authors would like to regroup the five factors into two: namely, changes in urban ground surfaces due to housing and construction work; and vast energy consumption in urban areas. The former corresponds with above-mentioned factors of (a), (b) and (c), and the latter with

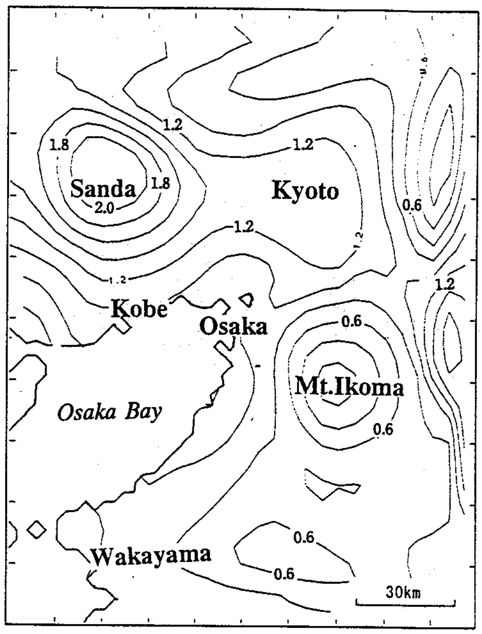

Figure 4. Distribution of difference in annual average minimum temperature between 1991-1993 and 1980-1982

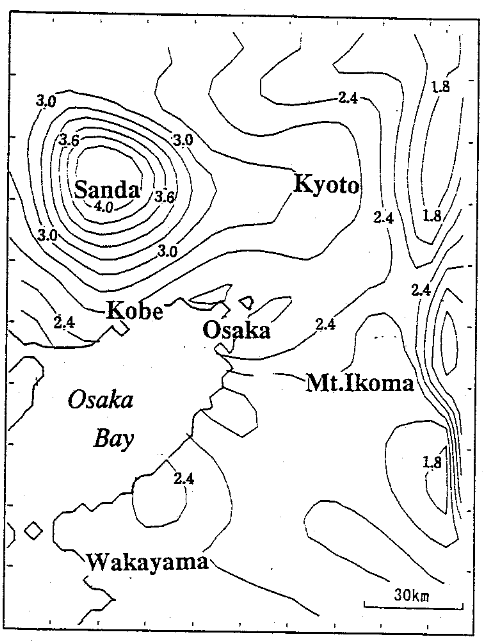

Figure 5. Distribution of difference in annual average minimum temperature in January between 1991-1993 and 1980-1982

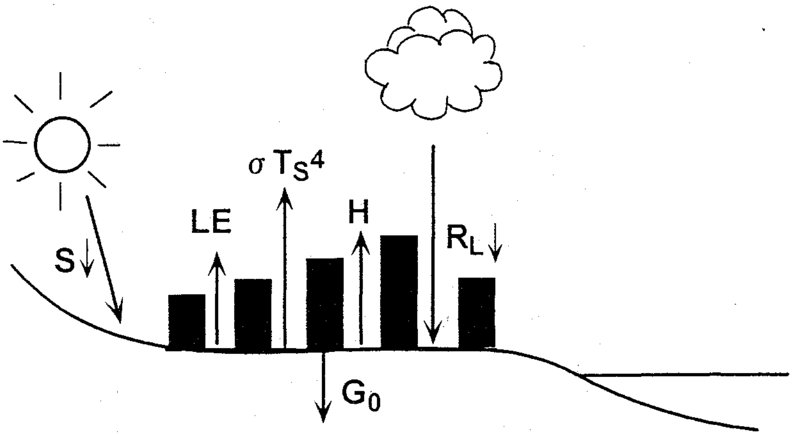

Figure 6. Energy balance on the ground surface

(d) and (e). Among them, the factors of (a) and (d) are examined in order to discuss the effects of these two factors upon the heat island phenomena.

3.2 Outline of Heat Energy Transfer at Ground Surface

Needless to say, it had better use a three dimensional atmospheric numerical model of meso-scale phenomena in the lower atmosphere in order to estimate effects of the change of land utilization on local climate. However, since the governing equations are time-dependent, typical values for the wind speed, temperature, relative humidity in the surface layer must be specified to construct initial values and boundary conditions. It is difficult to specify them at all computation domain as a function of time. In the present study, therefore, the effects of change of land utilization are examined using a heat energy transfer equation at the ground surface.

Figure 6 shows a energy transfer across the ground surface. The physical factors appeared in the figure is as follows;

$S\downarrow$; incident shortwave radiation from the sun,

$R_L\downarrow$; incident long-wave radiation from the atmosphere to ground surface,

δT_s^4 ; incident long-wave radiation from ground surface to atmosphere, hence $R_L\downarrow$ - $R_L\downarrow$ means the net long-wave radiation.

H ; sensible heat transfer depending on the difference in temperature between atmosphere and ground, and wind velocities.

LE ; latent heat depending on the difference in water vapor between atmosphere and ground, and the wind velocity,

G_o ; conduction of heat into the ground.

Sensible heat 'H' affects on temperature, that is, decrease on the ground surface and increase in atmosphere. A positive sign means usually upward. Latent heat 'LT' contributes not to increase in temperature, but also to transition of phase, for example, condensation, sublimation and evaporation.

The equation governing the heat energy transfer at the ground surface is given in the terms of above-mentioned factors. The net radiation R_n is represented as the following equation.

$$R_n = (1-r)S\downarrow + L\downarrow \tag{1}$$

where R_n is net radiation; $S\downarrow$ is solar radiation; $L\downarrow$ is downward atmospheric radiation; r is shortwave albedo of ground surface.

The net radiation 'R_n' changes sensible heat 'H', latent heat evaporation 'LE' and heat conduction into the ground 'G'. When Eq.(1) is integrated for one day, the heat conduction changes from positive sign in daytime to minus sign in night. Daily average values of 'G', therefore, become a very small amount. As a result, the daily average heat energy budget equation leads to the following simplified one. (Sunada and Nagashima; 1991)

$$< R_n > = < \delta T_s^4 > + < H > + < LE > \tag{2}$$

where δ is Stefan-Boltzman constant; T_s is the temperature of the ground surface; H is sensible heat; E is evaporation; L is heat of vaporization, and $< >$ means one-day integrated values.

The sensible heat 'H' and the latent heat 'LE' are given by the following equations respectively. (Ojima and Moriyama; 1978)

$$H = \alpha_c(T_s - T) \tag{3}$$

$$LE = Lk_q(q_s - q) \tag{4}$$

where α_c is heat conductivity of convection, T is atmospheric, k_q is mass transfer coefficient. q_s and q are saturated specific humidity for the temperature of the ground surface and the air specific humidity for the temperature, respectively. Equation (4) represents the latent heat under the condition where the surface is perfectly wet, that is "possible evaporation ETP". On the other hand, in determining the latent heat in a grass-covered plain, the ratio of practical evaporation E to ETP, f is introduced, that is, $f = E/ETP$. Generally speaking, since the evaporation from wet land is equivalent to possible evaporation, LE is often rewritten as the following equation.

$$LE = fLk_q(q_s - q) \tag{5}$$

As described above, fundamental coefficients of the heat energy transfer equation are, shortwave albedo of ground surface, r; convection heat conductivity, α_c; mass transfer coefficient, k_q and evaporation ratio, f. Since albedo r and evaporation f change depending on land utilization among them, the qualitative analyses of urbanization are examined as a function of r and f. (Ojima and Moriyama, 1978)

3.3 Changes of Coefficients, r and f, due to Changes in Land Utilization

(1) Case of Osaka City

The bar charts in Fig. 7 show the changes in land utilization in Osaka City every 5 years. As far as residential zones are concerned, the rate increased from 51% in 1965 to 56% in 1975. A decrease of residential zone in percentage in 1980 is caused by the expansion of administrative area of Osaka City. The zones for roads and other traffic purposes have increased by about 5%, while the ratio of agricultural zones have decreased by about 5%. It is evident from the change in land utilization that urbanization has made steady progress in Osaka City.

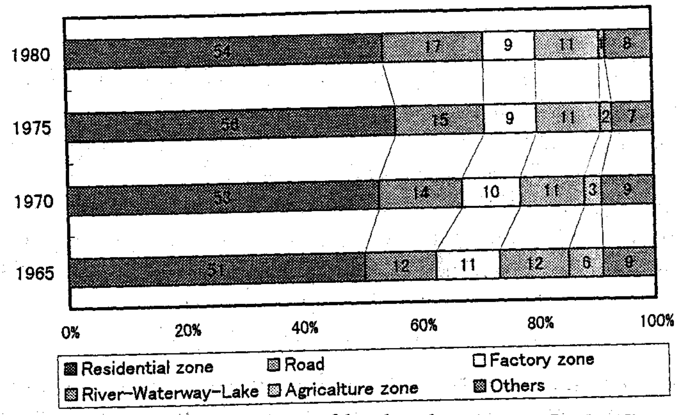

Figure 7. Time variations of land utilization in Osaka City

Table 3. Annual average albedo and evaporation ratio in Osaka City

Land Utilization	Albed	Evaporation Ratio
Wasteland	0.20	0.10
Building & Traffic	0.10	0.00
Lake	0.06	1.00
Forest	0.15	0.36
Agriculuture zone	0.18	0.30

In order to quantitatively examine the effects of land utilization on the ground surface temperature in Osaka City, the annual average values of albedo, r and evaporation ratio, f for various land utilization must be calculated based on their distributions of land utilization. The monthly values are given by Ojima and Moriyama (1978). The yearly average values are given for various uses as shown in Table 3. The annual changes in albedo and evaporation ratio at the ground surface, therefore, are calculated using the land utilization data as indicated in Fig. 7. The average monthly global solar radiation between 1975 and 1980 was 12.6 MJ/m^2.

Figure 8 shows temporal changes of calculated albedo and evaporation ratio, and observed air temperatures as well. It is obvious from the figure that the increase in buildings, roads and other traffic uses has caused the albedo and the evaporation ratio to drop monotonously from 1965 to 1981. If examined in detail, the value of albedo decreases from 0.11 in 1965 to 0.105 in 1974 and it keeps constant about 0.105 from 1974 to 1981. Similar tendency can be recognized in the temporal change of evaporation ratio, that is, the decreasing rate of f changes from 0.0018 to 0.0007 per year around 1974. On the other hand, the observed air temperatures tends to be constant during 1965 and 1974 and to increase at the average rate of 0.2°C per year, The air temperature in the last two years, namely in 1980 and 1981, was 15.9°C which is against the tendency observed from 1965 to 1979. However, as compared with the change of atmospheric temperature in the 1980s, the weather in both years is estimated to be abnormal.

As is generally known, urbanization forces the value of albedo and evaporation ratio to decrease and it contributes to an atmospheric temperature rise and dry weather warming.

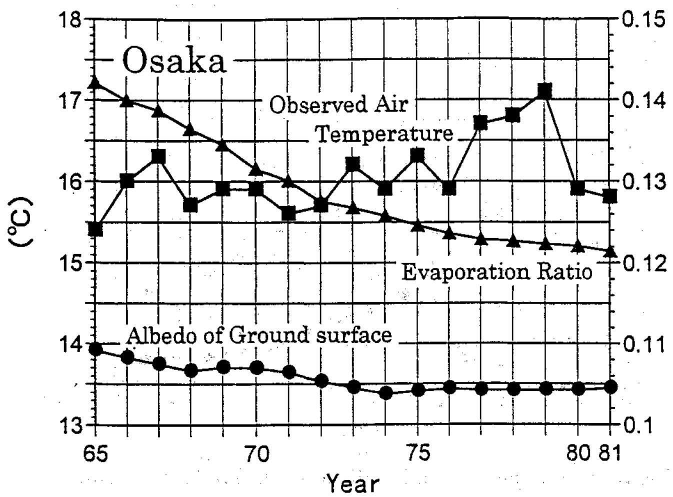

Figure 8. Time variations of observed air temperature, albedo and evaporation ratio in Osaka City

According to the sensibility analyses of various coefficients including a three-dimensional numerical simulation with a turbulence closure model by Nakatsauji *et al.* (1996), both ground temperature of ground surface and atmospheric temperature near ground surface increases with a decrease in albedo and evaporation ratio. However, the temporal change of observed air temperature in Fig.8 indicates much different tendency, preferably contrary one. That is, atmospheric temperature does not increase when the value of albedo decreases from 1965 to 1974, while the former remarkably increases when the latter keeps to be constant after 1975. The temperature rising in Osaka City is found to have no relation to the change of lad utilization.

(2) Case of Sanda New Town

The same calculation of albedo and evaporation ratio was carried out for Sanda New Town where the temperature rise over the last 10 years has been very large as shown in Figs.4 and 5. Sanda New town has been developed from 1979. Finally, its area will become about 2,000 ha with the population of 90,900 peoples. Land use was carefully planned, and the change of land utilization are shown in Fig.9. Usually the development procedure for the residential zone proceed in three steps; land preparation, ground leveling and hose building. The land preparation began in 1979 and the house building began to make rapid progress from 1983. Based on the development data, the values of albedo and evaporation ratio were easily calculated from 1979 to 1994.

The temporal change of calculated albedo and evaporation ratio is shown in Fig.10 with observed air temperature. As can be seen in the figure, the albedo of ground surface increases a bit within the initial stage from 1979 to 1982, and it decreases monotonously with time after 1985. The values of albedo changes from 0.18 in 1982 to 0.13 in 1994. On the other hand, the evaporation ratio continues to decreases with time. These tendencies are well known to be affected by the urbanization. The rates of change in albedo and evaporation ratio in Sanda New Town are surprisingly large as compared with those in Osaka City shown in Fig.8. The observed atmospheric temperature increases. It has risen by 1.2°C over 15 years, namely, at

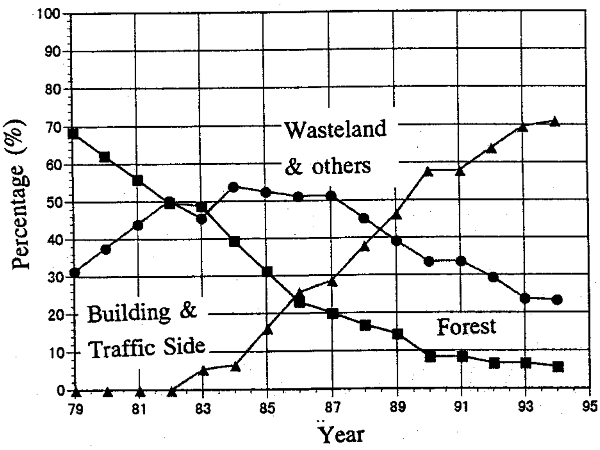

Figure 9. Change of land utilization in Sanda New Town

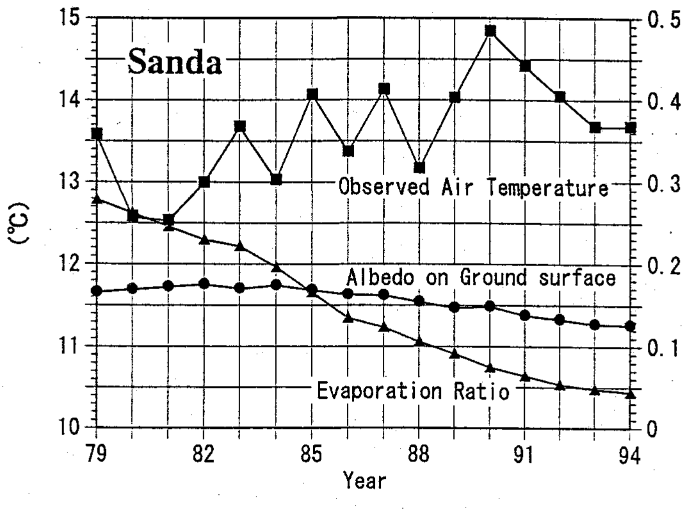

Figure 10. Time variations of observed air temperature, albedo and evaporation ratio in Sanda New Town

the average rate of 0.092°C per year.

The evaporation ratio is greatly related with latent heat flux. Rapid decrease in latent heat accelerates the temperature rise and the dry-up in air. This area is still under construction and only a small amount of heat due to energy consumption has been generated yet Therefore, the major cause of the temperature rise can be conjectured to be the change in land utilization. As the development progresses, and more heat due to energy consumption is generated, a significant temperature rise can be estimated.

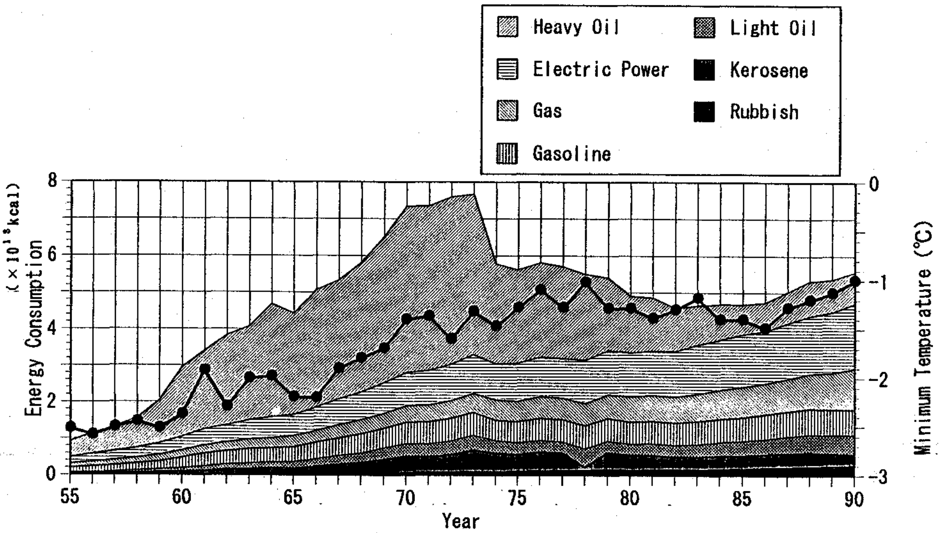

Figure 11. Time variations of energy consumption and minimum temperature in Osaka City

4. Correlation Between Energy Consumption and Observed Temperature

Temporal changes of energy consumption such as electricity, gas, gasoline, heavy oil, light oil, kerosene and burnt refuse, are examined, items of which are collected in Osaka City for the forty years between 1955 and 1993. It was impossible to correlate the collected figures of individual fuels with each other because they were specified in different units. Therefore, we calculated the amount of heat generated per unit and obtained the number of calories. The amounts of heat per unit we used are 860 kcal/kWh for electricity, 450 kcal/m^3 for gas, 8600 kcal/liter for gasoline, 8600 kcal/liter for heavy oil, 9200 kcal/liter for light oil and 8900 kcal/liter for kerosene. Since the heat generating rate of refuse per unit volume keeps increasing because the quality of refuse changes year by year, combustion heat was calculated for each year. As the data for refuse was available only for 1970 and later, the figures started to be added to the energy consumptions from 1970 onwards. The figures for oil and incinerated refuse are for Osaka Prefecture; hence they were converted into those for Osaka City by multiplying them by the ratio of population of Osaka City to that of Osaka Prefecture.

Figure 11 shows the temporal change of energy consumption of Osaka City. Consumptions of electricity and gas show constantly rising trends, gasoline and light oil also increase while kerosene has been decreasing moderately since 1973. Heavy oil, mainly used for industrial fuel, rose until 1972, after which dropped greatly. This is partly because of the so-called "Petroleum Crisis" around that period and partly because of the changes in industrial structures and some factories moving away from the coastal areas near metropolitan cities. The incinerated refuse has been increasing steadily. The correlation between the energy consumption and the variations in the minimum temperature with time was examined because the heat island phenomenon takes shape most strongly as a rise in average minimum temperature, as mentioned above. This rise in average minimum temperature in urban areas could be attributed not only to the heat island effect but also to global-scale fluctuations in temperature.

To eliminate the effect of the latter fluctuation, we subtracted the minimum temperature of Cape Shionomisaki, where a little rise has been observed for the past 40 years, from that of Osaka. The temporal change of temperatures excluding global-scale warming is shown by the solid line with circles in Fig.11.

Broadly speaking, the variations of the temperature with time, started to continuously rise in 1955, turning into a decrease in 1978, and again starting an increase in 1986. On the other hand, energy consumption increased continuously between 1955 and 1973, except for a temporary drop in 1964. After 1973, the energy consumption shows to be almost constant until 1978, and turning into a gradual decrease between 1978 and 1985. This trend reversed again starting in 1986 when both the energy consumption and the minimum temperatures showed a rising trend. A significant correlation can be seen between the energy consumption and the minimum temperatures, while there are periods where a sudden decrease in energy consumption is not reflected in the fluctuation in the temperature; and the ups and downs in the graphs of the two do not match in other periods.

The authors suspect that the method employed where the minimum temperature of Cape Shionomisaki is subtracted from that of Osaka to remove the effect of global-scale temperature changes, is not good enough. Another possibility may be that temperatures in urban areas are determined in a more complicated manner and are not governed only by energy consumption. Generally, it is an undeniable fact that the temperatures in Osaka have tended to rise with an increase in energy consumption in that area.

5. Concluding Remarks

Effects of urbanization such as the changes of land utilization, concentration of population and properties, and huge energy consumption on local meteorology in urban areas are examined. Special attentions are paid to Osaka City and Sanda New Town, because remarkable heat island phenomena can be observed near these cities. The analysis of meteorological data from the past 100 years indicates that the rate of increase in annual mean temperature in Osaka City is 3.37°C, which is higher than that of global warming, that is, 0.60°C for the earth and 1.34°C for north Asia. The analysis of AMeDAS data also shows a rise of 1.0°C in annual average minimum temperature for the last 15 years. Another surprising rise can be observed, that is, the annual average minimum temperature in January is now 4°C higher than that observed over the past only 15 years.

Its mechanism is examined on the basis of heat energy budget at ground surface, especially the albedo and the evaporation ratio, in terms of changes in land utilization. The temporal changes of albedo and evaporation ratio were not recognized to correspond to the temperature rise in Osaka City. Instead, the temporal change in minimum temperature in Osaka City coincides with that of energy consumption. On the other hand, the correlation of time variation of albedo and evaporation ratio with temperature rising was remarkably confirmed in Sanda New Town. These facts lead the conclusion that the principal reason of heat island phenomena in developed urban cities such as Osaka City is huge energy consumption, while that in developing urban cities such as Sanda New Town is the change in land utilization. The collection of consumption volumes of various energy items every year, however, is too difficult even in large cities except Osaka City in the Kansai District. The quantitative analysis of relationship between temperature and energy consumption remains unsolved.

References

Duckworth, F.S. and Sandberg, J.S. (1954): *Bull. Metheor. Soc.*, Vol.35, p.198.

The IPCC Impacts Assessment (1991): *Climate Change*, Island Press, p.274.

Kondo, J. (1967): Analysis of solar radiation and downward long-wave radiation data in Japan, *Science Report*, Tohoku University, Ser.5, Geophys., Vol.18, pp.91–124. (in Japanese)

Maeda, T. (1955): *Energy Conduction*, Shoukokusha Publ. (in Japanese)

Ojima, T. and Moriyama, M. (1978): Study on heat budget on ground surface for environmental assessment: II, *J. Japanese Society of Architecture*, Vol.265, pp.93–102. (in Japanese)

Saito, T. (1992): *Green-House Phenomena of The Earth and Urban Area*, Mookita Publishers, p.184. (in Japanese)

Slatyer, R.O. and Maclloy, I.C. (1961): *Practical Micrometeorology*, C.S.I. R.O.Melbourune.

Sunada, K. and Nagashima, K. (1991): Basic Consideration on Estimate of Evaporation in Large-Scale Basin, Reprint of Annual Meeting, *Japanese Soc. Hydrology and Water Resources*, pp.264–267. (in Japanese)

Suzuki, Z. and Yamaji, A. (1992): Analysis of methodological data related with global warming, Report of Collaborative Research Group of Green-House Effects, *The Kansai Branch of JSCE.* (in Japanese)

Takeuchi, K. and Kondo, S. (1981): Atmospheric phenomena near ground surface, *Ser.I Atmospheric Science*, Tokyo University Press, 108pp. (in Japanese)