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Chapter 9

Fusion Study of Geography and Environmental Engineering

Toshiaki Ichinose

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Abstract

The author focuses on urban area and shows case studies on urban energy planning and urban climate induced by concentrated human activities like energy use based on geographic information like land use data and numerical climate model linked to geographic information system (GIS). (1) In finding the candidate places to settle district heat supply facilities that make effective reuse of heat obtained from sewage, the usage of GIS gives the reasonable solution in scientific view point. (2) The spatiotemporal data in high resolution on human activity like energy consumption in urban area enable us to evaluate the impact of anthropogenic heat to urban climate by a numerical simulation model of the local climate. (3) The recent precise geographic information of urban vegetation cover derived from remote sensing (RS) data enables us to evaluate the contribution of urban green to cool our community with higher accuracy. (4) The author's approach is available not only to evaluate the current urban environment but also to evaluate the past one. If a certain scenario of future's urban land use and urban activity, this approach will be available for the future prediction. Thus, these outputs will give some sustainable urban design in viewpoint of climate change (mitigation and adaptation).

Keywords: urban environment, urban climate, energy system, GIS, sustainability

1. Introduction

Geography can be used to clarify the spatiotemporal distributions of various phenomena like climate, flora, fauna, human activities on the Earth, as well as their underlying mechanisms. In contrast, environmental engineering emphasizes the connections among individual elements such as air, water, soil, and living organisms, and attempts to link research findings to policy-making and technical development.

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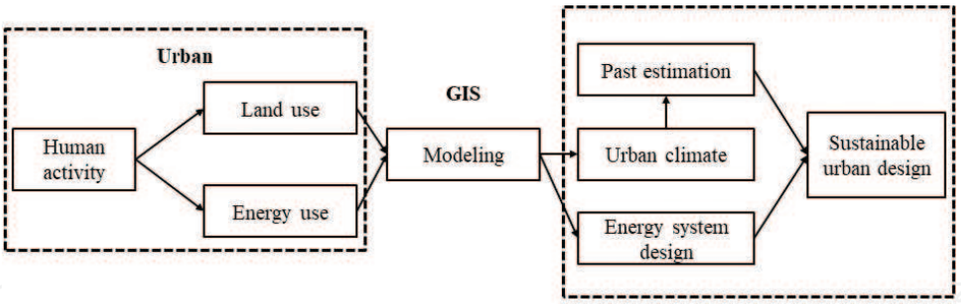


Figure 1. Conceptual structure of this chapter.

The author wants to promote environmental engineering studies to achieve urban design that incorporates environmental factors and fosters the diversity of natural ecosystems, with a focus on Asian cities, which are experiencing the fastest urbanization rate in the world. The author will show how urban physical forms can be designed to take advantage of surrounding natural environments, while also considering specific political and social systems. Another aim is to contribute to global urban design by helping to shift the paradigm of urban planning through innovations that will make low-carbon cities a reality.

Urban areas receive energy, water, products, and raw materials from the outside and emit other products, wastes, sewage, exhaust gases, and waste heat. These waste products are often emitted directly into the environment. This process is called "urban metabolism" in reference to its similarity to the metabolism of a living organism [1, 2]. Mitigating the environmental burden of urban activities requires optimizing the structure of urban metabolism. For example, incineration and heat pumps make it possible to recover heat from wastes and sewage, and the effective use of such untapped energy sources will not only reduce the environmental burden by cycling the energy flow within urban areas, but will also more effectively use energy and resources.

In this chapter, the author focuses on urban area and shows case studies on urban energy planning and urban climate induced by concentrated human activities like energy use based on geographic information like land use data and numerical climate model linked to GIS (**Figure 1**). These outputs will give some sustainable urban design in viewpoint of climate change (mitigation and adaptation).

2. Urban energy planning

Waste incineration plants supply far more concentrated heat than can sewage plants that produce energy, but incineration plants tend to be isolated so they can naturally serve only limited areas. With sewage, heat pumps make it possible to recover heat by taking advantage of the temperature difference between air and sewage. Tokyo (meaning the 23 special wards of the city proper) is covered by a sewerage network [3] (**Figure 2**); although the sewage in this network provides heat distributed widely in a low quality, heat recovery and supply are expected to be possible in broad areas. For such heat utilization to work, there must be quantitative congruence between heat demand and the use of waste heat in heat supply

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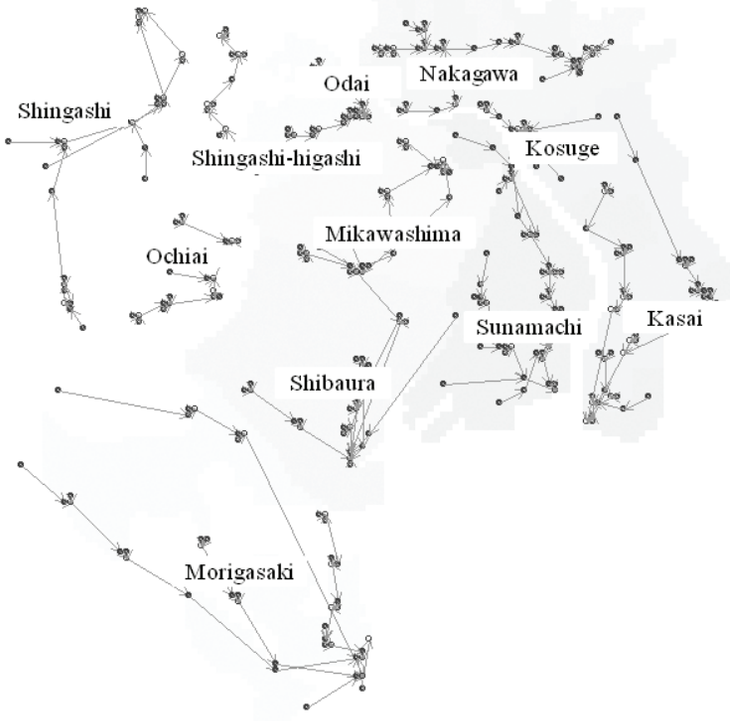


Figure 2. Extracted sewerage lines and sewerage treatment districts in the 23 special wards of Tokyo Metropolis [4]. (N-S: 32 km, E-W: 33 km).

operations. It would seem to be useful to search for such areas, and using a GIS may facilitate this process.

Connolly et al. [5] and Manfren et al. [6] reviewed computer tools that can be used to analyze the integration of renewable energy, including the currently untapped (and diffuse) sources of city energy. Some of the tools are GIS-based and applicable at the local community scale [7–10], but their target is mainly electricity (solar, wind, and biomass burning). Gils et al. [11] introduced a methodology for a GIS-based analysis of district heating potential. They assessed the energy demand for space heating and hot water in residential and commercial sectors in U.S. cities. The author's interest is the spatial conformity between energy demand and supply when referring to community-scale urban structure. This point is the reason why the author think GIS analysis is applicable for urban energy planning.

Accordingly, in relation to established plans of district heat supply facilities that make effective reuse of heat obtained from sewage, the author developed the GIS software to perform analyses of the spatial congruence between heat demand and the use of waste heat in heat supply operations [4]. The temporal and spatial distribution structure of energy consumption [12] was used as the basic data for the GIS, as was the distribution information for land-use types, height of buildings, and other relevant items used in the approximations.

The sewer system simulation model (SSSM) uses raster data on land-use types and building height (number of floors), and polygon data of sewage collection areas defined by sewerage

lines, as inputs for performing calculations and mapping [4]. Main data entered into the model included floor space by type of building use for each 250 × 250 m grid cell [13], energy consumption per unit floor space according to industry type [12], and heat demand data according to type of building used [12, 14]. This model can calculate heat demand in each grid cell (**Figure 3**), calculate the sewage flow rate at sewerage line nodes (**Figure 2**), and calculate the amount of recoverable sewage heat at the nodes and surrounding grid cells (**Figure 4**).

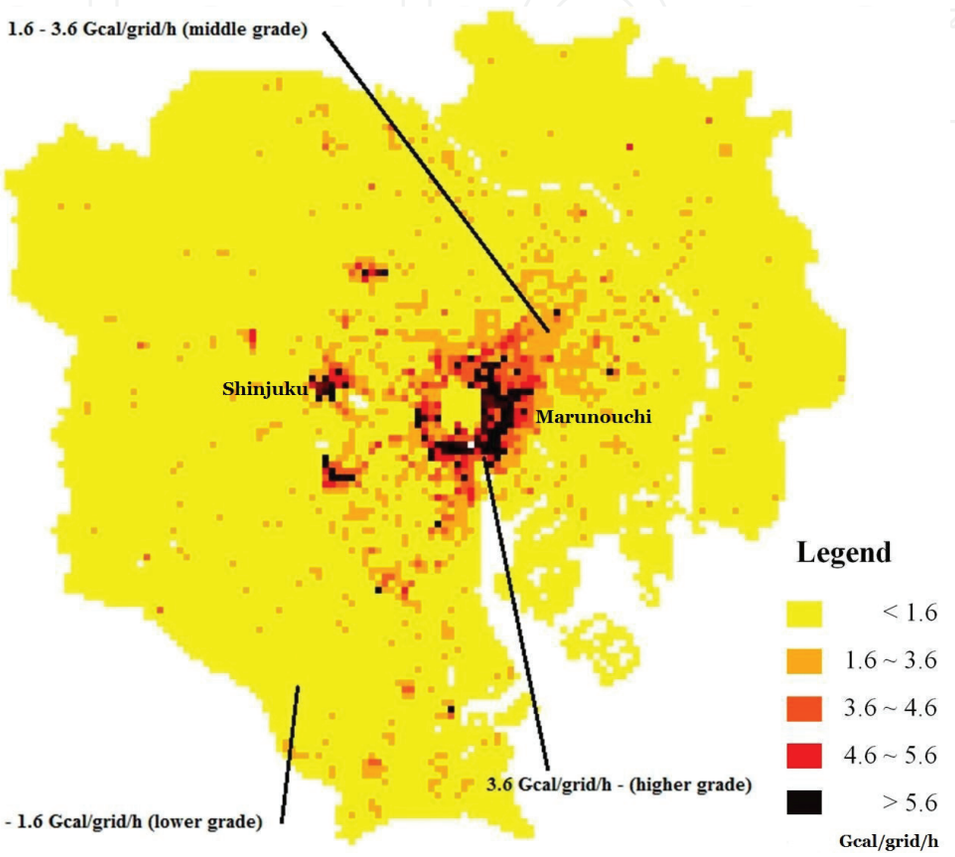


Figure 3. Distribution of heat demand density in Tokyo (daytime, winter, grid size: 250 m) [4].

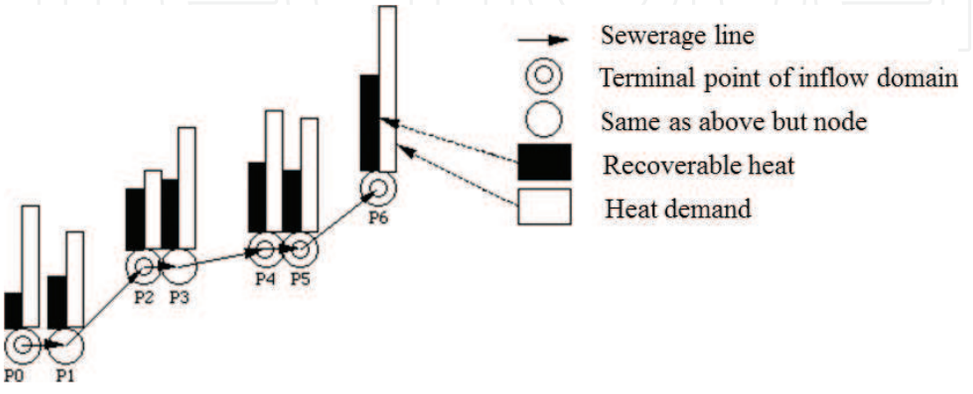


Figure 4. A schematic diagram of theoretical calculation results for recoverable heat at the points along a sewerage line [4].

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In the areas with a large amount of usable heat, there are long sewerage lines and many possible locations of heat recovery in general. Owing to the many possible locations of recovery, each with large heat demand in areas such as business districts, the amount of usable heat per heat pump is large. There were also a few cases where the flow rate was a limiting condition. When sewerage lines run through residential areas in main, the heat demand along the sewerage lines is small [4]. In finding the candidate places to settle district heat supply facilities that make effective reuse of heat obtained from sewage, the usage of GIS gives the reasonable solution in scientific view point.

3. Assessment of urban climate

3.1. Urban energy use and its impact

Expansion of urban areas and increase in urban activity have several impacts on urban environments. These impacts are represented by air pollution, water pollution, thermal pollution, caused by anthropogenic heat emission, and so on. Anthropogenic heat affects local climate in urban areas producing phenomena such as heat islands [12]. This process has been explored in a numerical simulation [12, 15]. It was reported that urbanization has both positive and negative impacts on thermal environment, as an increase in urban energy use and a decrease in incoming solar radiation [16]. On the other hand, evaluation of the impact of urban activity through land use change and anthropogenic heat on the urban thermal environment has been necessary in view of urban planning. Quantitative analysis of how human activities and urban structures should be changed to reduce heat island phenomena requires detailed data on anthropogenic heat sources, one of the surface boundary conditions, for use in numerical simulations of such impacts. Such analysis needs evaluation of the influence of spatial and temporal structures of anthropogenic heat on urban thermal environment. Field surveys of energy consumption over wide areas are difficult to carry out. The data for energy consumption as a source of anthropogenic heat must be in the form of grid cell data to be referenced geographically. Some studies which mapped the anthropogenic heat in Tokyo have been published [12, 15]. A time-series analysis of the distribution of urban energy consumption is necessary to evaluate its impact on the thermal environment. The author attempted a detailed analysis of the temporal variability of the distribution of energy consumption in the 23 special wards of the Tokyo Metropolis (Tokyo) [12]. He used a digital geographic land use data set containing the number of floors of building at each grid point to tabulate energy consumption (**Figure 5**) on an areal basis. The numerical simulation of urban climate was consequently performed to determine the effect of anthropogenic heat on urban climate in Tokyo. Annual and diurnal variability of energy consumption (**Figure 6**) is necessary for computer mapping of urban anthropogenic heat.

The author drew detailed maps of anthropogenic heat in Tokyo with data from energy statistics and a detailed digital geographic land use data set including the number of floors of building at each grid point (**Figure 7**) [12]. Computer graphics animation of the diurnal and annual variability in anthropogenic heat of Tokyo was also prepared with the same data

sources. These outputs characterize scenarios of anthropogenic heat emission and can be applied to a numerical simulation model of the urban climate [12]. The anthropogenic heat flux in central Tokyo exceeded 400 W m^{-2} in daytime, and the maximum value was 1590 W m^{-2} in winter. The hot water supply in offices and hotels contributed 51% of this 1590 W m^{-2}. The anthropogenic heat flux from the household sector in the suburbs reached

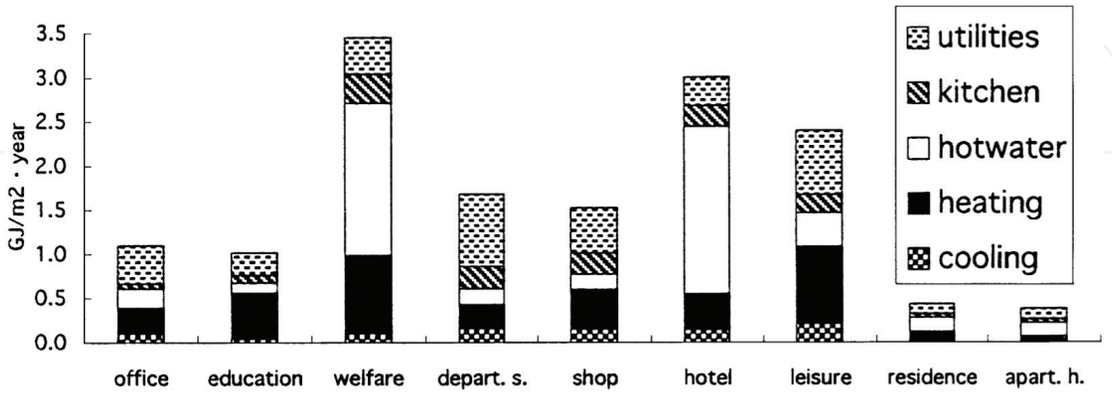


Figure 5. Areal energy consumption for each category on business or land use in Tokyo in 1989 [12]. It excludes industry, motor vehicle and trains. "Depart. S." means department store. "Apart. H." means apartment house.

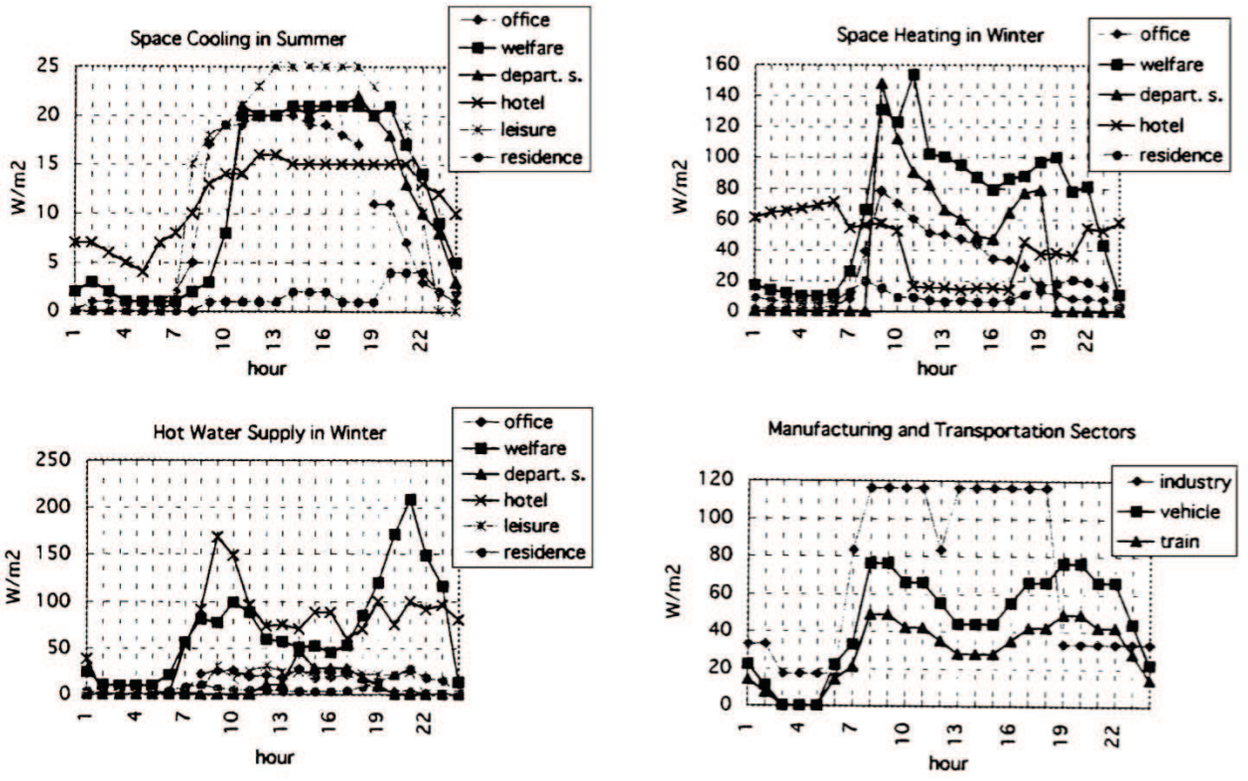


Figure 6. Diurnal variability of demand for space cooling in summer, space heating in winter and hot water supply in winter. Additionally diurnal variability of areal energy consumption in the manufacturing and transportation sectors is also shown [12].

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about 30 W m^{-2} at night. Numerical simulations of urban climate in Tokyo were performed by referring to these maps. A heat island appeared evident in winter because of weakness of the sea breeze from Tokyo Bay. At 8 p.m., several peaks of high-temperature appeared, around the areas with the largest anthropogenic heat fluxes (**Figure 8**). In winter, the shortwave radiation was weak, and the influence of anthropogenic heat was relatively large.

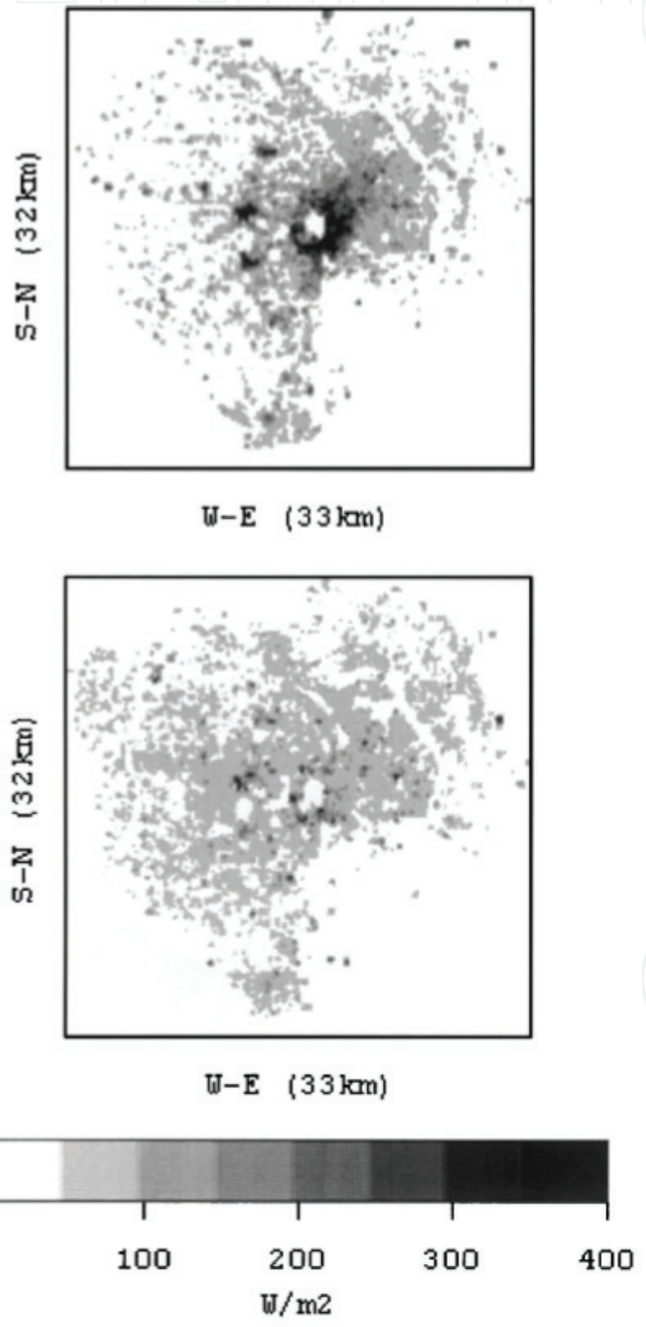


Figure 7. Distribution of anthropogenic heat in Tokyo at 2 p.m. (upper) and 9 p.m. (lower) in winter [12].

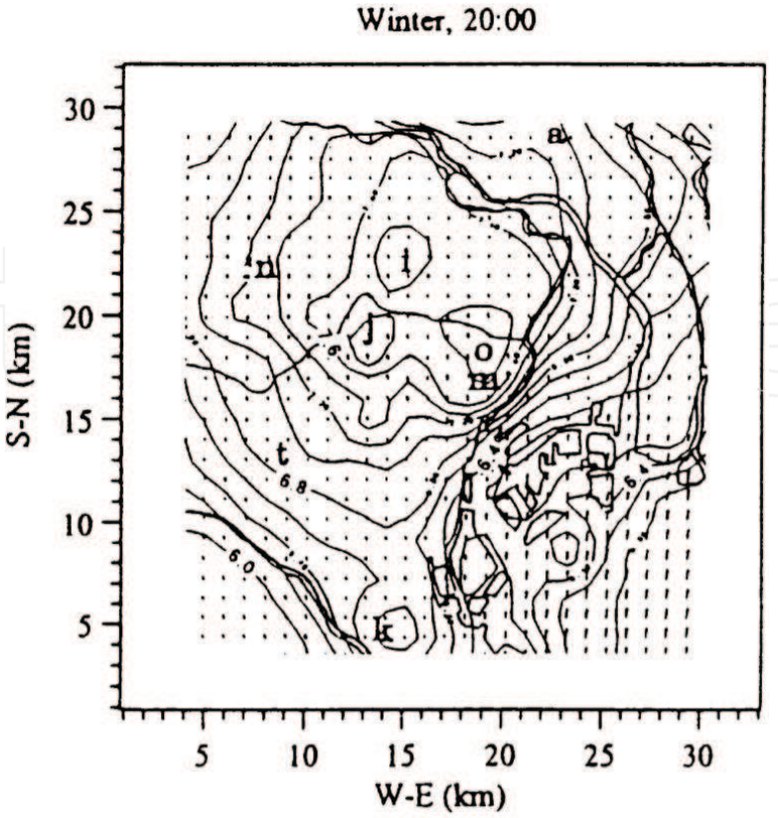


Figure 8. Horizontal distribution of air temperatures (°C) and wind system at 7.5 m above the ground in winter midnight [12]. Symbols as follows: n: Nakano, t: Setagaya, j: Shinjuku, i: Ikebukuro, k: Kamata, m: Marunouchi, o: Otemachi, a: Adachi.

The spatiotemporal data in high resolution on human activity like energy consumption in urban area enable us to evaluate the impact of anthropogenic heat to urban climate by a numerical simulation model of the local climate.

3.2. Urban green and its contribution

The following progress of RS and GIS technology brought a more advanced application of the author's approach. Hirano et al. [17] simulated local climate with surface boundary conditions based on satellite RS data. Most previous mesoscale meteorological modelling studies use land-use data instead as the surface boundary conditions. However, small patches of vegetation cover, such as garden trees and roadside trees, are excluded from the land-use data. Therefore, they made a fractional vegetation cover (FVC) data set with these small patches of vegetation cover from RS data (**Figure 9**), and then simulated the urban heat island in Tokyo with FVC data as new surface boundary conditions. The air temperature with the new boundary condition is up to 1.5°C lower than that with the old one (**Figure 10**). Furthermore, the new boundary condition led to predicted air temperatures closer to the measured temperatures than those with the old one. Therefore, it is important for urban climate simulations to include small vegetation cover.

The recent precise geographic information of urban vegetation cover derived from RS data enables us to evaluate the contribution of urban green to cool our community with higher accuracy.

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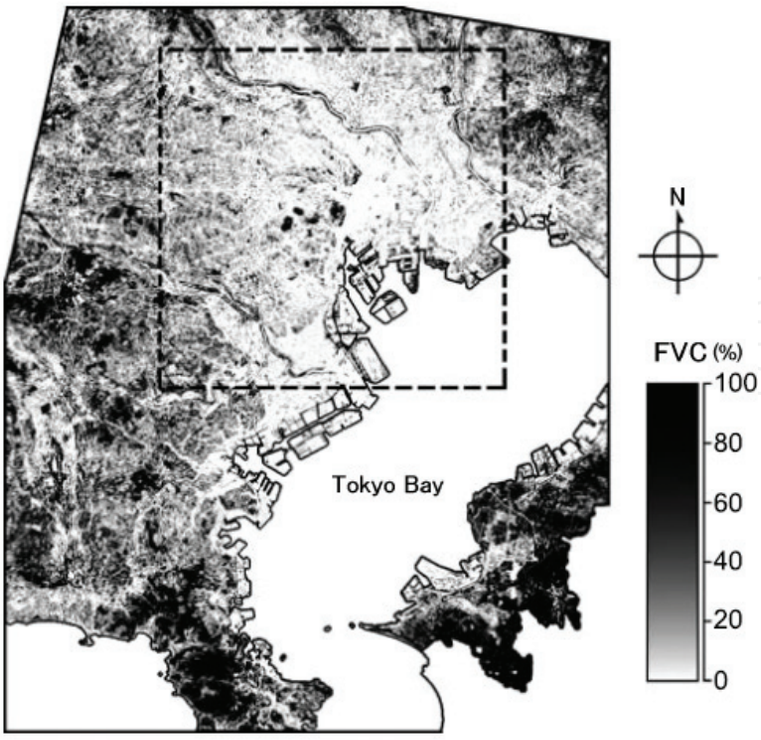


Figure 9. Estimated FVC (Fractional Vegetation Cover) around Tokyo [17]. The dashed-square indicates the target area of **Figure 10**.

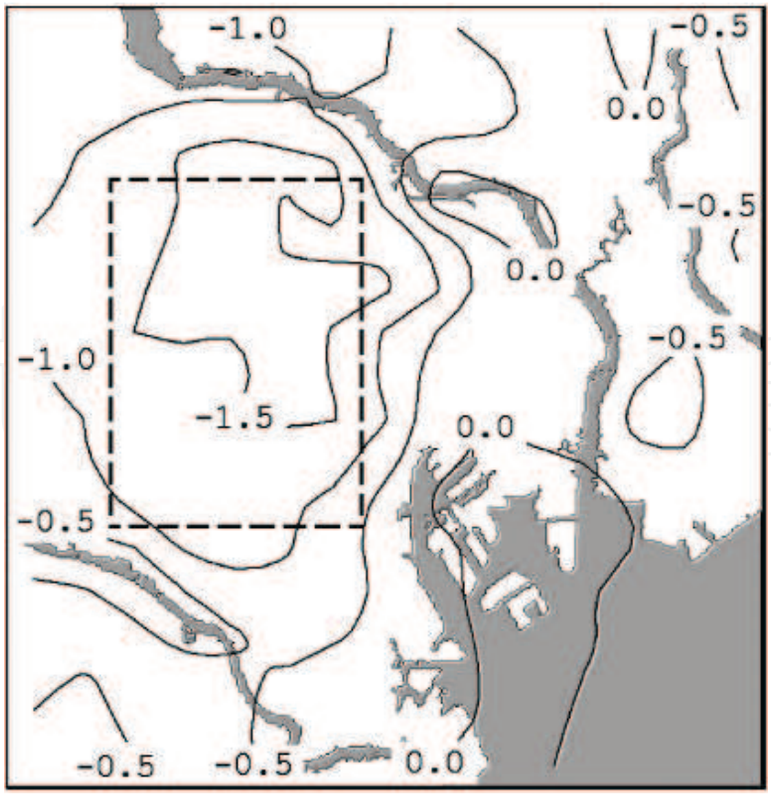


Figure 10. Temperature difference in °C between the case applying FVC data and the case not applying at 15:00 LST at 4.5 m above ground level [17]. Negative values show cooler temperatures under Case RS.

4. Estimation of past urban climate

About 120 years have passed since meteorological observations began in Asia; since then, researchers have used various methods to reconstruct the climate of earlier times. One such method has been to use notations about weather in ancient journals and documents. Since the early modern times, the Japanese have left many usable records, and, although these are mostly qualitative accounts, researchers have learned how hot in summer, or how cold in winter, it was in the past. Although the information collected from these documents contains many spatial and temporal gaps, recent advances in computerized meteorological modelling have made it possible to compute local distributions of climatologic parameters; for example, the distribution of surface air temperature is determinable if the surface boundary conditions, like the land-use distributions, are known [12, 15]. The author used numerical simulations with a mesoscale climate model referenced to digital land-use data (2 km grid) covering all of Japan to attempt to isolate the influence on surface air temperature of regional warming related to land-use change during a recent 135-year period [18]. During this period, areas of regional warming related to land use changes expanded around Osaka and Tokyo. However, the validation of the results of this study was difficult because the amount of available data on long-term climate fluctuations was limited.

To validate the results of modelling such as the author's [18], observed climatologic data (e.g., air temperature) are needed to provide initial values for the modelling. The weather stations' network and other observation facilities that have been established throughout Japan since 1876 provide long-term temperature fluctuations to the present. Data for Tokyo have often been used to associate changes in local climate in conjunction with urbanization [19]. Many instances of global warming [20] and changes of air temperature due to the regional climate change have been identified over broader areas and longer periods than those caused by local land-use changes [21]; comparing these to modeled temporal changes in air temperatures may elucidate the contribution of land-use change to climate change in Japan. Comparisons like this will also help to overcome the problem of spatial and temporal discontinuity in historical climatologic information.

Another reason such research is important in Japan is that urbanization in large Japanese cities has increased local air temperatures by about 1°C during the twentieth century [22]. Until now researchers have relied on statistical methods to distinguish between the influence on air temperature of localized warming caused by urbanization, and the influence of global warming and other broader scale changes of air temperature [23]. Of course, such methods cannot be applied to time periods or regions without any observed data. Much pioneering research has eliminated the influence of urbanization as noise when estimating temperature changes over large areas [24]. The use of a mesoscale model with past land-use distributions as surface boundary conditions to simulate past climatologic parameters (e.g., air temperature distributions) might help to distinguish the influence of localized warming due to urbanization from that of global warming and regional-scale (e.g., Far East Region, Eastern Asia, etc.) fluctuations of air temperature for time periods and regions without enough observed data [18]. Certainly, the urban-scale and mesoscale meteorological model have been widely used in other studies, such as Kusaka et al. [25] and Doan et al. [26], which created the weather research and forecasting model (WRF) to examine the phenomena of urban climate in different scales.

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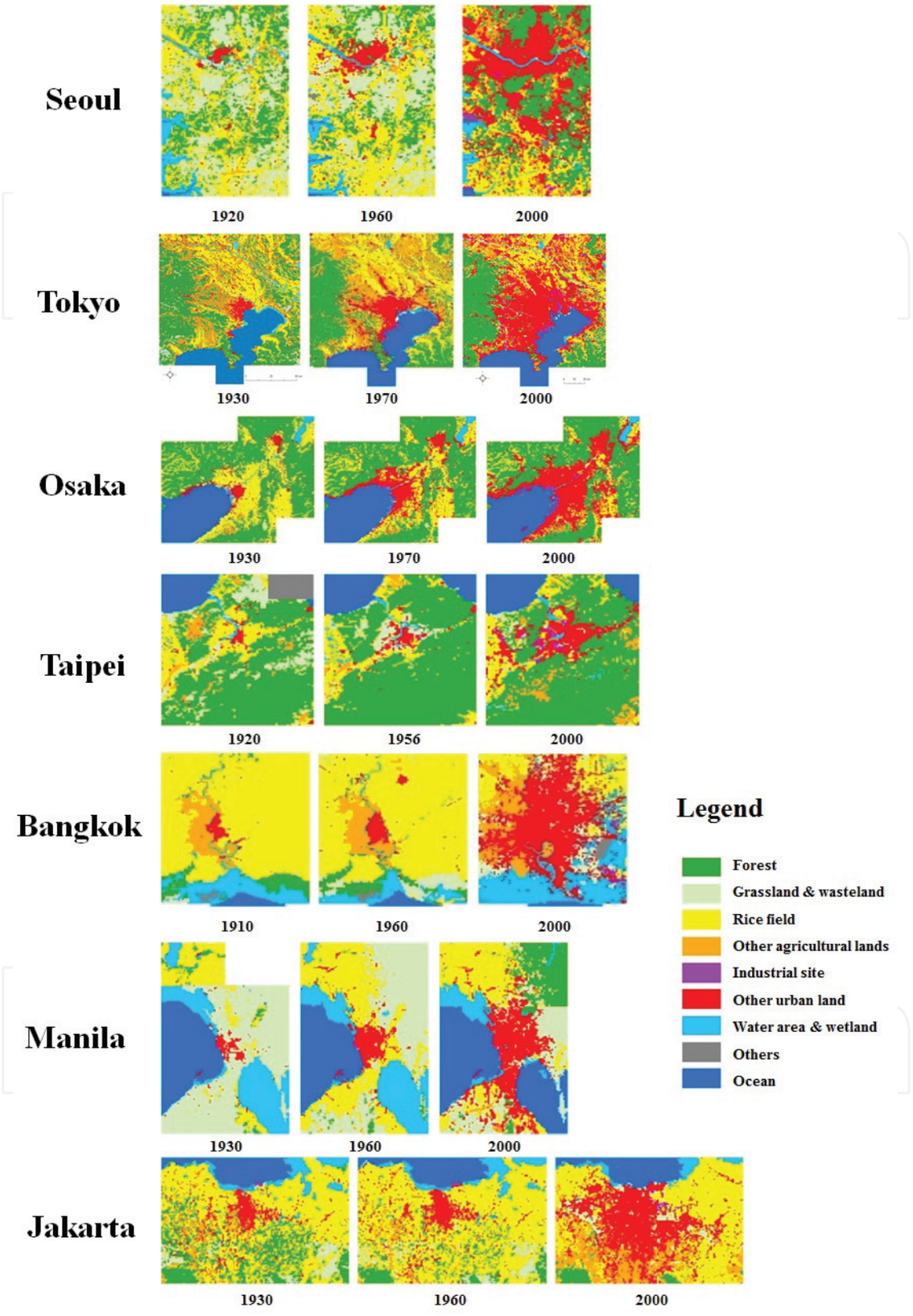


Figure 11. Urbanization around seven megacities in Asia (RIHN Research Project C-5 "Human Impacts on Urban Subsurface Environments") [28].

Case studies of the area around the upper reaches of the Rhine River as it was in 1710 [27] and of the Edo area (Tokyo was called "Edo" until the middle of the nineteenth century) during the first half of the nineteenth century [18] are examples of attempts to quantify the influence of urbanization-induced changes in the surface heat budget on surface air temperatures, as opposed to research from a historical climatology perspective. These researchers derived land-use distributions for the periods they studied from historical maps and other historical sources. Because the periods they studied predate the beginning of meteorological records, comparisons with observed meteorological data are impossible.

The author is focusing on both the past ground surface temperatures (T_{sfc}) of 100 years ago and the current one, in order to clarify the relationship between the urban development and subsurface warming in seven Asian megacities based on the numerical simulation of local climate, considering the land-use data in these megacities for three discrete years of the twentieth century [28], because subsurface temperatures are affected by surface warming (heat of the ground level is conducted downwardly). The author used the Colorado State University Mesoscale Model (CSU-MM) [29, 12, 18] and digital land-use data (2 km grid) from seven Asian megacities (Seoul, Tokyo, Osaka, Taipei, Bangkok, Manila, and Jakarta) to simulate T_{sfc} for three discrete years of the twentieth century (**Figure 11**).

Based on the vertical profile of subsurface temperature in boreholes, which is regarded to record the past T_{sfc}, Taniguchi et al. [30] identified surface warming during the twentieth

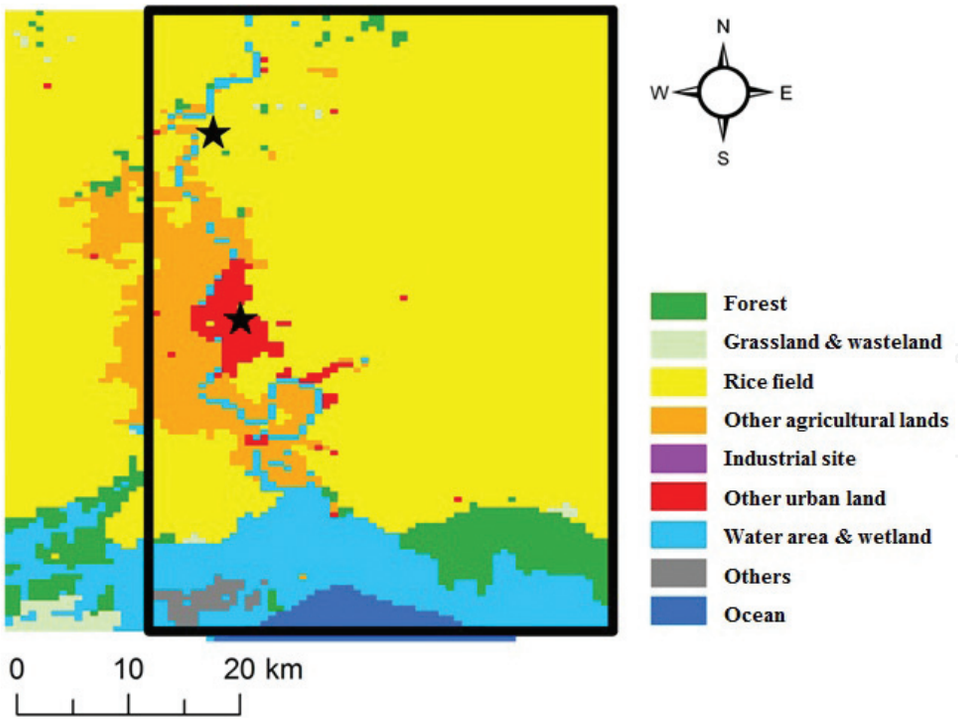


Figure 12. Land-cover/use around Bangkok in 1910 with its legend [28]. Stars show "City Center" and "Northern Suburb". Inside of solid rectangle line shows the areas displaying computed results in **Figure 13**.

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century of 2.8°C in Tokyo and 1.8°C in Bangkok. The seven land-use data sets (**Figure 11**) revealed the major characteristics of land-use change during the twentieth century expansion of urbanized areas in the seven megacities considered here. Such large-scale surface changes would be expected to bring about localized climatic changes in response to the resultant changes to the surface heat budget. In the modelling on a calm and clear day of the hottest season, the central Bangkok showed T_{sfc} to be increasing by about 1.1 K 100 y^{-1} during the twentieth century [28] (**Figures 12** and **13**).

There is almost no difference between the graphs of diurnal change of T_{sfc} between 1960 and 2000 in the city center of Bangkok (**Figure 14**), whereas in the northern suburbs of Bangkok, where land use between 1960 and 2000 has changed from rice paddy to urban, there has been a rapid increase of T_{sfc}. In particular, T_{sfc} in the northern suburbs of Bangkok in 2000 was higher than in 1960, by about 15 K in the daytime and by about 5 K at dawn. Thus, it appears that subsurface temperature profiles differ according to the start time of urbanization periods.

Thus, the author's approach is available not only to evaluate the current urban environment but also to the past one. If a certain scenario of future's urban land use and urban activity, this approach will be available for the future prediction.

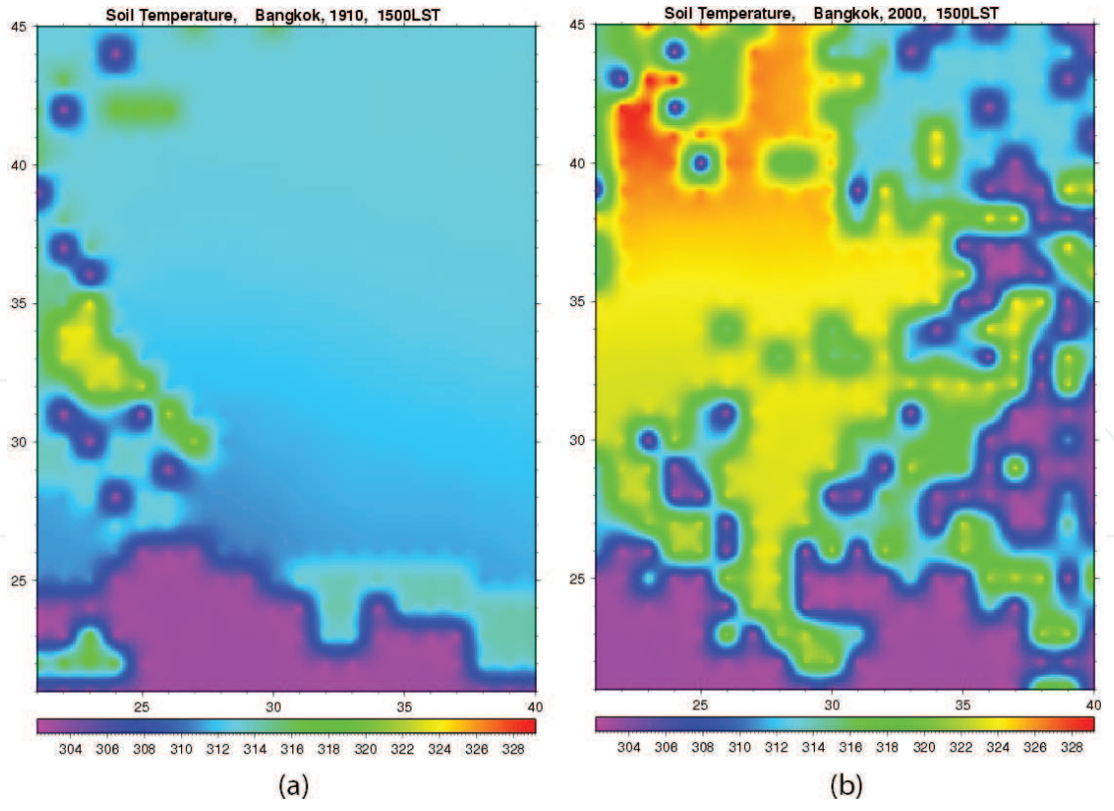


Figure 13. Computed T_{sfc} (K) around Bangkok in the hottest season (calm and clear day at the end of March) [28]. Left: 3 p.m. in 1910, right: 3 p.m. in 2000.

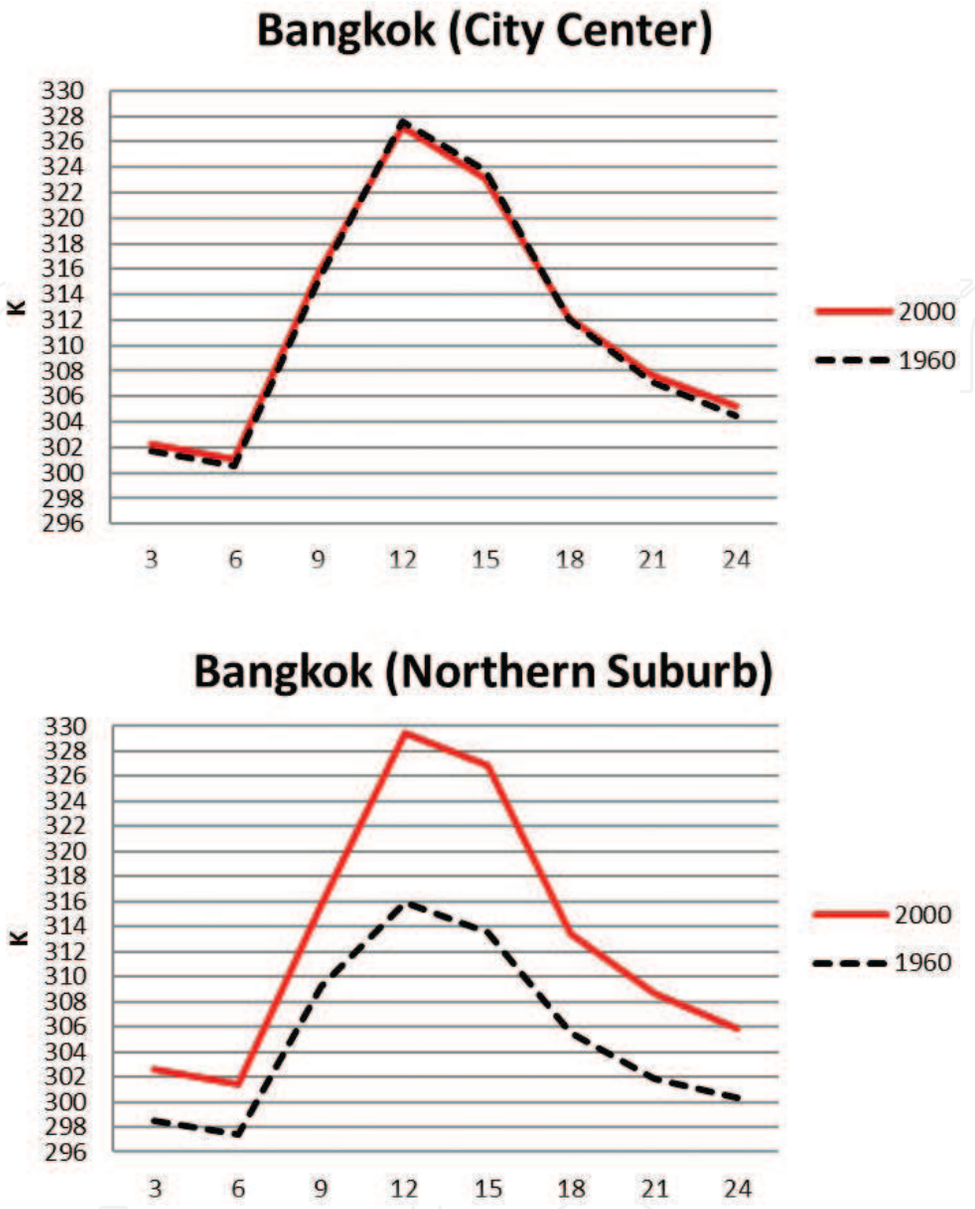


Figure 14. Diurnal variability of computed T_{sfc} in the hottest season (calm and clear day) in two stages [28]. Difference of computed warming of T_{sfc} in the same term (Bangkok).

5. Conclusion

In this chapter, the author focuses on urban area and shows case studies on urban energy planning and urban climate induced by concentrated human activities like energy use based on geographic information like land use data and numerical climate model linked to GIS. The author shows the following four outcomes: (1) In finding the candidate places to settle district heat supply facilities that make effective reuse of heat obtained from sewage, the usage of GIS gives the reasonable solution in scientific view point, (2) The spatiotemporal data in high resolution on human activity like energy consumption in urban area enable us to evaluate the

impact of anthropogenic heat to urban climate by a numerical simulation model of the local climate, (3) The recent precise geographic information of urban vegetation cover derived from RS data enables us to evaluate the contribution of urban green to cool our community with higher accuracy, (4) The author's approach is available not only to evaluate the current urban environment but also to the past one. If a certain scenario of future's urban land use and urban activity, this approach will be available for the future prediction. Thus, these outputs will give some sustainable urban design in viewpoint of climate change (mitigation and adaptation).

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Conflict of interest

The author declares there is no conflict of interest on this manuscript.

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